1-7993384

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

RELATING EXPLOSIVES SENSITIVITY LABORATORY RESULTS TO FIELD TESTS

E. Contestabile and R.R. Vandebeek

Canadian Explosives Research Laboratory

DECEMBER 1986

Presented to the Society of Explosive Engineers, at the "1987 Conference on Explosives and Blasting Technique"; Feb. 1-6, Miami, Florida.

14P

MINING RESEARCH LABORATORIES
DIVISION REPORT MRL 86-141(OP)

RELATING EXPLOSIVES SENSITIVITY LABORATORY RESULTS TO FIELD TESTS

by

E. Contestabile * and R.R. Vandebeek **

ABSTRACT

The continuing evolution of explosives has most recently introduced emulsion explosives and heavy ANFO's to the market place. An explosives engineer has a multiplicity of explosives to choose from: dynamites, slurries, water gels, emulsions, ANFO's, and mixtures of some of these products.

The purpose of this study is to present laboratory and field test results on the effect of various stimuli on the sensitivity of different explosives and how they relate to blasting practices. The explosives have been evaluated in the temperature range of -5°C to 40°C with the following tests:

1. Air gap test
2. Shock sensitivity test
3. Projectile impact test
4. Drop weight impact test
5. Nut and bolt friction test

Although these test results relate primarily to the safety properties of the explosive, in many cases, an extension can be made to expected performance in the field.

---

*Explosives Scientist, **Manager, Canadian Explosives Research Laboratory, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Keywords: Sensitivity tests, temperature effect and explosives.

SENSIBILITÉ DES EXPLOSIFS: RELATION ENTRE LES RÉSULTATS DE LABORATOIRE ET LES ESSAIS SUR LE TERRAIN

par

E. Contestabile * et R.R. Vandebeek **

RÉSUMÉ

L'évolution constante en matière d'explosifs a conduit à la mise au point d'explosifs à émulsion et d'un mélange lourd nitrate d'ammonium-fuel (ANFO) qui sont apparus récemment sur le marché. Un ingénieur en explosifs peut choisir parmi une variété d'explosifs: la dynamite, les explosifs en bouillie, les explosifs à émulsion, les mélanges ANFO et les mélanges de certains de ces produits.

La présente étude a pour but d'exposer les résultats d'essais effectués en laboratoire et sur le terrain concernant les effets de divers stimuli sur la sensibilité de différents explosifs et leur relation avec les techniques de sautage. Les explosifs ont été évalués à des températures variant entre -5°C et 40°C lors des essais.

1. Essai des intervalles explosifs
2. Essai de sensibilité aux secousses
3. Essai d'impact des projectiles
4. Essai de mouton de choc
5. Essai de frottement boulon-écrou (nut and bolt)

Bien que les résultats obtenus se rapportent principalement aux caractéristiques de sécurité de l'explosif, ils peuvent s'appliquer dans certains cas au rendement prévu sur le terrain.

---

*Scientifique et **Gestionnaire spécialisé dans les explosifs, Laboratoire canadien de recherche sur les explosifs, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa (Ontario).

Mots-clés: essais de sensibilité, effet de la température et explosifs.

CONTENTS

Page

ABSTRACT i

RÉSUMÉ ii

INTRODUCTION 1

THE EFFECT OF TEMPERATURE ON THE DETONATION VELOCITY 2

THE EFFECT OF TEMPERATURE ON THE INITIATION SENSITIVITY 2

- The CERL Modified Type 12 Tool Test 2
- The CERL Nut and Bolt Friction Test 3
- The Projectile Impact Test 4
- The Shock Sensitivity Test 4
- The Air-gap Test as Performed at CERL and in the Field 4

CONCLUSIONS 5

ACKNOWLEDGEMENTS 7

REFERENCES 8

TABLES

No.

1. List of explosives tested 9
2. Detonation velocity values at different temperatures, in confined/unconfined states, in m/s 9
3. Drop-weight impact test results, H-50 in cm 10
4. Nut and bolt friction test results (30 s test period) 10
5. Projectile impact test results, V-50 in m/s 10
6. Shock test results, grams of PETN for 50% fires 10
7. Detonator properties 11
8. A suggested equivalence of detonating cords and fulminate/chlorate and PETN detonators 11
9. Laboratory (unconfined) air-gap test results, range in cm 11
10. Air-gap field test (confined) results, in cm 12

CONTENTS (Cont'd)

TABLES

No. Page

11. Relative order of sensitivities for 25 mm diameter samples tested at 20°C 12

12. Comparison between laboratory (unconfined) and field (confined) air-gap tests at 20°C, as a function of sample diameter 13

FIGURES

No. Page

1. Production of nitroglycerine base, ANFO, and slurry explosives in Canada, 1921-1983 14

2. CERL's modified type 12 impact tool 14

3. Drop-weight impact test results 15

4. Cross-section of the sample used in the CERL nut and bolt friction test 15

5. .50 cal projectile impact test gun 15

6. Projectile impact test results 15

7. Shock test results 16

8. Laboratory set-up for determining the gap sensitivity 16

9. Field test set-up for determining the gap sensitivity 16

INTRODUCTION

This report presents the results of an investigation relating laboratory sensitivity tests to different stimuli and comparing them to field tests performed on slurry and emulsion explosives.

All explosive substances are sensitive to varying degrees to a multitude of external stimuli. A balance must be met among certain parameters to make a particular explosive practical to use in a given environment. A practical explosive is economical and safe to produce, transport, and detonate by controlled means. Therefore, by the nature of the explosive itself or sensitizers used, it is possible to have today's explosives.

