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ATTACK RESISTANCE OF STRUCTURAL COMPONENTS

By

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February 1976

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NAVAL FACILITIES ENGINEERING COMMAND

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This report describes an investigation of forceful entry resistance of walls, floors, and roofs of secure facilities. Attack resistance of conventional and secure construction methods is reviewed and data from tests on various barriers is summarized. Data from limited in-house tests and from other sources were used to develop several proposed barrier concepts for 10- and 20-minute denial times.

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INTRODUCTION

The Naval Facilities Engineering Command (NAVFAC) has a continuing responsibility to provide secure facilities. NAVFAC has also recently been assigned the responsibility for support of technology development for physical security in the Navy. Physical security is defined in Reference 1 as that part of an overall security program which is concerned with the physical measures designed to prevent unauthorized access. CEL is participating with NAVFAC in the technology development of physical security hardware and structures. This report describes an investigation of the forceful entry resistance of walls, floors and roofs of secure facilities. Entry, or penetration, is generally assumed to be made when an opening of 96 square inches has been made in the barrier (with one dimension at least 6 inches). This is considered a minimum man-passable opening. The time to penetrate (denial time) the structure must be compatible with the overall security system to provide the degree of security required.

Existing security construction requirements will be investigated for past effectiveness. Actual attack resistance of existing structures will be determined from data collected in recent tests run by the National Bureau of Standards (NBS) [2, 3, 4].

Available test data on standard building material attack resistance, supplemented as required by in-house tests, will be used to develop concepts for increasing the attack resistance of new and existing facilities. Emphasis will be placed on obtaining the lightest design weight of security barriers using standard building materials. Other important considerations which are not completely covered here are ease of construction and retrofit, cost, and availability.

EXISTING BARRIER EFFECTIVENESS

Existing Naval facilities have been designed to the requirements of manuals such as References 5, 6, and 7 as well as with the guidance of NAVFAC. Structural components (walls, floors, roofs) of these facilities have not been required to provide specific penetration resistance. However, security vault specifications require 4 to 8 inches of reinforced concrete, depending on the class of vault. Other secure facility construction has followed standard construction methods.

The structural components of these facilities have generally been adequate deterrents to forcible penetration. The psychological deterrent of a solid barrier as well as the overall base security has resulted in a small percentage of unlawful entries through walls or roofs. However, attacks involving the penetration of structural components have been experienced; for example, armory thefts and break-ins aboard ship through aluminum honeycomb bulkheads.

Although experience with the overall effectiveness of these structural components has been good, the actual resistance of standard construction is inadequate. Barrier penetration tests by the NBS in 1972 [2] and 1973 [3] demonstrated the short denial times of construction with wood, concrete masonry units (CMU), and even reinforced concrete. Table 1 summarizes the minimum penetration times determined in those tests. The standard wood and CMU constructed walls can be penetrated in less than 2 minutes. Only 4 minutes were needed to make a man-passable opening in a 4-inch reinforced-concrete wall. Tests on an 8-inch reinforced-concrete section indicated that it could be defeated in about 12 minutes. A jackhammer significantly reduces the time, as was demonstrated on the 8-inch concrete section. Use of explosives would also reduce the penetration time.

Table 1. Summary of Minimum Penetration Times for Standard Walls (NBS Tests)

Wall Construction	Attach Method	Minimum Penetration Time (min)
2 x 4 Stud + 2-inch wood panel	brace and bit, saber saw	1.5
Hollow CMU	sledge hammer	1.5
8-inch cinder block (mortar filled + brick veneer)	sledge hammer	2.4
4-inch Reinforced concrete	sledge hammer, torch	4.0[a]
8-inch Reinforced concrete	drill, sledge, punch, demolition saw	12.0[a]
8-inch Reinforced concrete	jackhammer	6.5[a]

[a] Includes time to cut rebar.

