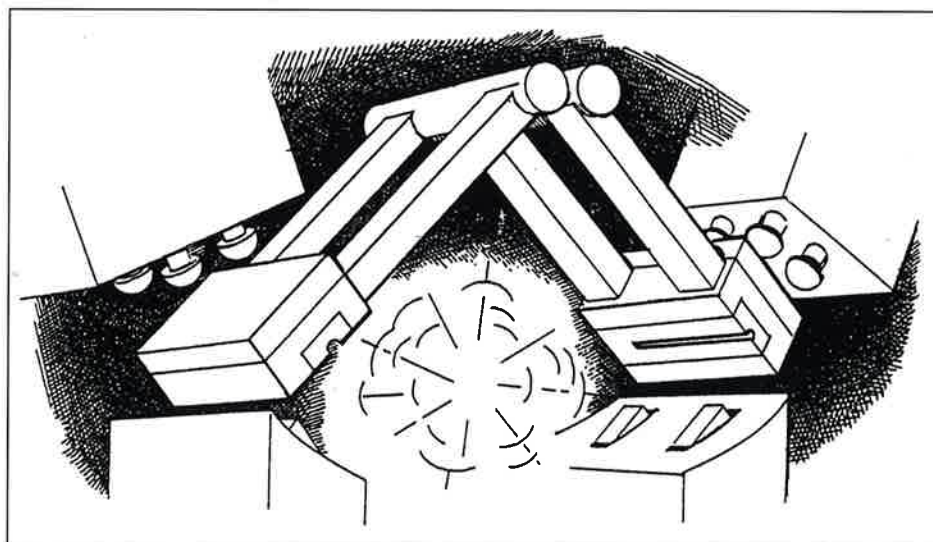




TWIN PENDULUM

New method to simulate the generation of toxic fumes

Gunnar Persson



STIFTELSEN SVENSK BERGTEKNISK FORSKNING
SWEDISH ROCK ENGINEERING RESEARCH
SveBeFo Report 20

TWIN PENDULUM

**New method to simulate the
generation of toxic fumes**

Gunnar Persson, SveBeFo

FOREWORD

A new method is described for measuring the amount of toxic shotfiring fumes generated by explosives. The method was developed in 1982 and is still deemed to be of high interest as a possible standard method for the classification of toxic fumes.

This report is an English version of the original research report in Swedish (SveDeFo DS 1982:21) and is now published by SveBeFo, which was founded in 1993 as a result of a merger of the former BeFo - Swedish Rock Engineering Research Foundation and SveDeFo - Swedish Detonic Research Foundation.

The objective of SveBeFo is to perform rock engineering research in a wide sense, where improving the working environment is often an indirect consequence of e.g. better reinforcing methods. Efficient rock blasting techniques also include the use of safer explosives, why methods to evaluate the poisonousness of blasting fumes are important. We hope that the presented method will mean a positive contribution in this respect.

Stockholm in March 1995

Tomas Franzén
Research Director

SUMMARY

The borehole pressure/time history of blasting practice is simulated in a twin pendulum apparatus, where the expanding shotfiring gases force two steel slab swingers apart. A pilot installation built at SveDeFo is described. The relevant factors, that govern the use of this test method as a means of classifying explosives with respect to their toxic fume potential, are described.

A twin pendulum which can simulate the actual borehole pressure/time history of explosive charges in the field with an energy content around 10 MJ should be large enough for a meaningful testing of all but a few of the cap sensitive explosives in the world market.

It is well worth further study and development as a potential international standard method for classifying explosives with respect to their toxic fume potential.

