

THE DEVELOPMENT OF PENETRATION CHARGES FOR INCREASING THE EFFICIENCY OF THE INTERVENTIONS OF FIRE RESCUE SERVICE UNITS

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Research article

Abstract: During building fires is often necessary to deliver nozzles with water to the desired point of intervention and the wall or ceiling must be penetrated for energy supply and the entrance of persons. Access openings for extinguishing are created with hand tools or explosives, but it is a very time-consuming activity and fragmented material may endanger persons. Another possibility is the use of charges with a water layer, which absorbs the shock wave of the explosion at the back and at the same time significantly suppresses the fragmentation of the building element on which the charge acts. The penetration charge developed in two versions allows a sufficient penetration of the partition wall.

Keywords: Partition wall, concrete, explosive, penetration charge, cumulation.

Introduction

This article is devoted to the problems associated with the development of penetration charges for the needs of Fire Rescue Service unit interventions. During building, large warehouse or service building fires, it is often necessary to create access routes to the center of the fire in order to initiate fire extinguishing or create openings for efficient ventilation of the building. In this case, the use of special types of charges seems to be a suitable and operative solution. Their preparation at the place of use must be fast and should utilize explosives which are normally available to blasters of the Fire Rescue Service of the Czech Republic. Charges should be designed for use on both vertical and horizontal structures. This article describes the development of the following two types of new progressive penetration charges:

- a penetration charge for energy conduction - the charge must create a hole of at least 150 mm in diameter for energy conduction in the below defined partition walls,
- a penetration charge for the entering of persons - the charge must create an opening in the shape of an equilateral triangle standing on a base and with a side length of at least 600 mm.

Both types of charges must be capable of creating a hole in a concrete or reinforced concrete partition wall with a thickness of up to 200 mm, beyond which there is an environment with a density of less than 100 kg.m⁻³ for at least the next 200 mm. In the case of reinforced concrete, it is assumed that only the concrete is released, the concrete reinforcement may remain undamaged in the created hole, the problem of its removal is not part of the assignment.

At present, concrete and its modifications are used to produce prefabricated parts such as panels and concrete lintels, but also various forms of "bricks" that are not usually used to build walls, but rather as tiles, or to create various aesthetic elements during construction. It is also used on a mass scale for construction works performed on site by casting into formwork, whereby extreme size monoliths can be prepared, see Fig. 1. (Dojčár et al., 1996; Cooper and Kurovski, 1996)

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Fig. 1 Concrete road panel and lintel (Dojčár et al., 1996)

An important, frequently used modification of concrete is the incorporation of steel reinforcement into the profile of a concrete product, called reinforced concrete. This modification is used both for prefabricated larger load products (panels, lintels) as well as for cast-in-place concrete. In comparison to concrete, reinforced concrete has, in particular, improved tensile strength, which makes it possible to use concrete for the installation of ceilings and bridges in places where the structure is stressed.

The following table (Tab. 1) summarizes the most important properties of concrete. (Makovička et al., 2009).

When concrete products are joined together, concrete mixtures are usually used for this purpose; the building panels are then joined by welding them in contact points which are subsequently sealed with filler material.

Other materials used for the construction of partition walls include, in particular, various compositions of the aforementioned bricks and concrete, often supplemented with foamed fillers to improve thermal insulation properties. Due to their highly variable structure, these materials have

generally completely indefinable properties, and their strength parameters are usually lower than those of bricks and concrete.

Most of the buildings we currently encounter have flat-type ceilings. In the past, timber beams with a plank layer were massively used. Later, however, steel or reinforced concrete beams began to be used instead of wooden beams, and the space between them is filled with special bricks of different materials which are usually cast with reinforced concrete on the top. The most durable option is to assemble the ceiling from individual reinforced concrete ceiling panels, which are tightly laid on the bearing wall and subsequently provided with a top covering layer of concrete or reinforced concrete. Reinforced concrete ceiling panels are usually different from building or road panels in that they are lightened by longitudinal holes. The thickness of such ceilings is usually 200 mm or more, see Fig. 2.