ATTACK TOOLS AND METHODS

Tools to be considered in developing denial times are listed below:

A. Nonpowered

- Sledge hammer (10-16 pound)
- Cutting maul
- Wrecking bar
- Battering ram
- Punches
- Wedges
- Burning bar
- Cutting torch
- Bolt cutters
- Brace and bit

B. Powered

- Rotohammer
- Drill (includes diamond core)
- Demolition saw
- Abrasive wheel saw
- Saber saw
- Pneumatic jackhammer
- Hydraulic jacks

C. Explosives

- Linear shaped charges
- Breaching charges

Most of these tools were considered, and many were used in the NBS tests to find the minimum penetration times. Little data exist on explosive attack, and linear shaped charges were used only on the concrete walls in the NBS tests. Of the other tools listed, only the jackhammer stood out as significantly better than any other combination of sledge hammer, drill, punch, and cutting maul.

A sledge hammer and cutting torch were used to attack a 4-inch-thick reinforced-concrete wall in one of the NBS tests. The concrete was broken away from the rebar with a 10-pound sledge hammer in 2.4 minutes. The total penetration time of 4 minutes included cutting time of 8 cuts of #5 rebars. CEL tests of rebar cutting with a torch showed that this time could be reduced significantly. Table 2 gives those results. The data indicate that under ideal conditions the 4-inch reinforced-concrete wall tested could be penetrated in less than 3 minutes ($2.4 + \frac{8 \times 2}{60} = 2.67$ min).

Table 2. Times to Cut a Reinforcing Bar

Bar Size	Time (seconds)
2, 3	1
4, 5	2
8	5
2-1/2 inch	27

An 8-inch reinforced concrete wall is too thick to penetrate with only a sledge hammer. Therefore a series of holes were drilled to different depths and, the back side of the wall was spalled using a punch. When the wall thickness was reduced to about 4 inches, a sledge hammer was able to remove the remaining concrete. An 8-inch reinforced-concrete wall takes about 3 times as long to penetrate as a 4-inch wall. A minimum time attack would require about 11 minutes to remove the concrete and additional time to torch any rebar. A jackhammer can cut the concrete removal time in half (5.5 min).

The commercially available shaped charge, makes a man-sized opening in 4-inch reinforced concrete with only 0.04 ounce per inch of explosive. Heavier shaped charges (0.10 ounce/inch) cannot immediately penetrate 8 inches of concrete. However, such a charge would crack the concrete enough to reduce penetration times significantly. Concrete, being low in tensile strength, is very susceptible to explosives, especially if they are in direct contact. The low tensile strength is also the reason concrete can be spalled off and broken up with a sledge-hammer attack.

Results of tests on standard walls and vault walls described in References 1 and 3 led to another series of tests, also found in Reference 3, to find ways of upgrading existing barrier walls and designing more attack-resistant walls.

STRUCTURAL SYSTEM ATTACK RESISTANCE

Material Penetration Times

An important step in the determination of the overall effectiveness of an attack-resistant wall system is determining the denial times of individual materials. The synergistic action of composite systems can then be predicted, knowing which materials will be complementary. The NBS testing on walls was not designed to directly test individual materials. However, analysis of the test histories does yield some data on material denial times. Table 3 lists the actual or projected penetration times of unreinforced-concrete building materials. This list includes steel-fiber-reinforced concrete (SFRC) and mortar-filled CMU's which can be considered homogeneous for attack resistance. Projections were based on penetration time of the individual materials in the composites tested.

The concrete building materials provide good compressive strength for structural design loads and high mass for resisting attack. However, they are low in tensile strength. This is a disadvantage in attack-resistant design since they are easily spalled and cracked by shock loading. Standard reinforcing does not appreciably increase attack resistance. Thus walls must be thick and heavy to provide adequate denial times.

Table 3. Penetration Times of Unreinforced Concrete Building Materials

Material and Thickness	Attach Tools	Penetration Time (min)
8-inch hollow CMU	sledge hammer	1.5
8-inch mortar-filled CMU	sledge hammer	2.0
4-inch concrete	sledge hammer	3
8-inch concrete	drill, sledge hammer, punch	11
8-inch concrete	jackhammer	5.5
8-inch lightweight concrete	drill, sledge hammer, punch	8
4-inch SFRC*	drill, sledge hammer, punch	8
8-inch SFRC	drill, sledge hammer, punch	25
8-inch SFRC	jackhammer	15

* Steel fiber-reinforced concrete.