CONTENTS

	Page
BACKGROUND	4
SIGNIFICANCE OF THE CONFINEMENT	4
WEST GERMAN TEST METHOD	6
QUANTITATIVE GAS MEASUREMENTS IN ROCK BLASTING	6
PRINCIPLE OF THE TWIN PENDULUM APPARATUS	8
PILOT TEST	9
FACTORS TO TAKE INTO CONSIDERATION WHEN USING THE TWIN PENDULUM	11
TWIN PENDULUM IN FULL SCALE	12
REFERENCES	14

BACKGROUND

The toxic components, especially carbon monoxide (CO) and nitrous oxides (NO_x), of the explosion gases (shotfiring fumes) are a great health risk in underground blasting. In order to determine the suitability of explosives for underground use, the generation of toxic explosion gases (fumes) must also be taken into consideration in addition to handling safety, environmental effects, detonability, and blasting efficiency.

The energy released during the detonation and the resulting detonation products can be determined by using thermochemical calculation programs. The reaction process is very complicated with many participating components. Before the chemical positions of equilibrium, the so-called freezing points, are attained during the cooling of the explosion gases, molecules, atoms, and free radicals have had many opportunities to enter into new combinations, all of which are dependent on temperature, pressure and the time conditions that prevail in the gas. It is very difficult to set up computer programs that calculate the NO_x fraction with any greater relation to reality.

Several test methods have been developed in different parts of the world in an attempt to determine in a laboratory scale the amount of toxic explosion gases generated by explosives. All of the known methods, with the exception of a West German method (see page 6), lack arrangements for a true to life simulation of the load that the explosion gases are exposed to in actual bore holes.

SIGNIFICANCE OF THE CONFINEMENT

Generally, the formation of NO_x decreases with a greater confinement (load) of the detonating explosive and from that fact higher pressure. Persson and Persson. /1/. The results of comparative blastings with the same explosive but under different confinements, which give different pressure/time histories, are shown in Fig. 1. The measurements were performed in collaboration with Kurt Lindqvist of Nitro Nobel AB, Lindqvist and Johnson /2/. The CO is only slightly affected by the confinement, and the tendency is then the same as for the NO_x. Under very strong confinements, non-systematic increases may occur, probably due to the burning of the wrapping under a lack of oxygen.