Unlike dynamites that are sensitized with nitroglycerine or similar substances, slurry and emulsion explosives may or may not contain an explosive sensitizer.

Slurries or water gels, as defined in Reference (1), "consist of saturated acqueous solutions of ammonium nitrate and other nitrates, which also contain additional amounts of undissolved nitrates in suspension, and fuels which take up the excess oxygen of the nitrates; the structure of the nitrate solution can be significantly affected by added thickeners (Guar gum) and cross-linking agents (borax). The most important fuel is aluminum powder; water soluble fuels such as glycol can also be employed; the nitrates may include also nitrates of organic amines (methylamine nitrate-MAN)".

Water-in-oil emulsion explosives are comprised of a continuous oil/fuel phase and a discontinous oxidizer salt phase made up of supersaturated droplets. These explosives are supposedly superior to slurries because their reaction rate has been enhanced due to the increase in contact surface area between the fueld and oxidizer.

A move away from nitroglycerine based explosives is evident in Canadian sales as indicated in Figure 1 (2). Since 1983 was the last year that domestic production figures were reported, it is estimated that total production has remained fairly constant over the past three years. The increase in sales of emulsion type explosives has occurred primarily at the expense of slurry explosives.

The explosives' sensitivity to external stimuli is affected to varying degrees by temperature. This fact has been demonstrated in many of the tests performed. To the blaster, however, the relative sensitivity of an explosive to shock is probably the most important. That is, the explosive must function as expected in a given environment.

The samples used in this study along with their general names and reference numbers are summarized in Table 1. This table also lists the cartridge diameters that were used.

THE EFFECT OF TEMPERATURE ON THE DETONATION VELOCITY

The detonation velocity of an explosive has been found to vary with its diameter and temperature. The velocities measured at the different temperatures on all the diameters are consistently higher for the emulsions than for the slurries for both the confined and unconfined states. Table 2 lists these results. Note that the detonation velocity of the water gels measured in the confined state, decreased faster than that of the slurry product as the temperature was decreased. Also, with one small diameter sample, the low temperature tests caused the critical diameter to increase to such an extent that the explosive failed to detonate. The detonation velocity of the emulsion explosives remained relatively constant in this temperature range. It can also be noted that the detonation velocity for confined explosives is normally higher than those that are not confined.

THE EFFECT OF TEMPERATURE ON THE INITIATION SENSITIVITY

Studies performed on explosives at CERL and elsewhere, indicate that the sensitivity to the different stimuli is greatly influenced by temperature. It must be stated that, since small amounts of explosives are used, some tests do not cause a detonation. What is observed is referred to as a 'reaction'. This reaction is normally accompanied by the emission of sound, light, fumes, and/or odour.

Two laboratory tests that use small amounts of explosives are the CERL Modified Type 12 Impact Tool Test and the CERL Nut and Bolt Friction Test.

THE CERL MODIFIED TYPE 12 TOOL TEST

The CERL Modified Type 12 Impact Tool is shown in Figure 2 and the test is detailed in Reference (3). In the drop-weight test, 35 mg of explosive are placed on a small piece of sand paper on the anvil. The 2.5 kg intermediate weight is gently lowered onto the sample and the 2.5 kg drop weight released from the desired test height. A standard up-and-down method (4) is then followed to determine the height (H-50) at which 50% of the samples react. Results from this test are listed in Table 3. The results that read 300+ indicate that no reaction was observed when the sample was tested at the 300 cm drop height. The values from Table 3 have been plotted in Figure 3.

Since the samples are placed on sandpaper when tested, there exist sufficient potential hot spots that any gritty material such as silica or aluminum in the explosive sample would not appreciably increase the sensitivity to this test. This fact makes studying the effect of, for example, silica or aluminum very difficult and indicates that only the quenching medium seems to drastically affect the H-50 value. Observations under a microscope have shown that as the sample is heated on a hot stage, the fluid settles to the bottom, exposing crystalline structures at the very top surface. With samples containing aluminum, the fluid could be seen collecting around the aluminum particles (probably due to the aluminum's high thermal conductivity). Since the liquid concentration of the sensitizer increases with temperature and that this hot liquid solution is the most sensitive part of the explosive, it can be seen why the drop weight impact sensitivity increases with increasing temperature.

The test results indicate that the order of sensitivity at all temperatures closely follows the water content of the explosive samples, with those having the most water being the least sensitive. Also, the samples containing aluminun were found to be the most sensitive at all the test temperatures.

THE CERL NUT AND BOLT FRICTION TEST

The CERL Nut and Bolt Friction Test is detailled in Reference (5). As shown in Figure 4, as 1 cc sample of explosive is placed in a nut whose bottom is plugged with a set screw. A bolt is then carefully screwed into the nut and placed in the apparatus for testing. With the use of an impact wrench the bolt is screwed down and the time to reaction is measured. The impact wrench is allowed to run for a maximum of 30s. With commercial explosives, the reactions that occur in this test are not very violent. Normally, the reaction will simply cause the nut to deform slightly. Table 4 lists the results of this test.

The discriminating power of this friction test is easily seen from the results. Explosives containing small amounts of gritty materials usually react partially. In Reference (5), it was shown that slurry explosives that normally show no reaction to this test, reacted every time after the addition of 1% of microballoons. The glass microballoons apparently served to generate hot spots between the faces of the moving screw threads.