SFRC increases resistance to attack because of its higher tensile strength and energy absorbing capacity. Table 3 shows that SFRC can almost triple the denial times obtained with equal thicknesses of normal concrete; conversely, it would provide the same denial time with less thickness than normal concrete at substantial savings in weight. Tests using linear shaped charge devices indicate that SFRC would also have significantly better resistance against explosives.

Standard steel materials will also increase attack resistance. Their effect on penetration resistance is listed in Table 4. These results are a combination of denial times from Reference 4, tests on mild steel (MS) plate at CEL, and cutting torch rates from Reference 8. Tests on cutting torch rates in steel plate were conducted with various torch tip sizes to find the optimum rate. These results agree closely with those given in Reference 8.

Table 4. Penetration Times of Steel Materials

Material	Attack Tools	Penetration Time		Source
		Inches per Minute	Minutes for Man-Size Opening	
1/16-inch steel plate	cutting torch	50	0.8	a
1/8-inch steel plate	cutting torch	30	1.3	b
1/8-inch steel plate	abrasive wheel saw	30	1.3	c
1/4-inch steel plate	cutting torch	30	1.3	a
1-inch steel plate	cutting torch	18	2.2	b
3-inch steel plate	cutting torch	10	4	b
3/4-inch no. 9 expanded metal	cutting torch	10	4	b
	abrasive wheel	16	2.5	c
	bolt cutter	20	2	c
3/16-inch expanded steel grill	cutting torch	13	2.9	b
No. 9 chain link*	bolt cutter	30	1.3	c
No. 11 chain link (2 in. x 4 in.)	cutting torch	27	1.5	c
	abrasion wheel	200	0.2	c
	bolt cutter	50	0.8	c

* Cut in six-layer group; values shown for one layer.

Sources: a CEL data.

b Reference 8.

c Reference 4.

Steel components provide high strength to weight ratios. At thicknesses of 1/8 inch or greater, an attack with cutting tools such as those listed in Table 4 is required. However, steel sheet or plate can be easily cut with an oxy-acetylene torch. Note that the 9-gage expanded metal takes at least as long to cut as a 3-inch-thick steel sheet because of the loss of heat between the separate bars. Fencing of 11-gage steel was easily cut by any method. Use of steel in any form should, therefore, be restricted to 10-gage or thicker. Because of the high ductility of mild steel it is a good material to use against explosive attack, especially if it is an open section, such as expanded metal, that will vent the pressure.

This study was limited to common, inexpensive, easily obtained materials. Research and testing of other attack-resistant materials should be considered if adequate results are not obtained with the concepts developed here.

Multicomponent Penetration Times

A multicomponent barrier will be defined as one consisting of multiple materials that do not act homogeneously. Reinforced concrete will then be taken to be multicomponent while fiber reinforced concrete, which for the purpose of this study is homogeneous, will be considered a single material. Multicomponent barriers can provide advantages in attack resistance by forcing attack tool changes and by combining complementary characteristics of materials to produce synergistic properties.

Design of a multicomponent wall can be developed from the single material attack-resistant effectiveness summarized in Tables 1 through 4. Three types of multicomponent walls, classified by the type of standard wall used in each system, were tested by NBS [2, 3, 4]. The standard wall systems were reinforced concrete, wood studs plus sheathing, and CMU block. The latter two were reinforced in various ways to test methods of upgrading existing barriers, while reinforced concrete was only tested at different thicknesses.

Reinforced Concrete. Reinforced concrete was tested in 4- and 8-inch thicknesses of lightweight concrete. The standard construction reinforcing was not heavy enough to be a significant factor in attack resistance. The effectiveness of reinforced concrete would be increased by using lacing bars between the standard reinforcing bar on opposite sides of the panel. This type of reinforcement, detailed in Reference 9, is used in blast-resistant designs. A typical section is shown in Figure 1.