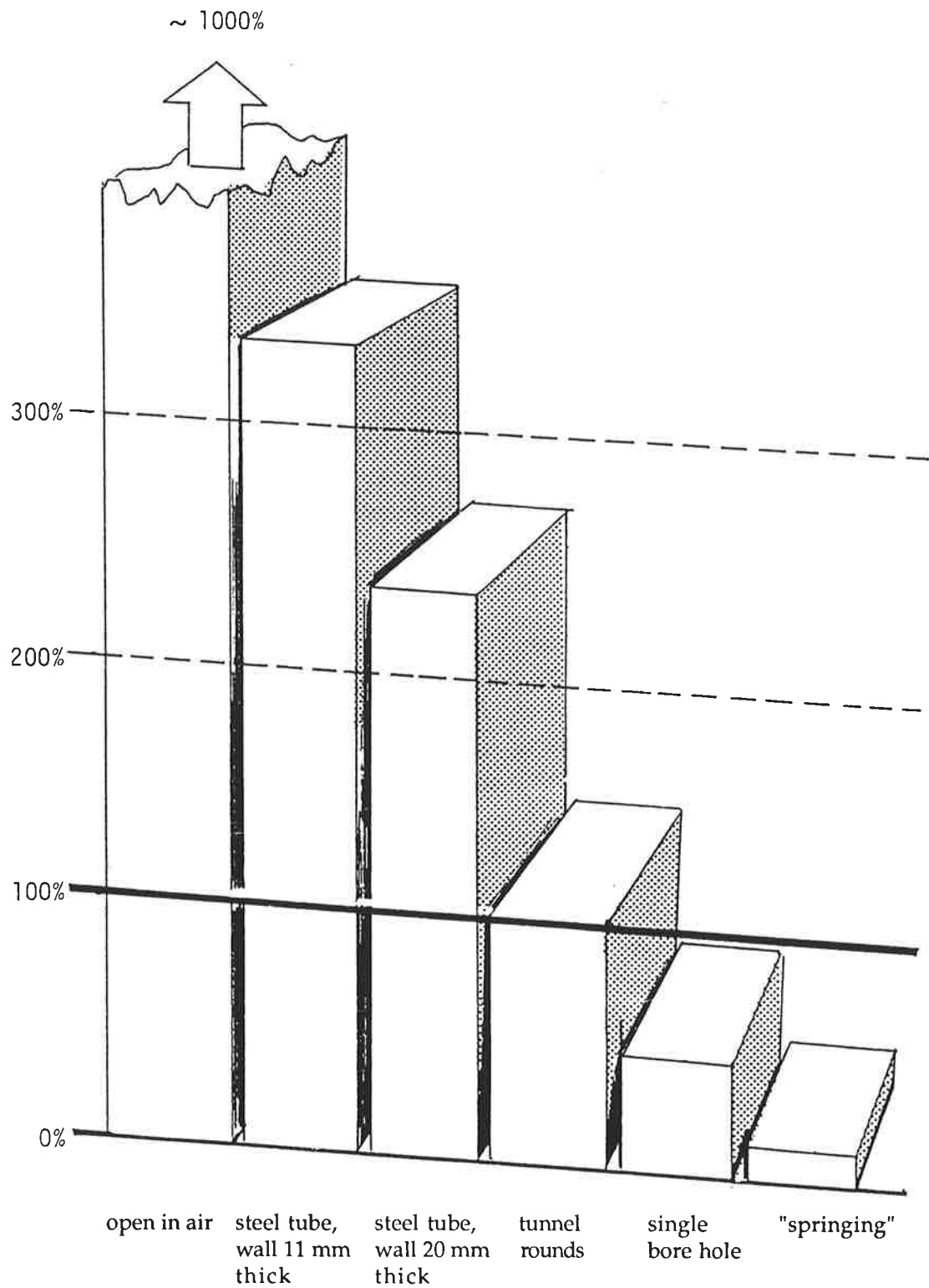


Figure 1. The bar diagram shows the effect of the confinement (load) on the formation of NO_x for a certain type of dynamite tested. 100% has been assigned as a standard value to the NO_x amount that has been measured during the blasting of 10 m² tunnel rounds of firing in waste rock with the specific charge of ~ 3 kg/m³.

The atmospheric post-oxidation, when the expanding explosion gases come in contact with the air in the environment, can affect the NO_x content to a max. of one percent. The cloud of fumes is cooled during the expansion, and the amount of nitrogen in the air that can be oxidized is therefore small.

In practical use, one should be able to perform a meaningful determination of the generation of toxic fumes by the explosive in laboratory scale if the testing apparatus is capable of simulation the pressure/time history that prevails in the actual bore hole.

The specific charge (explosive in kg per m^3 of blasted rock) can in underground work vary between 0.1 - 5.0 kg/m^3 , depending on the tunnel area, nature of the rock and blasting method. The inner holes in the cuts may have a specific load over 100 kg/m^3 . Consequently, the pressure/time history in the bore holes varies considerably. In addition, there are differences between the bore holes in a round of firings, depending on the degree of confinement (burden) and the cracks that have been produced by charges that have been detonated in nearby bore holes.

WEST GERMAN TEST METHOD

One test method is worth mentioning among the presently known test methods for simulating actual conditions of use. It is of West German origin and has been developed by Berggewerkschaftliche Versuchsstrecke in collaboration with Versuchsgarbe Tremona, Eitz and Zimmerman /3/. The blastings are performed as rounds with 7 kg of explosives distributed in 7-10 bore holes in a rock chamber with a removable wall. As the rock blasting proceeds, the wall is moved, so that a chamber volume between 30 - 100 m^3 is always maintained.

QUANTITATIVE GAS MEASUREMENTS IN ROCK BLASTING

In order to determine the amount of toxic fumes generated in liters per kg of detonated explosives during actual conditions of use, quantitative fume measurements can be made during the firing of well-defined rounds in rock. It is then suitable to blast stope holes with the same burden and spacing of holes, so that the specific charge can be determined with good accuracy. It should be noted

that the same specific charge does not always mean the same load for the explosive. This is exemplified in stope blasting where the explosives in the top (roof) holes work with gravity, and the bottom (floor) holes work against it.