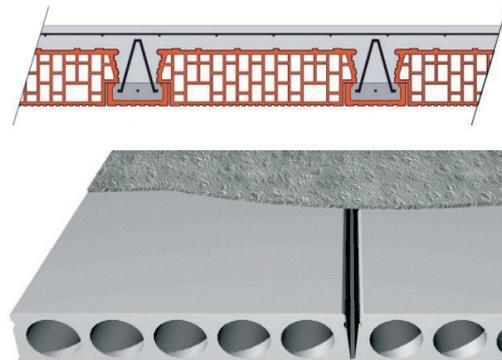


Fig. 2 Beam ceiling system with brick fillers and concrete ceiling panels

The mechanism of penetrating partition walls

Traditional methods for penetrating partition walls include, in particular, the use of chisels and hammers, and more modernly, electric or pneumatic demolition hammers. Although these tools allow for the penetration of virtually any partition wall, the problem is, in particular, the level of physical

Tab. 1 important parameters for different types of concrete

Material designation	Composition	Density [kg.m ⁻³]	Compressive strength [MPa]	Tensile strength [MPa]
Lightweight concrete	Aggregate (sand)	800-2 000	8-80	1-6
Common concrete	Cement	2 000-2 600	10-50	
Heavy concrete	Water	above 2 600	20-50	
High strength concrete	Additives	above 800	50-100	
Reinforced concrete	+ concreting steel reinforcement	Concreting reinforcement somewhat increases all the parameters, but tensile strength is increased several times.		

exertion of the penetrator and the breakthrough time, which can range from tens of minutes to hours, depending on the material resistance and thickness of the partition wall. The advantage of these methods is that when using a chisel and a hammer, a capable operator is sufficient, while in the case of a demolition hammer a relatively easily transportable source of electrical power or compressed air is necessary, see Fig. 3.

A significantly faster way is to use a construction machine designed for this type of activity. Penetration is relatively fast, in units up to tens of minutes. However, this method requires the presence of such a machine, and its transport to the penetration site can be a very lengthy process, and the penetration must be carried out in a location with good accessibility for the machine.



Fig. 3 Pneumatic hammer and demolition machine

An alternative way of penetrating the structural barrier is to use explosives. This method allows effective penetration through a wide range of partition walls, but has many pitfalls and obstacles. The destructive action of the charge (unsealed) on the concrete and reinforced concrete structures is largely caused by the impulse effect of pressure in the detonation wave of the explosive. This pressure change (with overpressure values usually within the order of units to tens of GPa) causes a system of stress waves in the structure, which results in the formation of a system of cracks by rebounding from free surfaces (e.g. on the reverse side of the panel-type structures) and by mutual interference. In the immediate vicinity of the charge, values of the pressure wave amplitudes exceed

the dynamic strength of the material, so during the destructive action of the shaped charge and if certain minimum pulse levels are reached, both destructive mechanisms coincide, i.e. a bowl-like destruction rupture on the face side of the panel and fragmenting on the other side (Müncner et al., 2006; Pravda and Bětík, 2010).

If a concrete or reinforced concrete slab is perforated by sufficient dimensioning of the charge, a breakthrough hole is created at the contact surface of the rupture craters and fragments. A characteristic of the perforation of these slabs is that the depth of the fragment rupture crater is always greater than the depth of the face rupture crater, so that the plane of intersection of the two destructive cones is always at approximately 40 % of the thickness of the slab.

Simple exponential relationships are given in literature and practically used in military practice to estimate the dividing phenomenon that is of interest in a given context, and which can be referred to as "limit perforation", formulated generally as follows:

$$h_{perf} = k_1 \cdot W^n \quad (1)$$

where:

h_{perf} the thickness of the concrete or reinforced concrete slab element [m],

W the corrected mass of the charge [kg],

k_1 the proportionality constant defined for the desired degree of structure destruction,

n the exponent, $n = 1/3$ for geometrically compact charges - concentrated, i.e. approaching the shape of a cube, equilateral cylinder, or optimally shaped hemisphere. The same exponent value can also be accepted for the non-ideally shaped charges compared - but not for linear ones which have a geometrically similar shape in a comparative series of masses.

