KLOTZ-CLUB TESTS IN SWEDEN

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CONTENTS

SUMMARY

In the paper the objectives of the Klotz-Club tests performed in Sweden are described. The main purpose of the tests is to give data on debris and fragment throw from detonations in ammunition storages in rock. The installation is described and results from four of the tests are given.

1. INTRODUCTION

The Klotz-Club has its origin in 1966 when a group of people discussed the possibilities of reducing the blast effects from accidental explosions in underground ammunition magazines with a large closing device, a block (in German: Klotz).

Theoretical and experimental studies were followed by a successful "full scale" proof test in 1973. The - by that time four - participating countries decided to continue a fruitful cooperation within the fields of explosives safety. A number of efforts have been made within the frame of the Klotz-Club, cfr /1/.

In October 1985 the now seven participating countries - the Federal Republic of Germany, France, Norway, Sweden, Switzerland, United Kingdom and the United States - decided to make a test series in a joint installation to be built at ArtSS, Älvdalen, Sweden. The objectives of the tests were to give data on

- debris and fragment dispersion
- blast propagation
- influence of geometry on debris flow and blast propagation
- groundshock effects
- TNT-equivalence for artillery rounds
- degrading effects of detonations on e.g. shotcrete.

For details see /2/.

2. BACKGROUND

The hazards in the vicinity of an ammunition storage in rock are mainly from blast, fragment and debris and from groundshock.

The airblast from a detonation in an underground installation is given in design manuals e.g. the Swiss TLM 75, /3/.

The distance, d, with the overpressure, p, outside a tunnel with the overpressure in the entrance, p_o - presuming that the rock cover does not break - is

$$d = 0.7\left(\frac{p_o}{p}\right)^{0.9} \cdot D$$

where D is tunnel diameter in the entrance.

The results from this formula can be compared with test results e.g. /4/ and /5/. Especially for low pressure levels the Swiss formula gives conservative values as can be seen in figure 1. This is due to the fact that the exponent 0.9 has been chosen instead of the theoretical value 2/3, cfr /6/. The test results in /4/ are condensed into the formula

$$d = 1.17\left(\frac{p_o}{p}\right)^{0.74} \cdot D.$$

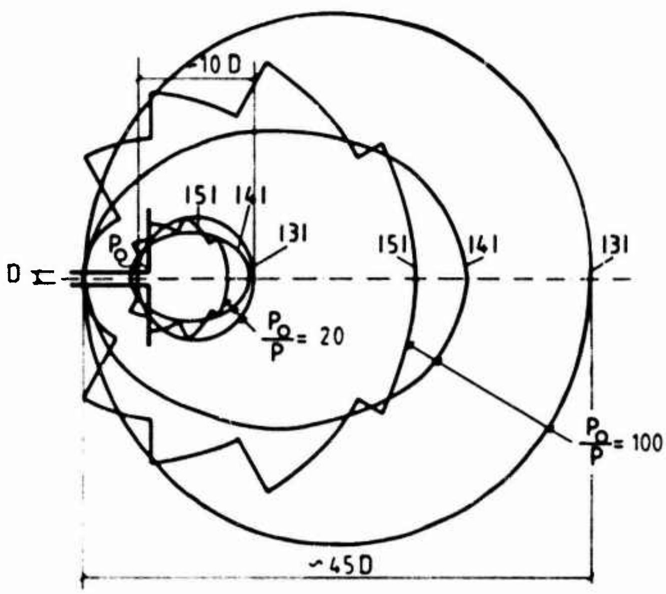


Figure 1. Comparison of different formulas for the overpressure outside a tunnel entrance from /3/, /4/ and /5/.

For debris and fragment throw very few reliable data exist that can be used for design purpose or risk analysis.

Again, the TLM 75, /3/, has stipulated hazardous zones outside the tunnel entrance basically according to figure 2.