Previously it has not been possible to obtain in field measurements a high accuracy and low interference gas sensitivity with direct-reading, battery-operated, portable gas analyzers for CO and NO_x. Therefore, SveDeFo has considered it necessary, together with instrument manufacturers, to improve and develop an ND-IR analyzer for CO and a chemiluminescence instrument for NO and NO₂. /4/.

The in situ measurement of explosion gases may be performed according to two methods:

1. Test chamber measurements, similar to the above-mentioned West German method, may be made on rounds of firings in mining areas or tunnels with a known volume. The chamber is sealed with a gate-type device, after which the explosion gas is thoroughly mixed by means of a fan, and the content of the desired toxic fumes is measured. The amount of fumes generated is calculated by multiplying the volume of the chamber by the gas content.
2. Air flow/gas content measurements, using a method tested at SveDeFo, where the fume content in the explosion gases coming from a blasting round is analysed in the passage of an accurately measured tunnel section. The air speed is measured at the same time with anemometers. When the explosion gas cloud passes through, its content of CO and NO_x is registered as a function of time with an XT printer. Since the volume of the amount of air flowing by is known, the volumes of the analysed gas components can also be determined. /4/.

In the above-mentioned quantitative measuring methods, it may be necessary, in certain cases, to take into consideration the explosion gas content in the rock blasted.

In order to imitate the conditions prevailing in the bore hole when the explosive detonates, pressure/time measurements should also be made in situ. At present, tests are being conducted at SveDeFo with a new method which makes it possible to register the entire pressure/time history when high energy explosives are detonated in bore holes.



Figure 2. Hole in wall stope with a powerful charge.

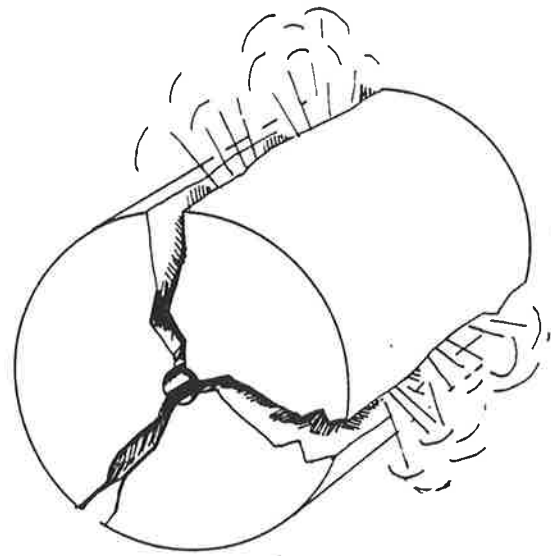


Figure 3. Hole with rotary symmetrical tamping and critical charging.

PRINCIPLE OF THE TWIN PENDULUM APPARATUS

The pressure/time history occurring in the above-described practical use of the explosive in bore holes (Figs. 2 and 3) can be simulated with a new test method where the explosion gases are forced to expand and work between two movably mounted steel slabs. The author has already described in EXTEST 78 the theory behind this method.

The testing apparatus consists of two or more steel slabs with planed surfaces that are pressed against each other. The explosive to be tested is placed in a groove (firing hole) milled between the steel slabs. This hole corresponds to the bore hole in the rock. When the explosive detonates, the steel slabs are forced apart. The speed of this movement depends on the size of the impulse, the steel slab mass and the loss that occurs when the expanding explosion gas rushes out into the widened opening between the steel slabs. The desired pressure/time history can be simulated by changing the energy content of the explosive charge and/or the size of the mass.

The steel slabs should be fastened in a device that provides them with a returning motion after the blast. For example, this can be achieved if the two steel slabs are placed on top of each other with the lower slab as an anvil and the upper slab mounted on a movable arm as a hammer. A variant with a suspended hammer, single pendulum, is also possible. (See Figs. 4 and 5).