The relation (1) of the determined value h_{perf} can be defined conventionally either as a limit value - i.e. to achieve a minimum observable penetration, or a breakdown of a higher degree of destruction (e.g. by defining a certain breakdown hole diameter relative to the thickness of the perforated slab - a dimensionless parameter), or by military custom in the case of reinforced concrete slabs, not only by the creation of simple penetration but also a required degree of destruction of the steel reinforcement, e.g.:

- a) a simple breakthrough while fully preserving the reinforcement,
- b) a breakthrough with partial destruction of the reinforcement,
- c) a complete breakthrough including total reinforcement destruction.

The qualitative difference between concrete and reinforced concrete resulting from the presence of steel bar reinforcement in reinforced concrete structures does not significantly affect the mechanism of destruction. By quantitative comparison, the reinforced concrete resistance is obviously higher, while steel bars are subject to bending plastic deformation at the lowest stress level and to some extent restrict the free movement of concrete fragments. As a result, an increased resistance to spontaneous fragmenting of the fragment material can be observed on the other side of the reinforced concrete slabs, although latent breaking up of the concrete mass by a system of cracks will occur.

The basic physical inhomogeneity of the concrete mass, of course, leads to only limited reproducibility of penetration and perforation processes, so the geometric characteristics (diameter, depth and overall shape) of ruptures and fragments are subject to relatively large statistical variance. For reinforced concrete structures, this degree of irregularity of the destructive effect results in a random relevant position of the contact surface of the charge against the individual bars of the steel reinforcement - a charge centered against the gap between the individual bars always performs a somewhat greater depth of rupture than an identical charge situated exactly against any of the individual bars, or their crossing (Müncner et al., 2006; Vávra and Vágenknecht, 2004).

Methods of penetration using differently applied charges

Charges embedded in a bore

As noted above, much better results can be achieved by using embedded charges in the partition wall. Usually, the recess is realized by drilling a hole approximately to the center of the partition thickness. This method is therefore considerably more demanding and practically impossible to do without the use of adequate equipment and energy sources. The disadvantage may be a significant extension of the installation time.

Again, considering the creation of a single hole in a 0.2 m thick concrete partition, the following formula is used to calculate the weight of a single recessed and sealed charge, according to (Dojčár et al., 1996):

$$M = A \cdot B \cdot R^3 \cdot f \quad (2)$$

where:

M the mass of a given charge type [kg];

- A the strength coefficient of the disrupted material = 1.4 (concrete);
- B the placement and sealing coefficient of the charge = 1.3;
- R the effective distance of the charge = 0.1 (1/2 of the partition wall thickness) [m];
- f the coefficient gaining values in the interval of 3-6 according to the degree of perforation of the structure.

After substitution into the above equation (2) and the substitution of the coefficient $f = 3$, the weight of the embedded charge $M_z = 0.006$ kg is suitable. Compared to the calculated amount of explosive when using an applied charge, this amount is up to two orders of magnitude lower, which demonstrates the convenience of the arrangement. Of course, the application of such a small amount of explosive also significantly reduces the effect of the charge on its surroundings.

Applied charges

This is the simplest, as well as the fastest way to apply explosives to penetrate the partition wall, while the explosive charge is merely attached to it. The advantage of this arrangement is in particular its simplicity and speed of execution. The main disadvantage is the relatively low efficiency, and usually a higher degree of acoustic and pressure load on the environment. Efficiency can be improved by effectively sealing the charge, thereby reducing the impact on the environment. However, the implementation of such sealing of the charge is often very complex. (Government Regulation No. 272/2011 Coll.)

For example, considering the creation of a single hole in a 0.2 m thick concrete partition, the following formula (2) is used to calculate the weight of a single unsealed charge, taking into account the limit points of the coefficient $f = (3-6)$.

The material strength coefficient $A = 1.4$ (concrete), the coefficient of the placement and sealing of the charge $B = 9$ (in the case of effective sealing it reaches the value of 5) and the assumed thickness of the partition wall is the same as in the previous case of 0.2 m.

In the case of a sealed charge, the mass is in the interval: $M_n = (0.302-0.606)$ kg, for a sealed charge $M_u = (0.168-0.336)$ kg. However, the formula (2) does not take into account the charge geometry and the parameters of the explosive used and assumes the use of trinitrotoluene (TNT), which can significantly affect the results achieved. In the case of charge sealing, the parameters of this seal are not further specified.