CMU Block. The standard 8-inch hollow CMU walls were reinforced, in the NBS testing program, on the interior side in four different ways (Figure 2): (1) ferrocement panel of 3/4-inch, No. 9 gage, expanded metal between two layers of No. 9 gage wire fencing (Figure 2a); (2) ferrocement panel of six layers of 2 x 4-inch No. 11 gage welded wire fencing (Figure 2b); (3) 4-inch solid concrete block behind 3/4-inch,

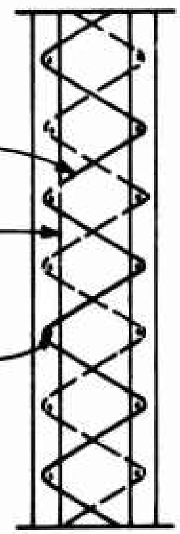

Figure 1. Plan view of typical laced reinforced-concrete section.

No. 9 gage expanded metal (Figure 2c); and (4) a 3-inch thickness of 2% steel-fiber-reinforced concrete (Figure 2d). The CMU wall reinforced with fiber-reinforced concrete was the only wall also filled with mortar (Figure 2d). Attachment details are given in Reference 4.

The ferrocement reinforcing was added by nailing steel mesh to the CMU and then applying mortar (Figure 2a). The addition of the mortar added about 3.5 minutes to the denial time that would be predicted by adding the steel-mesh and CMU wall denial times from Tables 4 and 3, respectively. No overall ferrocement thickness was reported in Reference 4; however, it must have been close to 2 inches to cover the reinforcing mesh. Thicker ferrocement panels, with the same percentage of reinforcement, are hard to fabricate because of difficulty in forcing the mortar through the reinforcement.

For its weight, the solid 4-inch concrete block was relatively ineffective in increasing resistance. The block added about 1.5 minutes to the denial time expected of the hollow CMU plus the expanded metal.