Examples of practical solutions for simulating actual load conditions on the explosive.

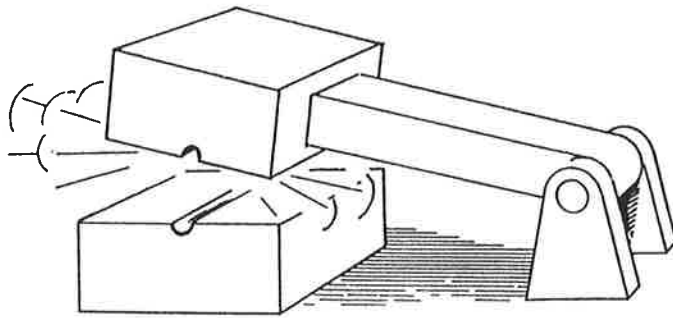


Figure 4. Hammer with anvil.

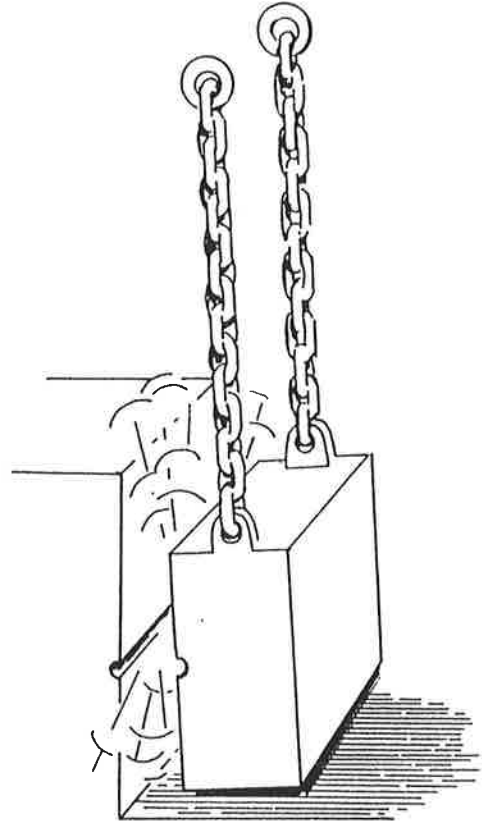


Figure 5. Single pendulum.

PILOT TEST

Our pilot installation of the testing apparatus is designed as a twin (double) pendulum with brakes consisting of a bunch of logs for each half of the pendulum. When both of the steel slabs swing back to meet again, a rubber-covered steel plate has fallen down between them. This prevents any damage to the firing hole and to the contact surfaces. (See Figs. 6-8).

The detonating explosive causes wear and tear on the firing hole, which, however, can be reduced considerably if a tube-shaped protective lining is used. We have developed a sand/air lining designed as self-supporting tubes. The density of the mineral is 2.65 g/cm^3 and the density of the lining: 1.60 g/cm^3 .

The testing apparatus, which we call "Twin pendulum", was mounted in our 235 m^3 large test chamber in the Stripa Mine. After the blasting, the chamber was sealed by means of tight doors, and the explosion gases were mixed by a powerful fan. /1/. When the gas mixture had become homogeneous, it was analyzed as to its content of toxic fumes with direct-reading instruments. CO was measured with an ND-IR analyzer, and NO_x (NO and NO_2) with a chemiluminescence instrument.