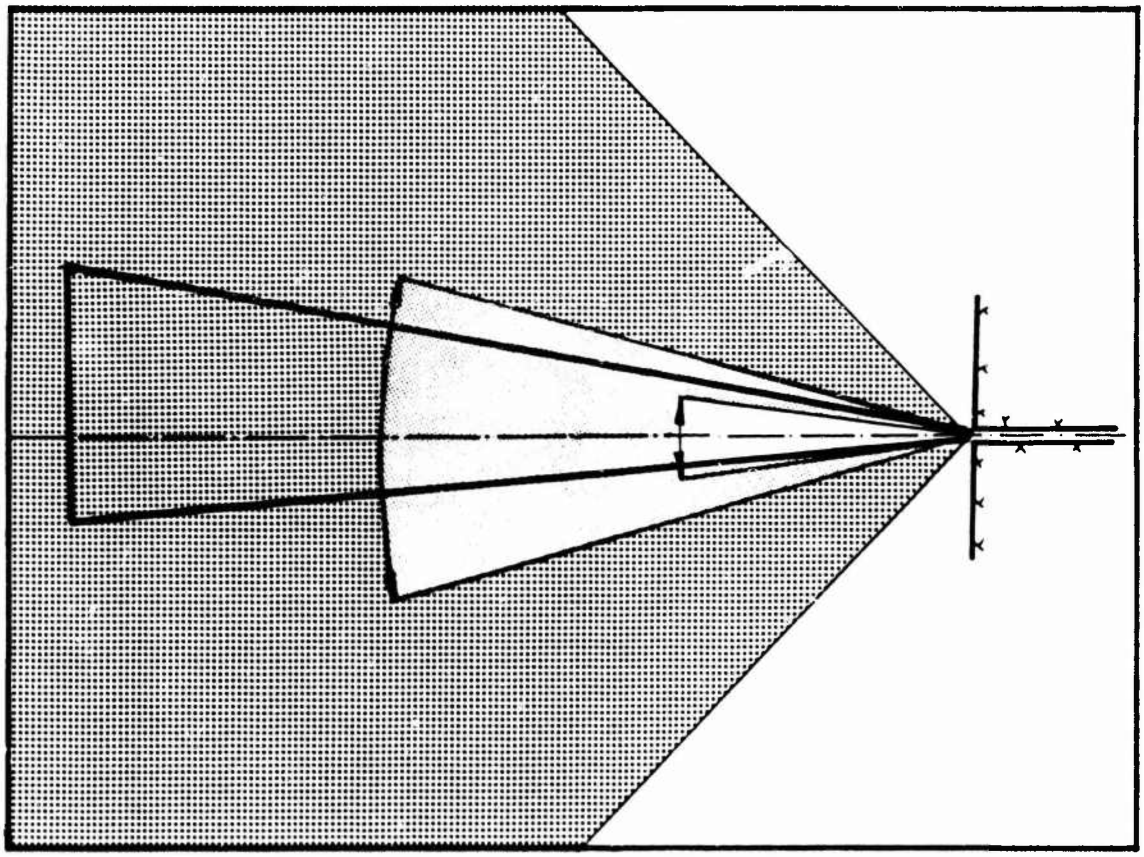


Figure 2. Lethality zones outside an ammunition storage due to debris and fragments according to /3/. Principle.

The hazardous area due to blast can be predicted with a higher degree of certainty than that due to debris and fragments. Also model tests for studies of blast propagation can often be made at low costs and give accurate results. Model tests have even been permitted as a basis of design for some magazines when it comes to blast, cfr /5/.

For debris and fragment dispersion models can not be used easily for predictions due to substantial scaling problems e.g. air resistance and gravity.

Especially, when a more sophisticated concept for desing codes, like risk analysis, is to be adopted a more comprehensive database on debris and fragment throw is mandatory.

The main objective of the initial tests at the installation was to study debris.

The velocity of debris can be calculated, theoretically, e.g. according to the model in figure 3.