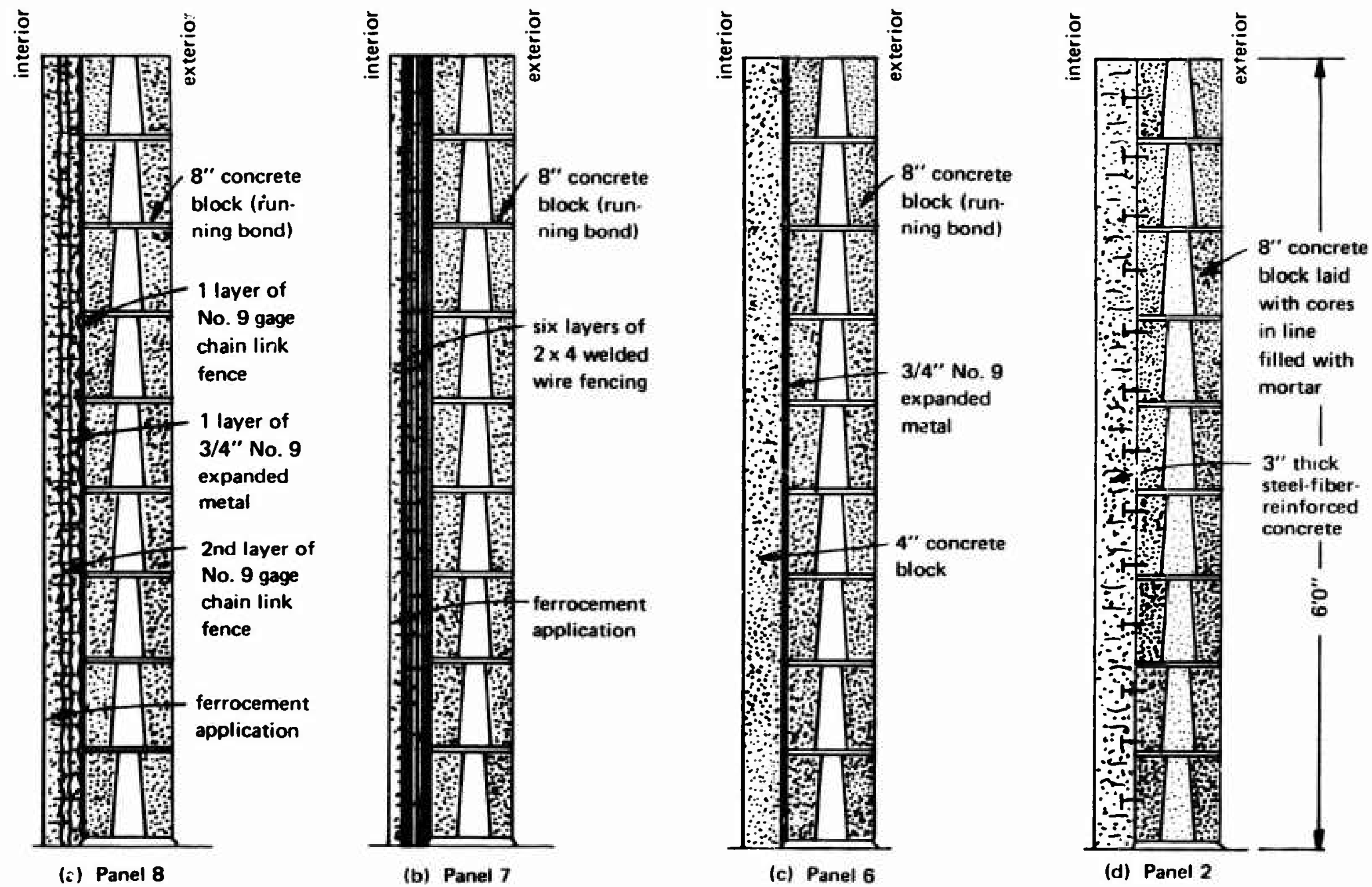

Figure 2. Construction of panels.

The total of the denial time given in Table 3 of mortar-filled CMU plus 4 inches of SFRC is 10 minutes. However, when only 3 inches of SFRC was used to reinforce a mortar-filled CMU wall the denial time was 26 minutes. The SFRC backing eliminated spalling and forced much of the CMU plus mortar to be dug out with a 6-pound maul. It required 11.5 minutes to make a large enough opening in the CMU to allow an efficient attack on the SFRC. The total time indicates that it was still not as easy to penetrate the 3-inch SFRC that was solidly attached to the CMU as it was with 4-inch SFRC acting alone. Synergistic properties are thus evident because of the elimination of spalling and the increased support of the SFRC.

Wood Studs Plus Sheathing. A basic wood wall panel was tested by NBS [4] with four different reinforcing methods. The basic frame, from inside to outside consisted of 3/8-inch gypsum wallboard, 2 x 4 stud (16 inch on-center), 1 x 6 sheathing (diagonally laid), one layer of 15 lb felt paper, and bevel siding. From previous tests, it is known that this wall can be penetrated in about 2 minutes. The four reinforcement systems used were: (1) ferrocement with 6 layers of No. 11 gage 2 x 4 welded wire fencing; (2) wood 2 x 6's (to form 6-inch thick section); (3) No. 9 gage, 3/4-inch, expanded metal plus 3/4-inch plywood; and (4) 1/16-inch steel sheet plus 3/4-inch plywood. These systems required 6.8, 6.8, 6.7, and 6.0 minutes attack times respectively. Not many attacks were made in an attempt to minimize the time. It is, therefore, probable that minimum times would be closer to the sum of the times given for individual reinforcing materials plus 2.0 minutes for the basic wood panel. This would result in the following denial times for the reinforced walls:

Reinforcement	Time (min)
(1) Ferrocement [2.0 + 6(0.2) + 3.5]	6.7*
(2) Wood 2 x 6's	6.8
(3) Expanded metal plus plywood [2.0 + 2.5]	4.5
(4) 1/16-inch steel sheet plus plywood [2.0 + 1.0]	3.0

*Estimate based on 1.3 minutes for 1/8 inch.