Pilot version of the twin pendulum

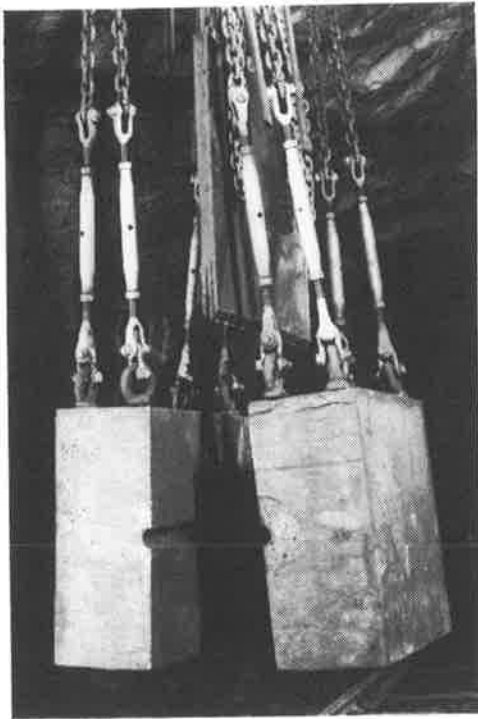


Figure 6. Twin pendulum with the two pendulum halves swung partly outwards to show the location of the firing hole.

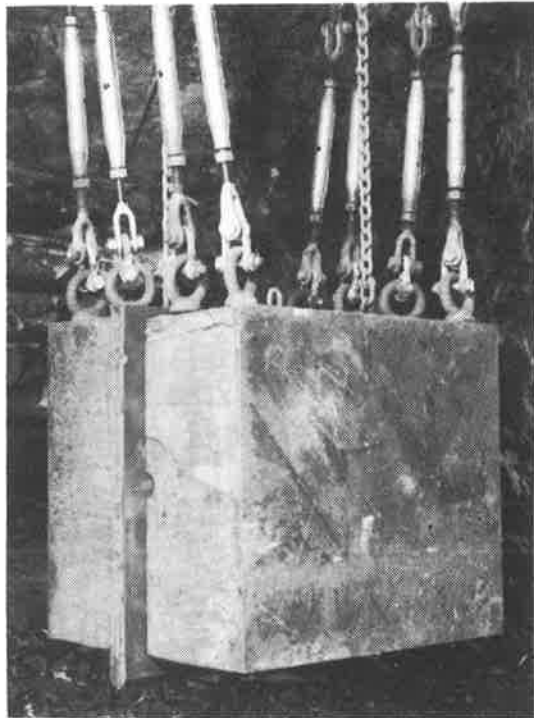


Figure 7. The rubber-covered steel plate falls down between the two pendulum halves and protect the contact surfaces after the blast.