This test gives an indication of the safety required when explosives are mixed or pumped by mechanical means. In general, it is important to avoid situations where explosives are forced into small spaces between metal parts where continuous action can cause the metal and explosive to overheat. In such cases the trapped explosive, especially if it is only a small amount, will be unable to dissipate the ehat at a rate that would prevent a reaction from occuring. Given a certain stimulus, the explosive may react if hot spots are generated within a low thermal conductivity area. However, if the heat can be quickly dissipated, as in explosives containing high percentages of water, the rate of reaction may be greatly reduced. With these principles in mind, it is expected that explosives having lower percentages of water and potential hot spot generators such as silica, aluminum, or microballoons will be more susceptible to initiation by frictional loads. Note that in the above, a transition to detonation can be eliminated by assuring that subcritical dimensions are used in mechanical and related areas.

Laboratory tests that use samples that are so large as to be induced to detonate include the projectile impact test, the shock sensitivity tesst, and the air gap test.

THE PROJECTILE IMPACT TEST

The projectile impact test is detailed in Reference (6). Basically, a 50 cal gun, as shown in Figure 5, is used to fire brass projectiles, 12.7 mm in diameter and 12.7 mm long, at a freely suspended, unconfined, 500 g sample of explosive. By firing at different speeds, it is possible to determine the velocity (V-50) at which 50% of the samples detonate. The projectile impact test results are listed in Table 5 and depicted in Figure 6.

It has been found that, in general, the sensitivity of all the samples increases with increasing temperature and that the samples containing aluminum are the most temperature dependent. Attempts to correlate the V-50 to the composition of the explosive has led to the conclusion that the V-50 tends to increase with increasing amounts of the liquid phase plus oxidizers.

THE SHOCK SENSITIVITY TEST

The shock sensitivity test is detailed in Reference (7). It utilizes a 500 g sample of explosive and the initiator can be either a blasting cap or detonating cord. The three methods used to determine the sensitivity of these explosives to shock are referred to as the blasting cap, the detonating cord tracer and the detonating cord booster.

In the blasting cap method, a blasting cap with either PETN or fulminate/chlorate base charge is completely inserted into the explosive. The strength of the blasting cap is then either increased or decreased depending on the outcome of the experiment. The blasting caps available for this study were #6, #8, HS electric (PETN) and #1-#6 inclusive, and #8 fulminate/chlorate non electric-caps.

In the detonating cord tracer method, the detonating cord is placed in the longitudinal axis of the sample. The charge weight of the detonating cord is then either increased or decreased depending on the experimental outcome.

The third technique involves taking that size of detonating cord that initiated the sample under test and reducing the length in contact with the explosive in 0.5 cm increments until a fire/no-fire point is reached.

The results are listed in Table 6 and shown in Figure 7. Table 7 lists the properties of the detonators and the amount of sand crushed in the Sand Bomb Test (8). Table 8 shows a comparison between detonating cords and fulminate/chlorate and PETN detonators.

Results indicate that in general, the samples' sensitivity to the shock test increases with increasing temperature.

THE AIR-GAP TEST AS PERFORMED AT CERL AND IN THE FIELD

The air-gap test is used to determine the sensitivity of an explosive to shock loading. The Encyclopedia of Explosives and Related Items (9), defines shock sensitivity as "the reaction of condensed explosives in time frames of microseconds to shocks whose amplitude is generally in the MegaPascal (kilobar) range. Furthermore, shocks are defined as steep-fronted compression waves that propagate at supersonic velocities in the medium that they traverse".

The sample is prepared, as shown in Figure 8, by wrapping a donor and a receptor charge a fixed distance apart in waxed paper. A length of detonating cord is used as a witness to the receptor charge detonating. As with the other tests, and up-and-down method is used to vary the separation distance between the charges and bracket the 50% firing level. Table 9 lists the results of this test.

Air-gap tests that were performed in the field were comprised of a series of confined tests in which a donor explosive is separated by a selected distnace from the receptor explosive. Figure 9 shows the air-gap field tests as performed in boreholes in granite and Table 10 lists the results. Details of this work are outlined in Reference (10).

In general, the trend is for the air-gap to increase as the temperature is increased. The emulsion products, however, all showed very poor cross-propagation sensitivity with higher temperatures having little or no effect. As already discussed under the effect of temperature on the detonation velocity heading, the detonation velocity will decrease with decreasing temperature. It will have a corresponding effect on the detonation pressure that in turn will reflect changes in the air-gap sensitivity.

In the field work reported in Reference (10) it is shown that a linear relationship exists between charge diameter and gap distance (see Table 10) and that this seems to agree quite well with the theory that the impulse from the end of a cylindrical explosive charge, varies with the charge diameter in an approximately linear fashion.

The results indicate that the sensitivity of the explosives decreases as the temperature is lowered and increases as the temperature is raised.

CONCLUSIONS

The change in the detonation velocity and the sensitivity of the explosives tested with temperature can be partly explained by considering the mode of sensitization. When a product such as the emulsions is sensitized with the use of microballoons, the temperature is expected to have little effect on the initiation and propagation. That is, the inert microballoons are not physically altered by the small temperature changes. However, if a product such as the slurries/watergels are sensitized by entrapped air bubbles or chemical sensitizers, then one would expect a variation in the results. A change in temperature will alter the size of the air bubbles and disturb the concentration of the liquid phase.