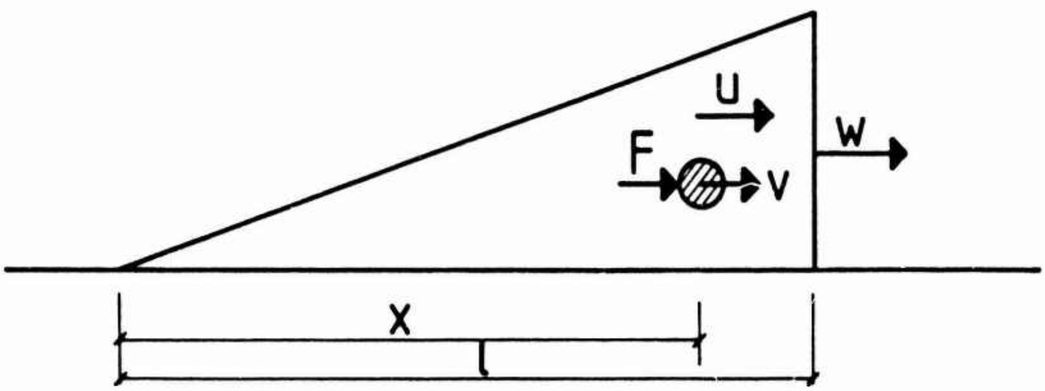


Figure 3. Simplified model for calculation of debris velocity.

The dynamic pressure, q_t, is calculated from

$$q_t = \frac{1}{2}\rho_t(u_t - v_t)^2 \quad \text{where}$$

air density

u air particle velocity

v debris velocity

For debris

$$m \cdot \dot{v}_t - \frac{A \rho_t}{2} \cdot C_D (u_t - v_t)^2 = 0 \quad \text{where}$$

C_D drag coefficient

A drag area and

m mass.

A solution of this equation has been used in a computer program for the pre-calculations of debris velocities, /7/.

3. INSTALLATION

As the main objective with the installation was to make multiple tests with debris a site had to be selected where large amounts of explosives could be detonated without impairing the community, where competent rock with adequate rock cover could be found and at the outside of which a surface suitable for collecting fragments and debris could be arranged.

This led to the shooting range at ArtSS, Älvdalen, Sweden, very close to where the original large Klotz-Club test was made in 1973.

The rock at the selected site consists of porphyritic granite, poor in puartz, /8/.

Outside the entrance cutting a surface from which debris and fragments could be collected was made. The area in the form of a sector was close to flat up to 150 m from the entrance and then steeper to form a target area in total more than 300 m from the tunnel.

Figure 4 debicts the geometry outside the installation.