Shaped charges

Cumulative shaped charges can basically be divided into concentrated and linear. Both versions can be described as very sophisticated with a number of specific features. In order for the application to be successful, the charges must be installed by a blaster.

Concentrated shaped charges belong to the category of charges that achieve high to extreme performance. For example, a top-of-the-range shaped charge can break through a 0.2 m concrete partition with the weight of the explosive of up to 10 g. Holes created by a concentrated shaped charge usually have a small diameter, in the order of tens of millimeters; in the case of a special structure which, however, means a decrease in the breakthrough, the diameter of the created hole can have a size of up to 200 mm. Their price is very high due to relatively demanding manufacturing. Linear shaped charges do not provide as high performances as concentrated ones, but allow for penetration through the partition wall linearly, with significantly greater reliability, at approximately half the amount of explosive. As with concentrated charges, the width of the cut is very narrow, but it is very advantageous thanks to the linear penetration. If the charges are also flexible, it is possible to create very difficult penetrations through partition walls in terms of shape. Their price is relatively high, as is the case with concentrated shaped charges. (Lichorobiec and Barčová, 2015; Lichorobiec et al., 2016)

Technical solution design

Due to the requirements for efficiency, operability and efficiency, a solution can be devised which will advantageously use applied or shaped charges covered by a suitable medium. This assumption seems to be the best compromise between all relevant input parameters. Although the use of embedded charges is very effective, it is also time-consuming, since the creation of the necessary boreholes for placing the charges can prove very complicated in the field.

Applied or linear shaped charges covered with a suitable medium allow for quick and easy installation with a minimum of auxiliaries. The relatively low efficiency of applied charges can also be significantly increased by a covering (sealing) layer, the application of which reduces the amount of explosive required to execute the work. (explosives.net)

A bag or container with water, which is an almost perfect covering medium, is envisaged as a cover-seal layer. Its stability and environmental

friendliness, as well as its efficiency, cost and availability, are all important arguments for its use.

Applied charges are the simplest option of using explosives. Under this term, it is possible to imagine any charge applied to a penetrated partition wall of some weight and varying geometry which, however, may be of utmost importance for achieving the desired effect. To ensure a sufficiently reliable action on reinforced concrete partition walls, it is necessary to determine the charge weight, define the parameters of the explosive and its geometry, and it would be appropriate to define this charge both for use without a cover and with effective coverage. These variations are important for the extreme demands in terms of the speed of the solution. If there is enough time to use a charge with a cover, which can be estimated to be tens of minutes, it is definitely preferable to use this option because it is cheaper, less burdensome and generally safer. In the event of a direct threat to life or major material damage, penetration using a charge without a cover can be significantly faster, in a matter of minutes. The disadvantage of this solution can be a very high load on the people performing the intervention in the form of significant pressure changes, and consequently on the environment, damage in the form of window cracking and the like. Similarly, the conditions for the use of linear shaped charges should be defined if it is found to be preferable to use this type of charge to accomplish the desired task.

Experimental results

During a series of experiments, the general amount of explosive needed to penetrate the partition wall was to be found. The basic design of the amount of explosive and charge geometry was based on the formulas given in paragraphs 1 and 2, and on the practical experience of the investigators. The weight of the charges calculated according to these formulas appears to be quite optimistic, but it should be considered that the formulas assume that the weight of the wall will also have an influence on the destruction, for example, in the case of a linear wall cut, and during the perforation of the hole a diameter of 0 mm is essentially considered. Upon requirement of a larger hole, the size of the charge increases, but the formula does not specify the rules. In order to break through the tested reinforced concrete partition wall, the weight of the explosive ranges from 0.3 to 0.6 kg. Due to the requirement to make a 150 mm diameter hole, the tests were commenced with an explosive weight near the upper calculation limit.

Experiment no. 1: Circular applied charge

- Circular charge, diameter 150 mm, explosive width 18 mm, weight 500 g.
- Reinforced concrete slab 210 mm wide, see Figs. 4 and 5.
- Result: penetration of slab 240 x 390 mm, damage 570 x 610 mm.