In tests in which small samples of explosives are used, the result is normally a reaction. Therefore the results are useful only for obtaining relative sensitivities and for predicting the possibility of initiating small amounts of explosive by well defined mechanical means. Due to the inherent difficulties with these tests, there has been a tendency to design and perform tests that utilize larger samples. It is interesting to note, however, that the one commercial explosive that did react in the Nut-and-Bolt test was involved in a production-related accident.

The laboratory tests that utilize larger samples tend to generate results that better relate to hazards tha may be encountered in the manufacture, transport, and/or use of explosives.

Projectile impact and shock tests reveal that all the explosives are more sensitive to these stimuli at higher temperatures. A comparison of the relative order of sensitivities at 20°C of the 25 mm diameter samples of these tests with laboratory and field air-gap tests indicate that there is some correspondence. These results are shown in Table 11. Perfect correlation cannot be expected as the mode of initiation in each of these tests is different.

Results for the air-gap test for the confined and unconfined configurations indicate that the gap decreases with decreasing temperature for slurries and water gels. A similar tendency but to a lesser extent is demonstrated by the results for the emulsion explosives. The fact that emulsions are less able to propagate across air gaps than slurries or water gels is probably due to their use of glass microballoons as sensitizers. It seems natural that more energy would be required to cause the glass microballoons than entrapped air bubbles to act as detonation centres. This condition could be due to the high physical strength of the microballoons or to the fact that non-reactive silica is on the outside surface of the "hot-spot". It could also be due to the low gas content of the microballoon (the pressure inside the balloon is low) that would require a higher degree of compression to attain the same energy level as a gas microballoon at atmospheric pressure. Table 12 compares the 20°C air-gap results for the laboratory (unconfined) and field trails (confined). The results for the emulsion explosives have been segregated from those for the slurries and water gels. Both sets of data, however, indicate that the air-gap increases with the diameter and that the relative order between both tests is fairly consistent.

Projectile impact test results have often been compared to air-gap test results. The average V-50 at 20°C for about 40 samples of commercial explosives (6,7) was determined to be 610 m/s with a range of 210-1020 m/s. From shock tests such as the card gap and the cap test performed at CERL and the Bureau of Mines, a 5 to 6.2 cm gap and a #8 electric blasting cap correspond to a velocity range of about 610 to 720 m/s. Also, for the purpose of comparison, flake TNT (= 0.8), pelletized TNT (= 1.0), and ANFO (= 0.9) have V-50's of 650 m/s, 760 m/s, and 1400 m/s.

The results presented in this paper indicate that temperature does modify the behaviour of explosives and that one should be aware of these changes to ensure a safe operation and simultaneously obtain the required results. As an example, consider the fact that a couple of small diameter explosives did not detonate, even in the unconfined state. Therefore, in varying temperature conditions, it is important that a choice of initiator be based on the knowledge of cap sensitivity and air-gap sensitivity of the product being used. It has also been shown that laboratory tests can certainly be used to some extent to predict the behaviour of explosives in production and usage.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the recent data gathering efforts of T.R. Craig and D. Cox and thank J. Folta for the graphics.

REFERENCES

1. Meyer, R. Explosives; Verlag Chemie; Weinheim, New York; 1977.

2. Report of the Explosives Branch; Explosives Branch, Energy, Mines and Resources Canada; 1983.

3. Contestabile, E., Pike, E.T. and Craig, T.R. CERL's Modified Type 12 Impact Tool; Canadian Explosives Research Laboratory; Report ACEA/MRL 85-84(TR); CANMET, Energy, Mines and Resources Canada.

4. Dixon, W.J. and Massey, E.J. Jr., Introduction to Statistical Analysis; McGraw-Hill Inc.; New York; 1969.

5. Contestabille, E. The Canadian Nut and Bolt Friction Test; Mining Research Laboratories; Report MRP/MRL 76-128(TR); Energy, Mines and Resources Canada.

6. Contestabile, E. and Craig, T.R. The CERL 13 mm Projectile Test and Correlation of its Results with those from 30.06 Projectile Tests; Mining Research Laboratories; Report MRP/MRL 78-2(CF); Energy, Mines and Resources Canada.

7. Contestabile, E. and Vandebeek, R.R. Physical Testing of Explosives with Reference to those of Division 1.5; Mining Research Laboratories; Report MRP/MRL 78-3(CF); Energy, Mines and Resources Canada.

8. Vandebeek, R.R., Maddick, W.D. and Hendrick, B.E. Evaluation of Detonators in the Sand Bomb; CANMET Report MRP/MRL 75-36; Energy, Mines and Resources Canada.

9. Fedoroff, B.T. and Sheffield, O.E. Encyclopedia of Explosives and Related Items; Picatinny Arsenal; Dover, New Jersey.

10. Bauer, A.W., Bauer, A., Feng, K.K. and Vandebeek, R.R. Evaluation of the Propagation Sensitivity of Small Diameter Slurries, Water Gels, and Emulsions; submitted for publication to the Canadian Institute of Mining and Metallurgy.