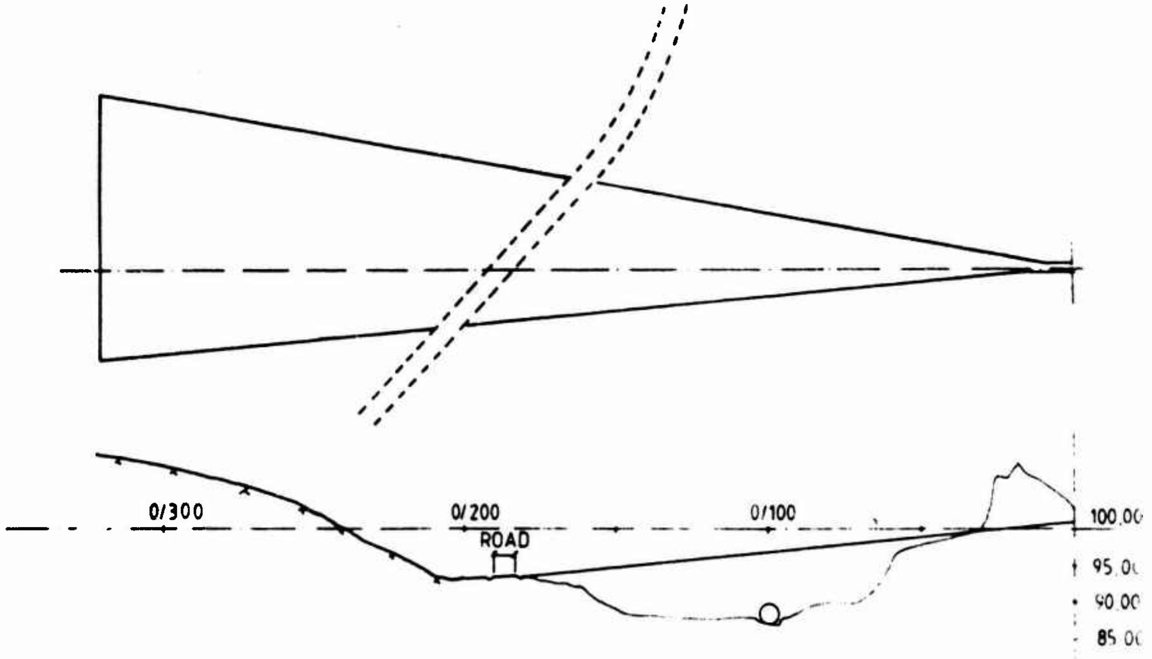


Figure 4. Geometry at the test site.

The tunnel in the rock was made with a crossection of 6.3 m^2. The walls were shotcreted. In the end of the tunnel was a chamber with a crossection of 12 m^2 and a volume of 300 m^3 e.g. a length of about 25 m. In 45° to the tunnel another tunnel with the same crossection was built. At the end of one end of that tunnel a chamber 17 m long with a volume of 200 m^3 was made. The other end of that tunnel was made 10 m long with the purpose of collecting debris and fragments coming out of the 200 m^3 chamber.

The tunnels and the chambers were bolted. The entrance part was made of reinforced concrete to ascertain that the geometry of the entrance would not change during the test series. Also to facilitate comparison with other test data a well defined geometry was needed.

The installation was made during the winter and early spring, 1986.

4. MEASUREMENTS

Measurements were made of blast, debris trajectories and groundshock. The groundshock measurements will not be given in this paper, however.

The blast was measured in the chambers, on different locations along the tunnel and outside and even above the installation. As the dynamic blast pressure is of interest e.g. for the studies of the drag forces on ejecta not only the static pressure was measured but - in front of the tunnel where it was significant - also the stagnation pressure. The placing of pressure gauges is shown in figure 5.