Figs. 4 and 5 Installed circular applied charge and hole created the by charge



Figs. 6 and 7 Installed circular applied charge and hole created by the charge

Experiment no. 2: Circular applied charge

- Circular charge, diameter 150 mm, explosive width 16.5 mm, weight 454 g.
- Reinforced concrete slab 210 mm wide, see Figs. 6 and 7.
- Result: penetration of slab 300 x 450 mm, damage 600 x 700 mm, including additional unmeasurable disruption by small cracks.

Experiment no. 3: Semtex Razor 30 type linear shaped charge

- Flexible Semtex Razor 30 type charge, 200 mm length = 250 g of explosive with a detonator in the middle.
- Reinforced concrete slab 190 mm wide, see Figs. 8 and 9.
- Result: no penetration, damage 450 x 380 mm, depth 80 + 95 mm.

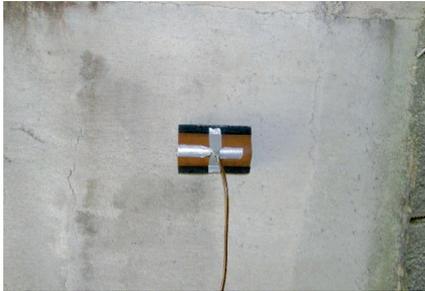


Figs. 8 and 9 Installed Semtex Razor 30 type charge and slab damage created

Experiment no. 4: Semtex Razor 40 type linear shaped charge

- Flexible Semtex Razor 40 type charge, length 150 mm = 330 g of explosive with a detonator in the middle.
- Reinforced concrete slab 190 mm wide, see Figs. 10 and 11.

- Result: 190 x 130 mm penetration, 460 x 460 mm damage.



Figs. 10 and 11 Installed Semtex Razor 40 type charge and created penetration of the slab



Figs. 12 and 13 Installed Semtex Razor 40 type charge and created penetration of the slab

Experiment no. 5: Semtex Razor 40 type linear shaped charge

- Flexible Semtex Razor 40 type charge, length 150 mm = 330 g of explosive with a detonator on the edge.

- Reinforced concrete slab 190 mm wide, see Figs. 12 and 13.
- Result: 160 x 130 mm penetration, 400 x 400 mm damage.

Experiment no. 6: Semtex Razor 40 type linear cumulative shaped charge

- Flexible Semtex Razor 40 charge, 120 mm length = 264 g of explosive with a fuse detonator on the edge.
- Reinforced concrete slab 190 mm wide, see Figs. 14 and 15.
- Result: 70 x 60 mm penetration, 400 x 400 mm damage.

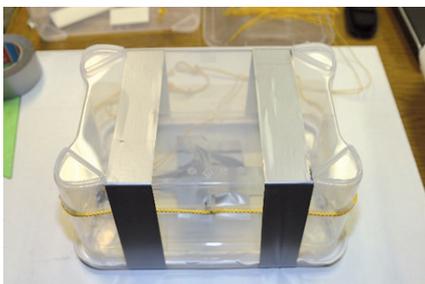
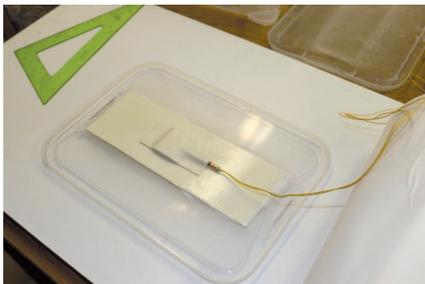


Figs. 14 and 15 Installed Semtex Razor 40 type charge and penetration of the slab

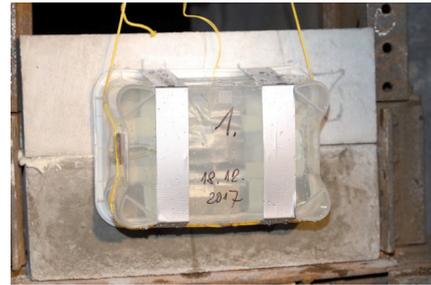
Partial conclusion: This series of experiments (1 to 6) can be considered successful. By using the 150 mm Semtex Razor 40 charge, a sufficiently large penetration can be reliably created to conduct energy. Better results can be achieved by initiating a Semtex Razor 40 charge in the middle, which will be complicated to apply, for example, when covering the charge with a sack containing a damping material. For this reason, an edge initiation test was carried out, with a sufficiently large penetration hole being formed even with a slight reduction in performance. Using a Semtex Razor 30 charge or a shorter Semtex Razor 40 charge does not create a sufficient penetration hole.