TABLE 1 - LIST OF EXPLOSIVES TESTED

Number	Type	Diameters (mm)
1	Slurry	25, 32, 38, --, 50, 65, --
2	Slurry	25, 32, 38, --, 50, --, --
3	Water gel	25, 32, --, 44, 50, --, 75
4	Water gel	25, 32, --, 44, 50, --, --
5	Emulsion	25, 32, --, 44, --, --, --
6	Emulsion	25, 32, --, 44, --, --, --
7	TNT - flaked	(e = 0.8 g/cc)

TABLE 2 - DETONATION VELOCITY VALUES AT DIFFERENT TEMPERATURES, IN CONFINED/UNCONFINED STATES, IN M/S

Sample		Temperature (°C)			
No.	Diameter (mm)	-5	5	20	40
1	25	----	----	---- 3300*	----
	32	3470	3050	3560/3900*	4150*
	38	4080	4300	4270 ----	----
	50	----	----	4210 ----	----
	65	----	----	---- 4030*	----
2	25	----	----	3390/2810*	3000*
	38	----	----	---- 3460*	----
	50	----	----	4310/4200*	----
3	25	ND	ND	3260/3140*	----
	32	3380	3410	3930/----	----
	44	----	----	4110 ----	----
	50	----	----	4200 ----	----
	75	----	----	---- 3780*	----
4	25	----	----	3550 ----	----
	32	----	----	4140/3380*	----
	44	----	----	4250 ----	----
	50	----	----	3980/4065*	4650*
5	25	4750	5070	4410/4280*	----
	32	5110	4790	5250 ----	----
	44	----	----	5510/4580*	5400*
6	25	----	----	4550/4280*	----
	32	----	----	4790 ----	----
	44	----	----	5270 ----	----
TNT		----	----	6900 ----	----

ND - No Detonation.
* - Laboratory (unconfined) results.

TABLE 3 - DROP-WEIGHT IMPACT TEST RESULTS, H-50 IN CM

Sample	0	10	20	30	40
1	274	256	108	34	63
2	252	117	82	38	95
3	300+	300+	300+	270	189
4	300+	300+	300+	214	131
5	300+	300+	300+	300+	300+
6	300+	300+	300+	300+	300+
TNT	----	----	31	----	----

TABLE 4 - NUT AND BOLT FRICTION TEST RESULTS (30 s TEST PERIOD)

Sample	0	10	20	30	40
1	0/3	0/3	0/3	0/3	1/5 (5 s)
2	0/3	0/3	0/3	0/3	0/3
3	0/3	0/3	0/3	0/3	0/3
4	0/3	0/3	0/3	0/3	0/3
5	0/3	0/3	0/3	0/3	0/3
6	0/3	0/3	0/3	0/3	0/3
TNT	0/3	0/3	0/3	2/5 (1 s)	1/5 (2 s)

TABLE 5 - PROJECTILE IMPACT TEST RESULTS, V-50 IN M/S

Sample	0	10	20	30	40
1	701	609	533	394	388
2	748	625	503	398	399
3	729	562	456	494	427
4	632	520	494	460	461
5	---	---	857	835	806
6	---	---	731	---	---
TNT	667	---	648	---	579

TABLE 6 - SHOCK TEST RESULTS, GRAMS OF PETN FOR 50% FIRES

	Temperature (°C)				
Sample	-5	10	20	30	40
1	0.280	0.040	0.053	0.029	0.029
2	0.190	0.132	0.096	0.041	0.018
3	0.220	0.070	0.032	0.032	0.076
4	0.332	0.132	0.053	0.032	0.032
5	-----	-----	-----	-----	-----
6	-----	-----	0.347	-----	0.248

TABLE 7 - DETONATOR PROPERTIES

Detonator	Base Charge (g)	Primary Explosive (g)	Sand Crushed (g)
#6 PETN	0.19	0.23	43.7
#8 PETN	0.39	0.24	80.9
HS PETN	0.78	0.37	133.1
#1 F/C-80/20	0.30	----	14.3
#2 F/C-80/20	0.40	----	19.0
#3 F/C-80/20	0.54	----	29.9*
#4 F/C-80/20	0.65	----	36.8
#5 F/C-80/20	0.80	----	49.1*
#6 F/C-80/20	1.00	----	62.8
#8 F/C-80/20	2.00	----	133.5

TABLE 8 - A SUGGESTED EQUIVALENCE OF DETONATING CORDS AND FULMINATE/CHLORATE AND PETN DETONATORS

Detonating Cord		Detonator	
(g/m)	(cm)	Fulminate/Chlorate	PETN
21.30	>1.5	--	HS
10.20	>3.5	--	#8
10.20	3.0	#8	#6
5.86	2.5	#6	--
5.86	2.0	#5	--
4.26	1.5	#3	--
4.26	1.0	#2	--
4.26	0.5	#1	--

TABLE 9 - LABORATORY (UNCONFINED) AIR-GAP TEST RESULTS, RANGE IN CM

Sample		Temperature (°C)		
No.	Diameter (mm)	-5	5	20
1	25	---	---	<1.5
	32	1.5-2	1.5-2	4.5-6
	50	---	---	22.5-35
	65	---	---	22.5-35
2	25	ND	ND	<1.5
	38	---	---	6-10
	50	---	---	10-15
3	25	---	---	3-4.5
	75	---	---	25-35
4	25	---	---	4.5-6
	32	---	---	10-15
	50	---	---	>50
5	25	ND	ND	ND
	44	ND	ND	<1.5
6	25	ND	ND	ND

ND - No detonation.

TABLE 10 - AIR-GAP FIELD TEST (CONFINED) RESULTS, IN CM

Sample		Temperature (°C)		
No.	Diameter (mm)	-5	5	20
1	32	44	51	74
	38	41	69	74
	50	--	--	119
2	25	--	--	48
	50	--	--	124
3	25	ND	ND	15
	32	15	30	76
	44	--	--	137
	50	--	--	132
4	25	--	--	71
	32	--	--	104
	44	--	--	112
	50	--	--	130
5	25	4	4	4
	32	6	5	22
	44	--	--	32
6	25	--	--	1
	32	--	--	8
	44	--	--	36

ND - No detonation.