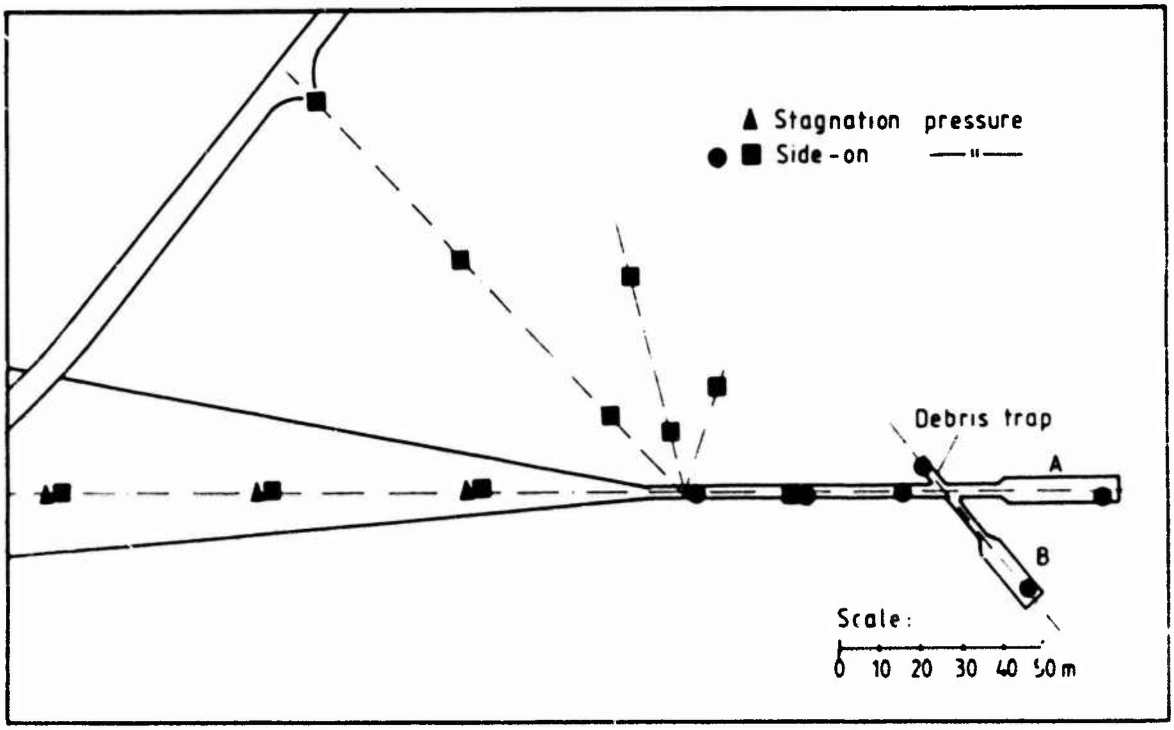


Figure 5. Blast measurement points.

To facilitate the measurements of the trajectories of the ejecta the area outside the tunnel was prepared with timber logs laid down perpendicular to the tunnel axis at 10 m distances across the sector and vertical poles for reference placed along the tunnel axis.

High-speed cameras and videocameras were placed perpendicular to and along the tunnel axis as can be seen in figure 6.

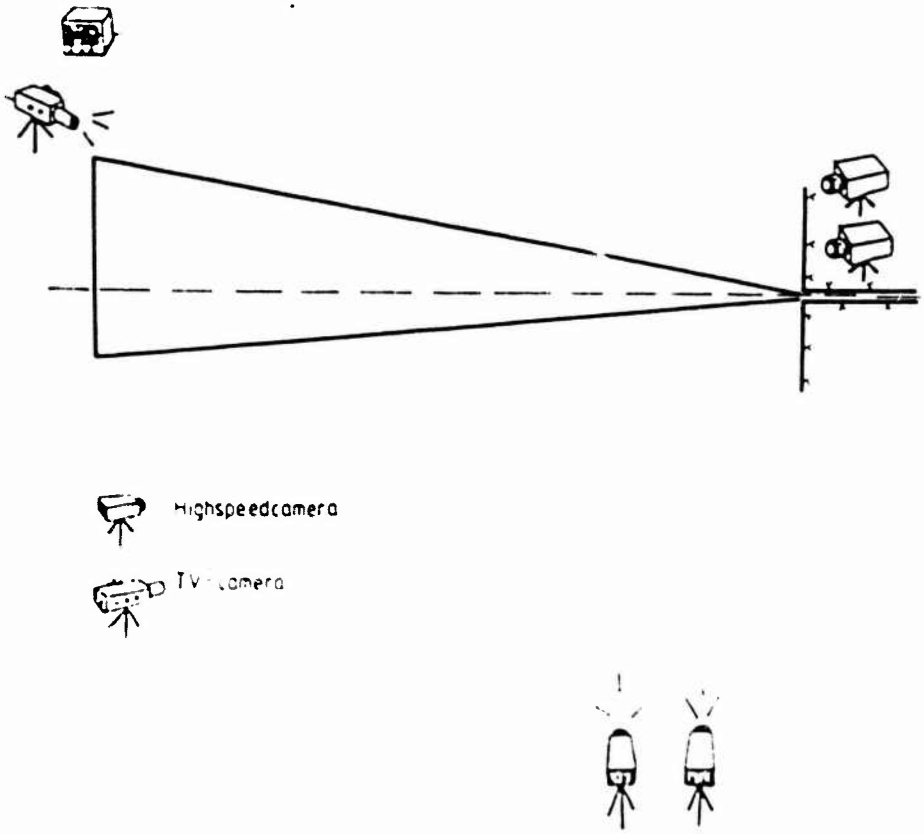


Figure 6 Highspeed cameras and TV during the test. The cameras along the tunnel axis were used only in tests 1-3.