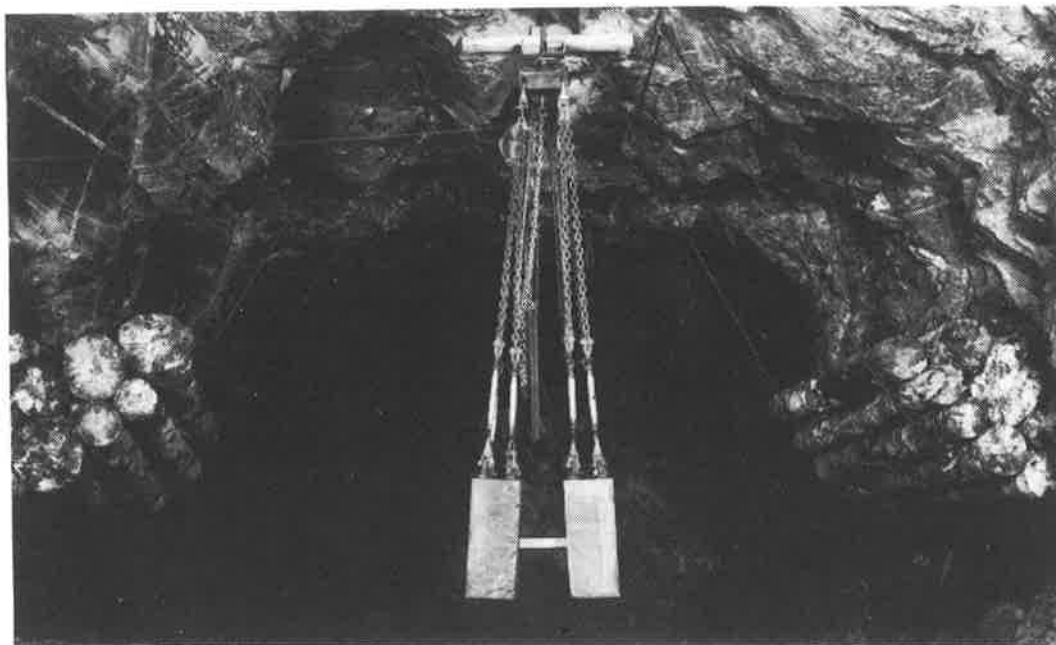


Figure 8. The twin pendulum with the suspension device and brakes.

When necessary, samples of other explosion gas components could be pumped into tubes for analysis by gas chromatography.

Our pilot installation of the twin pendulum had pendulum masses of approx. 700 kg with the dimensions 240x570x650 mm. The length of the pendulum arm from the supporting point to the firing hole was 2100 mm. Charges with an energy content up to 1 MJ could be placed in this twin pendulum. Then the load condition becomes such that the toxic gases generated correspond approx. to the wall stope blasting in granite with a specific charge of $\sim 3 \text{ kg/m}^3$. Since our small twin pendulum only permits the firing of small explosive charges, a difficulty may arise in obtaining an even velocity of detonation.

FACTORS TO TAKE INTO CONSIDERATION WHEN USING THE TWIN PENDULUM

If an explosive is to be classified with respect to its generation of toxic explosion gases, then the testing process must be accurately thought out and the load conditions must be well known. Naturally this also applies to the twin pendulum. Some of the most important factors are discussed here, and some practical advice is offered in the following.

1. The pressure/time history in the twin pendulum must correspond to the loads under which the explosive is mainly intended to operate. This may be measured with pressure gauging according to an earlier mentioned method, or it may be tested by comparing blastings with actual rounds of firing.
2. When classifying explosives, the intended conditions of use must be taken into account. Standardized loading conditions should be possible to introduce during twin pendulum blasting. For example: A specific charge of 3 kg of explosives per m^3 of granite, which is a normal load in the blasting of smaller tunnel areas.
3. Load changes should first of all be made by changing the twin pendulum mass, and secondly, by varying the size of the charge.
4. The main part of the explosive tested must attain a stable rate of detonation. The charge should be so long that the acceleration distance of the detonation is a small part of the total length of the specimen.

5. The relation between the charge and firing hole diameter should be the same as in actual bore hole firings that are to be simulated during the test.
6. The uncharged part of the firing hole should be so long that it prevents a load that is too low in the outer part of the explosive sample.
7. The dimensions of the firing hole are easily altered if removable steel linings are used on both sections of the pendulum.
8. The wear and tear on the firing hole is reduced considerably if energy-absorbing lining tubes of a sand/air type are used. Note that the pressure/time history can thereby be changed. By using sand of the same rock material as the explosive will be used in, the explosion gas effects, due to the mineral, can be studied during twin pendulum blasting.
9. Stemming can, of course, also be used in twin pendulum blasting, but in packing it, steps must be taken to prevent the pendulum sections from gliding apart.
10. It is necessary to effectively mix the explosion gases in the test chamber in order to make them rapidly homogeneous before the analysis is performed with high-class, direct-reading instruments.

TWIN PENDULUM IN FULL SCALE

A twin pendulum which can simulate the actual bore hole pressure/time history of explosive charges in the field with an energy content around 10 MJ should be large enough for a meaningful testing of all but a few of the blasting cap sensitive explosives in the world market. Since the pressure/time history for specific charges between 1 and 4 kg/m³ is probably the most interesting to simulate, the format of the twin pendulum can be kept within manageable dimensions.

In an international standardization of methods for determining the generation of toxic explosion gases by explosives, the twin pendulum may be a proposal worth studying closer and developing further.

Rigid pendulum arms and a very strong mechanical structure consisting of supports and fastenings for the hydraulic brake cylinders which will brake the pendulum motion, are required for pendulum masses of 5 - 10 tons. The construction cost is estimated to be 4-5 million Swedish Crowns in 1995 year's value.