TABLE 11 - RELATIVE ORDER OF SENSITIVITIES FOR 25 mm DIAMETER SAMPLES TESTED AT 20°C

Sample Number			
Projectile Test	Shock Test	Air-Gap Laboratory	Air-Gap Field*
3	3	4	4
4	4	3	1
2	1	2	2**
1	2	1	3
5	NA	5	5
6	6	6	6

INCREASING SENSITIVITY

* Confined.

** 32 mm diameter.

TABLE 12 - COMPARISON BETWEEN LABORATORY (UNCONFINED) AND FIELD (CONFINED) AIR-GAP TESTS AT 20°C, AS A FUNCTION OF SAMPLE DIAMETER

Laboraty			Field		
Sample No.	Diameter (mm)	Air-gap (cm)	Sample No.	Diameter (mm)	Air-gap (cm)
6	25	ND	6	25	1
5	25	ND	5	25	4
5	44	<1.5	5	44	32
2	25	<1.5	3	25	15
3	25	3-4.5	2	25	48
4	25	4.5-6	4	25	71
1	32	4.5-6	1	32	74
4	32	10-15	4	32	104
2	50	10-15	1	50	119
1	50	22.5-35	2	50	124
4	50	>50	4	50	130

DECREASING SENSITIVITY

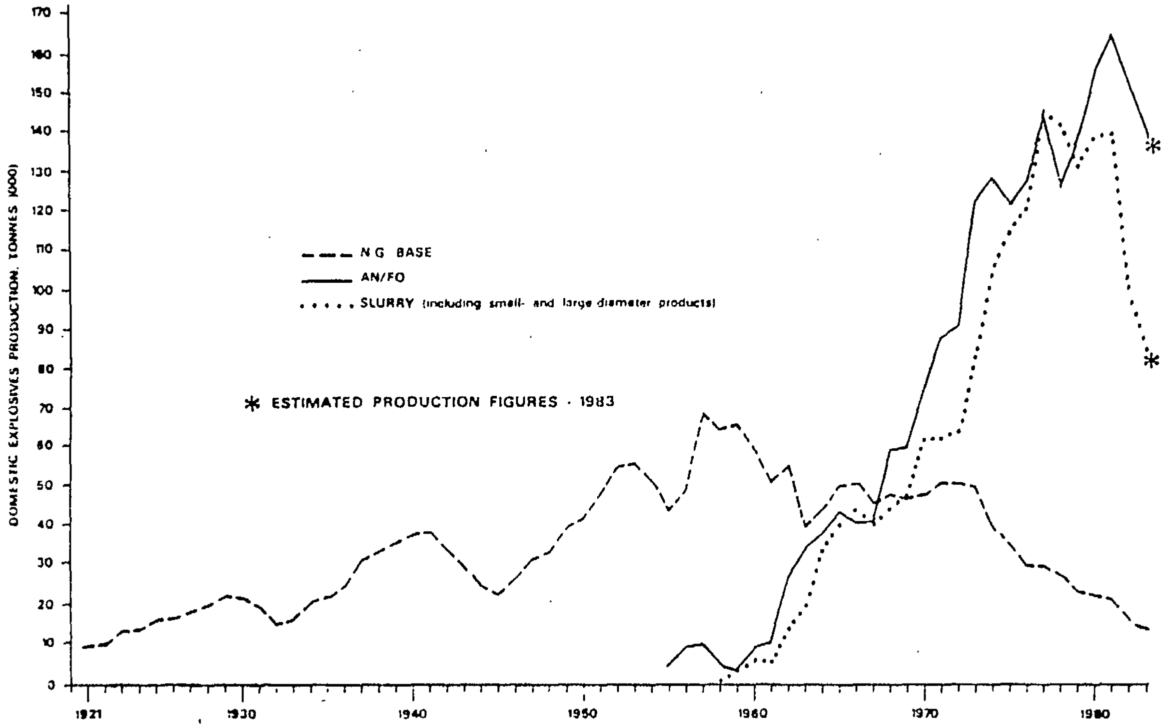

Fig. 1 - Production of nitroglycerine base, ANFO, and slurry explosives in Canada, 1921-1983