Experiment no. 7: Rectangular applied charge with a water cover

- Semtex 10-SE type charge with the dimensions 300 x 100 x 2 mm with a weight of 100 g, glued onto a cover container filled with water before the explosion, container dimensions 38 x 26.5 x 19 cm - 14 liters, the water is both in the shaped cavity to create working pressure and behind it as a cover (seal).
- Concrete slab, length 60 cm, height 20 cm, width 25 cm, the slab is reinforced with reinforcing wire with a diameter of 6 mm, with a grid size of 10 x 10 cm. Concrete density - 2126 kg/m³. Average compressive strength - 20.2 MPa. Two slabs stacked together and fixed with adhesive.
- The total charge weight is 130 g (30 g used to fix the detonator to the middle of the charge), see Figs. 16 and 17. The charge is placed in the middle of the glued slab, see Figs. 18 and 19.
- Result: the upper concrete slab is completely disrupted by the charge and the fragments are projected forward through the wire reinforcement. The bottom concrete slab is largely disrupted by cracks and remained intact only thanks to the reinforcement grid. The scattering of fragments towards the back is restricted by the water seal to a distance of about 1 meter - large pieces. The scattering of fragments forward is to about 6 meters, see Figs. 20 and 21.



Figs. 16 and 17 Installed explosive charge on the lid of the water container



Figs. 18 and 19 Installed explosive charge on the lid of the water container



Figs. 20 and 21 The destruction of the top concrete slab

Experiment no. 8 Linear shaped charge with a water cover

- Semtex 10-SE type charge with the dimensions 300 x 170 x 2 mm and a weight of 170 g, placed on a shaped plastic liner with the dimensions 30 x 10 x 5 cm - semi-cylinder with a circumference of 17 cm, sealing container dimensions 38 x 26.5 x 19 cm - 14 liters.

- Concrete slab, length 60 cm, height 20 cm, width 25 cm, the slab is reinforced with reinforcing wire with a diameter of 6 mm, with a grid size of 10 x 10 cm. Concrete density - 2126 kg/m³. Average compressive strength - 20.2 MPa. The slabs are stacked and fixed with "PUR" adhesive.



Figs. 22 and 23 Location of the explosive on the cumulative liner and in the cover container



Figs. 24 and 25 Placement of the container on the concrete slabs before the explosion

- The total charge weight is 220 g (50 g used to fix the detonator to the middle of the charge), see Figs. 22 and 23. The charge is placed on the bottom concrete slab, see Figs. 24 and 25.
- Result: the bottom concrete slab is completely disrupted by the charge and the fragments are projected back about 2 meters, forward about 8 meters. In the two meters in front, the reinforced wire grid torn out by the explosion is visible, see Figs. 26 and 27.



Figs. 26 and 27 Result of the shaped water-covered charge effect on reinforced concrete slabs

Conclusion

In the case of developing a penetration charge, its use significantly reduces the operational time required to create access openings in the structural obstacles of buildings that are subject to an extraordinary event - an explosion or fire. The expected time from the preparation of the charge, through its installation and use will be in the order of minutes. The charges can be placed side by side and thus create openings of sizes according to the needs of the Fire Rescue Service intervening units in a short time. Using these charges will also minimize the negative effect of the explosion, i.e. the scattering of material into the environment, which will greatly contribute to increasing the safety of IRS members and surrounding inhabitants. Moreover, the implementation of the development tests will precisely define their application and the safety radius depending on the type of material to be disrupted. The charges will

be further tested for heat resistance to the radiant heat of a fire and a safe time of use will be defined. Last but not least, a positive impact on the overall effectiveness of the intervention of IRS units can be expected, for example, when rescuing people, as well as the related reduction in the costs of removing the damage caused by the disposal of the consequences of extraordinary events.

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