5. TEST EXECUTION

The initial test program comprises six tests:

- 1. 10 kg TNT in chamber A
- 2. 10 kg TNT in chamber B
- 3. 1000 kg TNT in chamber A
- 4. 1000 kg TNT in chamber B
- Artillery rounds with net explosive weight 1000 kg in chamber A
- Ditto chamber B

Of these the first four will be commented subsequently. The last two tests in the program - among other things to give data on fragment dispersion and on TNT-equivalence - will be described in another paper.

The tests 1 and 2 mainly for calibrating purposes were made with the charge placed in the middle of each chamber. No debris was included in these tests and only blast measurements in the tunnel system and just outside the installation were made.

During the tests 3 and 4 1000 kg of TNT in the shape of a cubicle was placed in the middle of the chambers respectively.

Artificial debris in the shape and with the mass approximately like the artillery rounds for the final two tests were used. These debris were 680 mm long 160 mm diameter steel pipes filled with concrete. The mass was 47 kg.

These tubes were placed in the chamber standing on the floor behind the charge (4 of them) and lying and standing in front of the charge on the same level (16 of each). In the tunnel system pairs of cylinders were placed on the floor on the three locations were pressure gauges were installed. At test number 3 a pair of cylinders was also placed in the short access tunnel to the chamber.

Spheres of reinforced concrete approximately 110 mm in diameter (mass appr. 2 kg) were placed on top of the cylinders in the tunnels.

Figure 7 shows the location of the artifical debris.

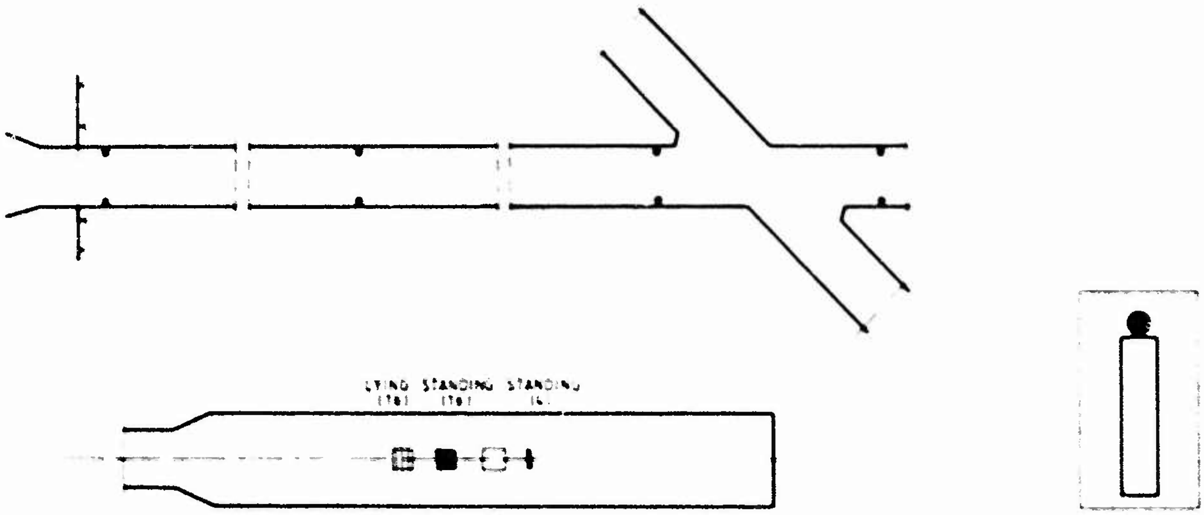


Figure 7. Artificial debris in test 3 and 4.

6. RESULTS

The overpressure at the entrance of the tunnel, which is used for calculating the blast outside the tunnel according to chapter 3 was measured to

Test	Pressure (kPa)
1	23
2	25
3	850
4	700.

The measured pressure outside along the tunnel axis are shown in figure 8 together with the calculated values according to /3/ and /4/. The measured values differ slightly from the calculated values according to /3/ and /4/ which, as is to be expected, gives conservative estimates. As the testing range was not made to be ideal for blast propagation studies a detailed comparison of precalculations based on ideal conditions with the actual measurements are not justified. This is especially true for measurements in other directions than the tunnel axis.