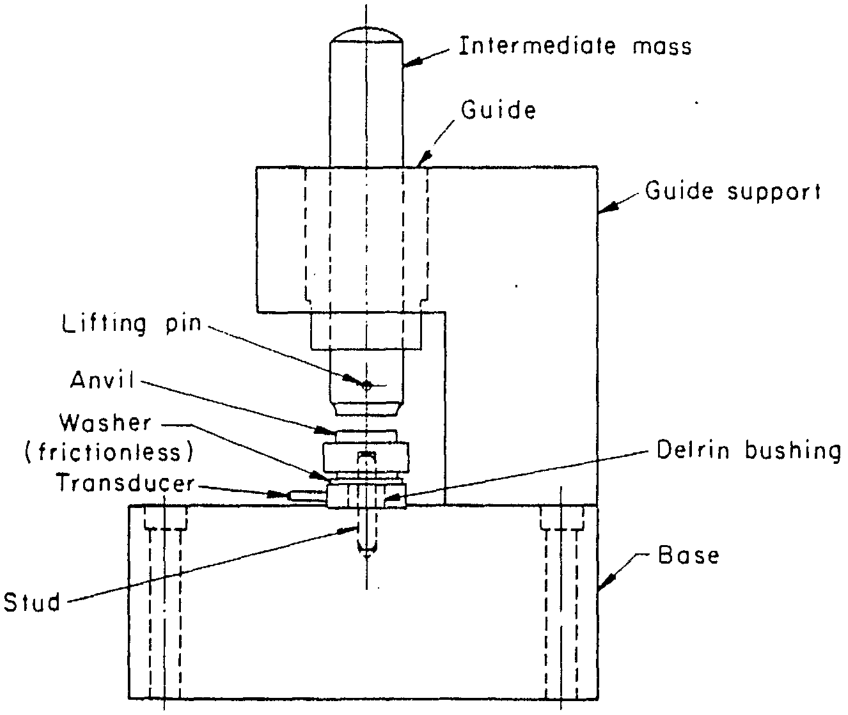

Fig. 2 - CERL's modified type 12 impact tool

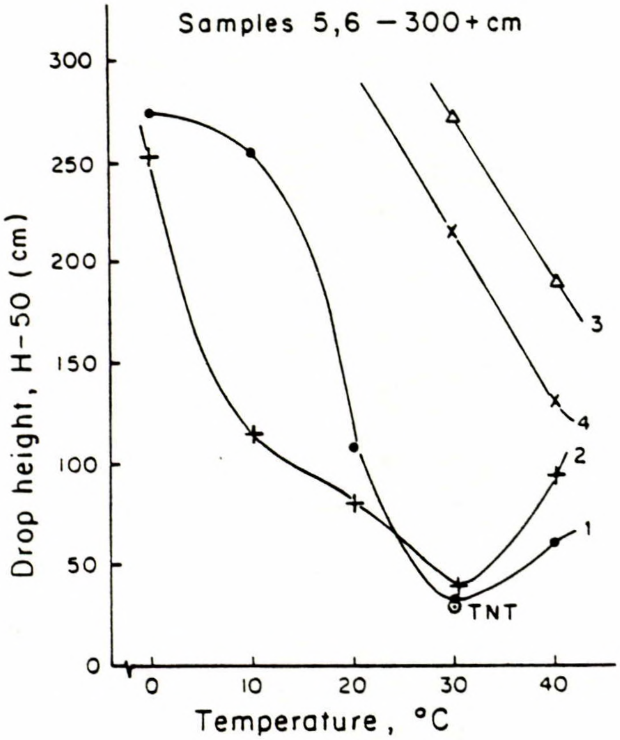

Fig. 3 - Drop-weight impact test results

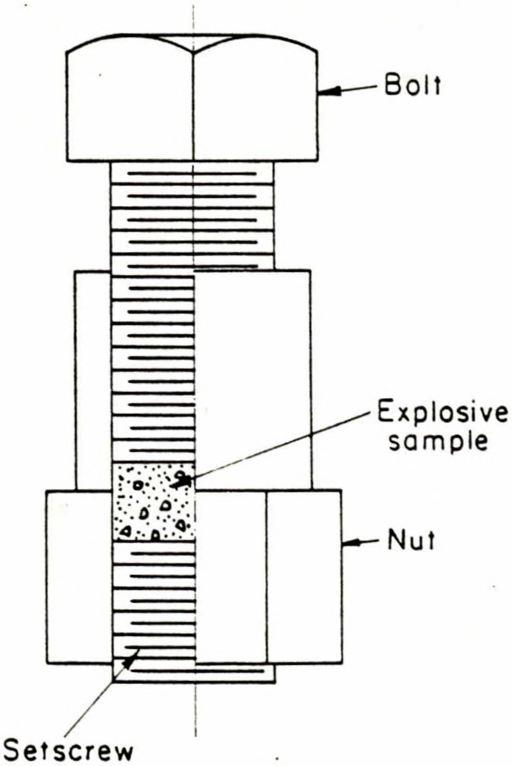

Fig. 4 - Cross-section of the sample used in the CERL nut and bolt friction test

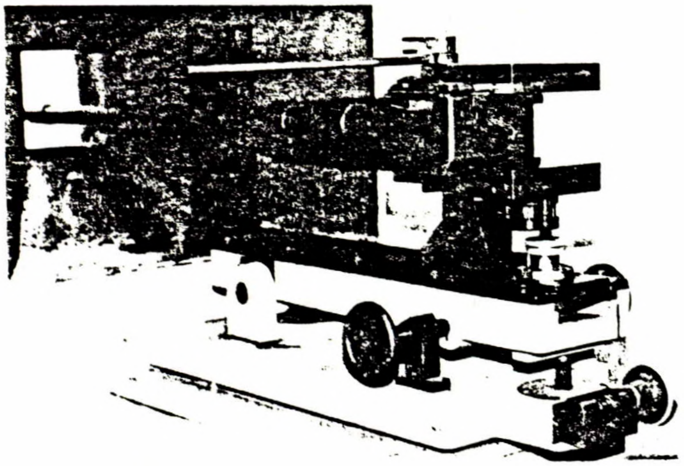

Fig.5 - .50 cal projectile impact test gun