A common testing installation for several manufacturers of explosives or the construction of a few separate installations around the world, together with state-owned testing centers or similar organizations, should make it possible to share the cost among the persons interested in the testing method described in this report.

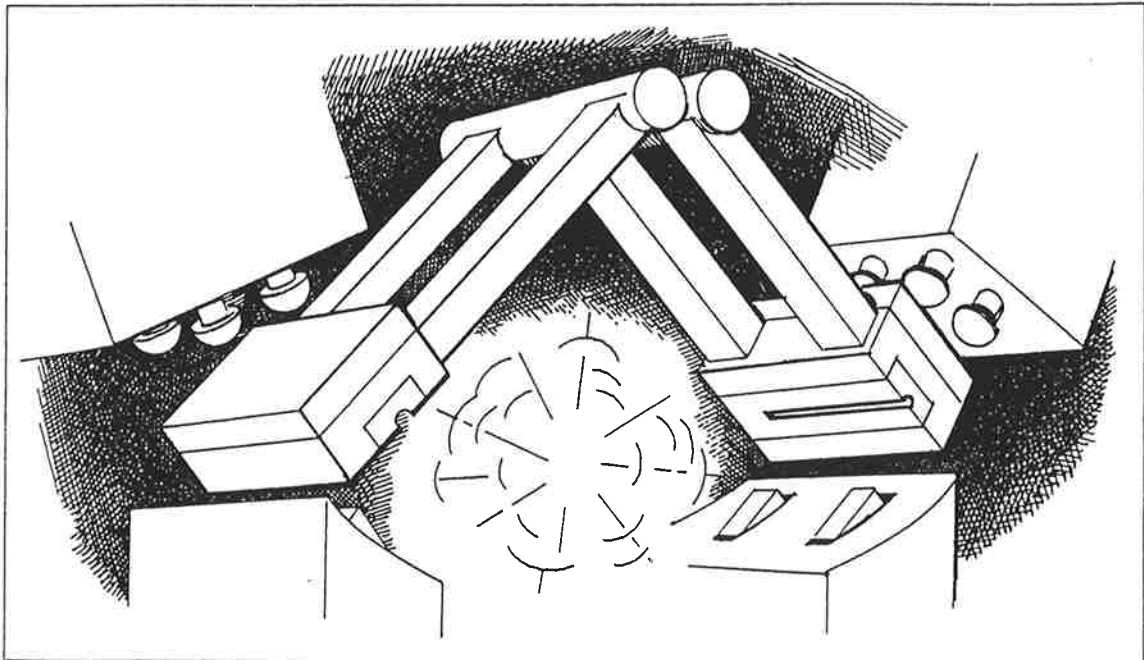


Figure 9. Proposal for a twin pendulum for charge energies up to 10 MJ. Note the hydraulic shock absorbers, the hooking-up device, the replaceable loads and steel linings. The sketch is schematic. The contact surfaces (operating surfaces) are provided with labyrinth tracks (grooves) in order to reduce the gas loss between the surfaces during the initial phase.

REFERENCES

1. Persson, G
Persson, P-A "Estimation of Toxic Fume Characteristics of Explosives from Steel Tube Blasting", EXTEST 78, Propellants and Explosives, vol. 5, (1980), p. 75.
2. Lindqvist, K
Johnson, N O "A Test Site for Shotfiring Fumes Experiments", EXTEST 78, Propellants and Explosives, vol. 5, (1980), p. 79.
3. Eitz, E
Zimmerman, R "Die in der Bundesrepublik Deutschland benutzte Methode zur Bestimmung der toxischen Bestandteile der Sprengschwaden", EXTEST 76, Propellants and Explosives, vol 3, (1978), p. 17.
4. Persson, G "Metoder att minska emissionen av luftföroreningar vid sprängningsarbete under jord", SveDeFo report DS 1983:18 (in Swedish).