As the length of the crosstunnels in the installation is small their influence on the blast pressure outside the tunnel will be minor, /9/.

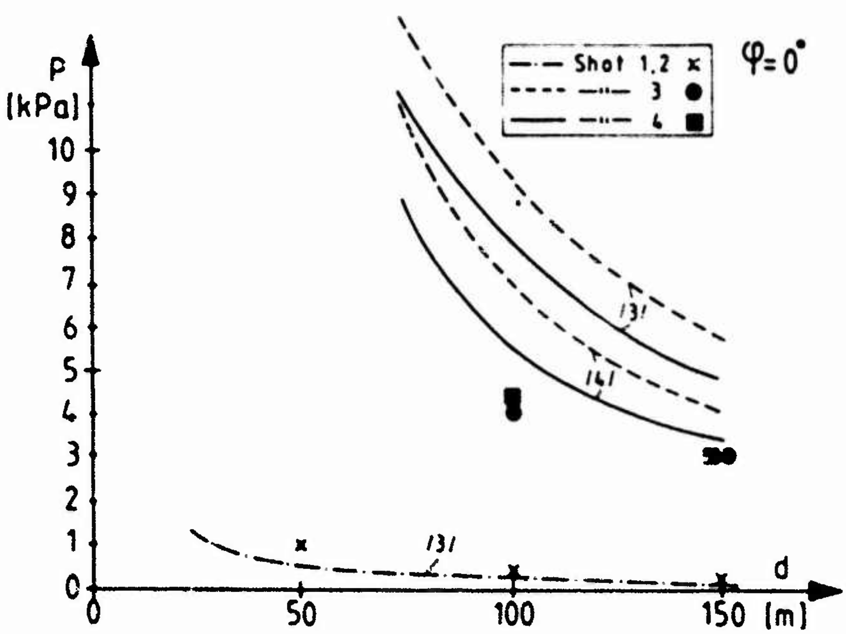


Figure 8. Measured overpressure outside the tunnel entrance

At the tests the blast was followed by debris at high velocity and then large amounts of black smoke came out of the entrance to the installation.

Figure 9. Fragments impacting the debris trap and smoke coming out of the entrance.

The artificial debris were found in the tunnel system and in a sector less than ±10° from the tunnel axis.

The debris close to the charge in the inner end of the chamber were all found remaining in the chamber after the test - though deformed.

In shot 3 the artificial debris were impacting on the chamber and tunnel walls and some of them stopped. Other went out of the tunnel. Most of the artificial cylinder shaped debris were recovered and identified. The velocities of the debris were measured from high-speed films. The maximum velocity measured was 120 m/s appr. 100 m outside the tunnel.

Shot 4 showed the debris trap to be efficient. Almost all debris were found in the tunnel system after the test while the artificial debris placed in the tunnel were thrown out. All debris were recovered and identified.

The debris trap would have been ever more effective if it had been wider.

The maximum debris velocity at shot 4 was measured to 135 m/s.

According to the precalculated values debris with velocities up to 150 m/s at the tunnel entrance are to be expected. For large debris like the artificial ones used in the test the air resistance does not lower the velocity very quickly in this range, /10/.