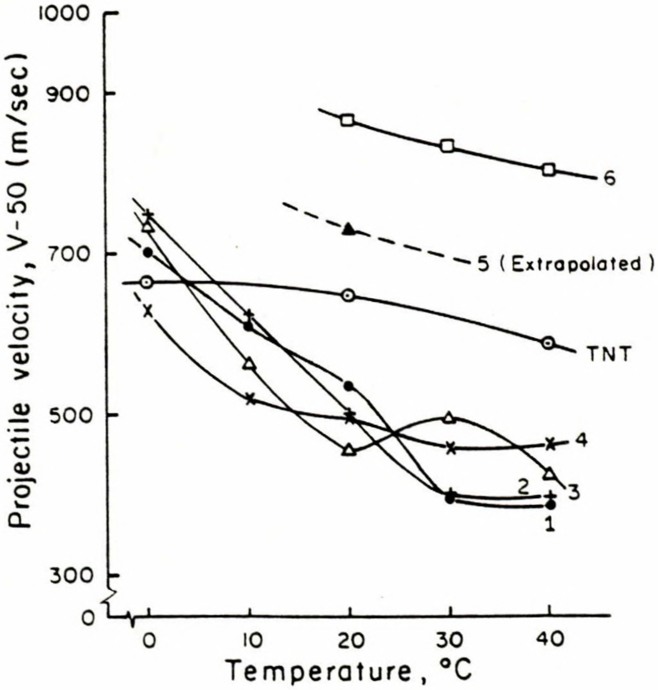

Fig. 6 - Projectile impact test results

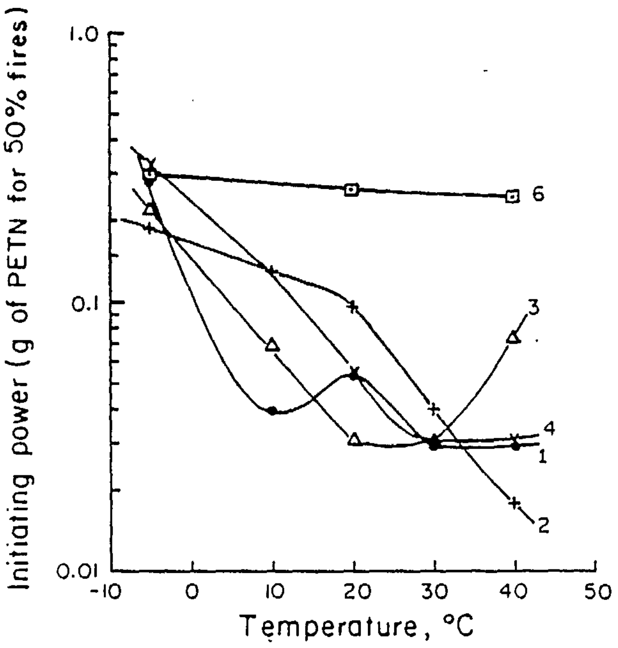

Fig. 7 - Shock test results

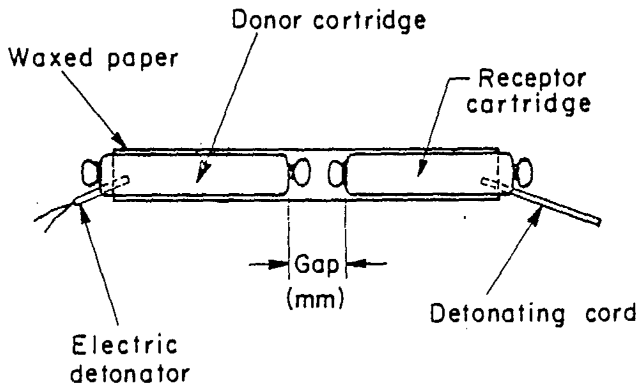

Fig. 8 - Laboratory set-up for determining the gap sensitivity

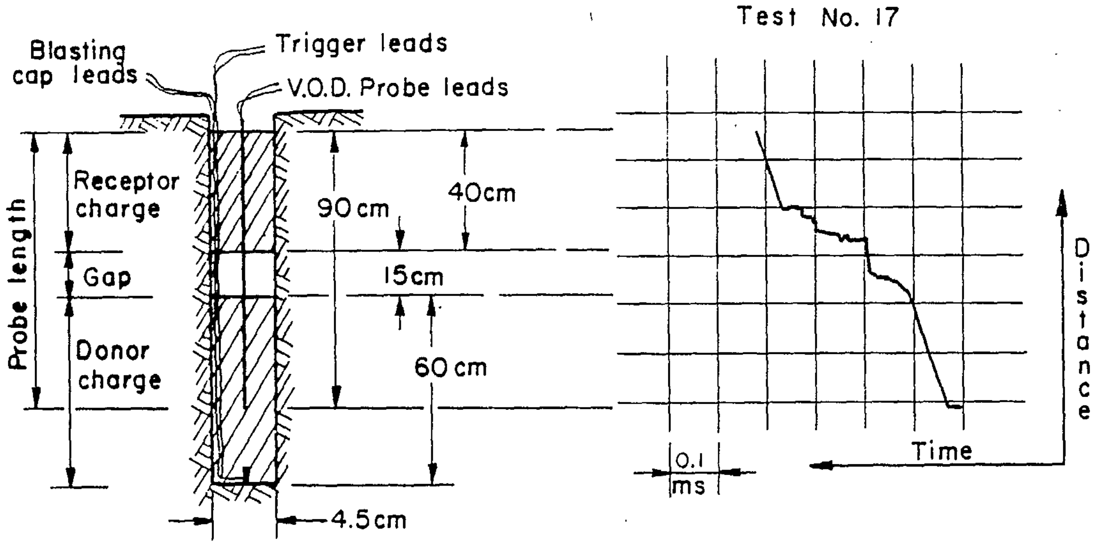

Fig. 9 - Field test set-up for determining the gap sensitivity