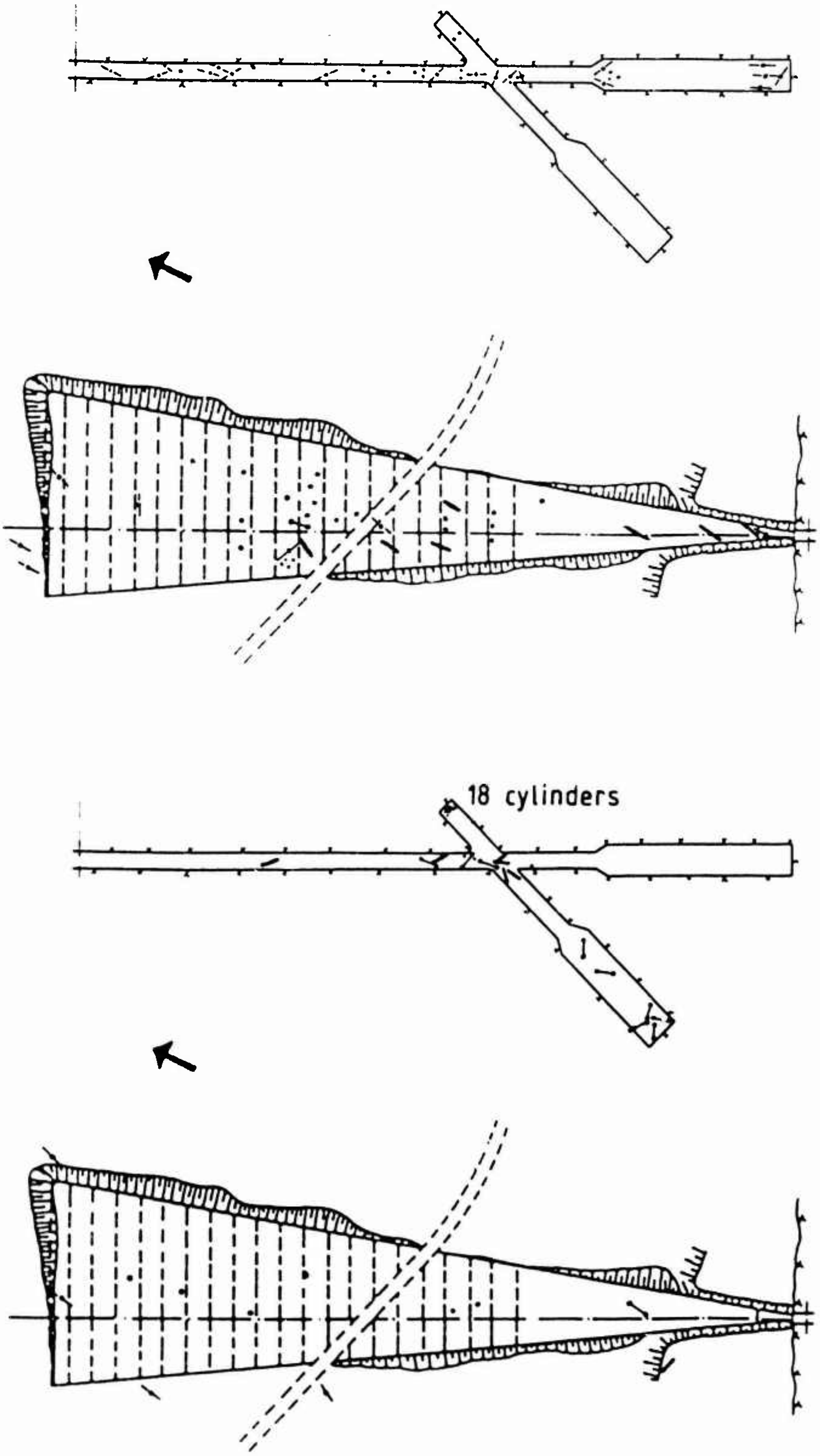
In figure 10 the location of debris after the tests 3 and 4 are shown.

7. CONCLUSIONS

The installation at ArtSS has shown to be a versatile tool for the measuring of the debris throw out of ammunition storage in rock. The tests performed so far have shown that the debris will fall in a narrow sector from the tunnel axi The velocity of the debris is in correlation with precalculations.

8. ACKNOWLEDGEMENT

In the planning and during the execution of the tests many valuable suggestions have been given by different members of the Klotz-Club. Excellent efforts have also been made by a lot of individuals at ArtSS and FortF. The author is most thankful for all dedication and to outstanding achievements he has met during different stages of the project.



cylinders

• part of cylinder or sphere

Figure 10. Debris postshot test 3 (above) and 4 (below).

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