The latter two times [(3) and (4)] assume that the plywood would force the use of an abrasive wheel saw for the minimum time since the torching rate would be decreased with the wood backing. There are no data for the wood 2 x 6 attack resistance alone, so the combined test time of 6.8 minutes will be taken as a minimum. The 6-inch solid wood reinforcement thus adds about 4.8 minutes to the denial time of any wall.

Summary. Analysis of available test data has shown that, in general, the total penetration of a multicomponent standard material panel can be determined by summing the individual denial times of the components. Some caution must be used, however, since a material behind steel reinforcing may significantly increase the penetration of the steel with cutting torch or bolt cutters. Therefore, some judgment must be used in choosing the proper attack tool and corresponding time from Table 4.

One wall that did exhibit synergistic properties was the CMU reinforced by a 3-inch steel-fiber-reinforced concrete layer. SFRC has been shown to be an outstanding attack-resistant material and is recommended for new construction and reinforcement of existing facilities where weight is not a factor.

RESULTS AND CONCLUSIONS

The structural components (walls, floors, roofs) of secure facilities do not generally provide attack resistance of more than 2 minutes. Vaults with 4 to 8 inches of reinforced concrete provide greater security but not as much as has generally been expected. A knowledgeable, well-equipped attack force can make a man-passable opening in a 4-inch concrete wall in 3 minutes and in an 8-inch concrete wall in 11 minutes. An explosive attack or use of a jackhammer would reduce these times significantly.

In this study of available test data on penetration resistance of standard materials, two were much better against all types of attack. Fiber-reinforced concrete (with 2% steel fiber) is at least as effective as reinforced concrete at twice the thickness. It is also superior against explosive attack, though existing test data is inadequate to determine actual resistance. No. 9 gage, 3/4-inch, expanded metal was found to offer uniformly high resistance against all forms of attack. It is lighter than SFRC but more expensive. Expanded metal would also be effective against explosive attack because its mesh design allows blast pressures to vent and equalize around the mesh. Both materials can be used to upgrade existing facilities but the expanded metal would be easiest to apply. The SFRC would meet structural requirements in new construction while the expanded metal would only provide attack resistance.

COMPARISON OF PROPOSED BARRIER CONCEPTS

The attack-resistance information acquired in this study can be used to design barriers that could provide any desired denial time. The data from Tables 1 to 4 were used to project barrier concepts, compared in Table 5, that would provide denial times of about 10 and 20 minutes.

Table 5. Proposed Barrier Concepts

Denial Time (minutes)	Barrier	Weight (psf)	Relative Cost[a]
10	8-inch reinforced concrete	100	1.5
	4-inch steel-fiber-reinforced concrete	50	1.0
	six layers 9-gage, 3/4-inch expanded metal	11	3
	1/8-inch steel sheet 3/4-inch plywood four layers 9-gage, 3/4-inch expanded metal	15	3
20	8-inch laced reinforced concrete	110	6
	8-inch steel-fiber-reinforced concrete	110	2
	12 layers 9-gage, 3/4-inch expanded metal	22	6

[a] Based on author's experience and on discussions with materials experts and contractors.

The table does not reflect explosive attacks or pneumatic jackhammer attacks. Little data are available to determine explosive effects on these barriers, though the SFRC and the expanded metal would be superior to the other barriers shown. If a pneumatic jackhammer were used, it could reduce the attack time on any type of concrete wall and almost halve the denial time of regular reinforced concrete.

The barrier concepts include some margin for possible multiple-man attacks, while the test data only reflect a single-man attack with a given tool. Because of the small opening that is needed, the efficiency of multiple-man attacks declines quickly.

The advantages of SFRC and expanded metal are shown in Table 5. SFRC has a cost advantage while expanded metal has a weight advantage. Both concepts can be used in new construction or as reinforcement of existing construction.

These two wall types should be designed, constructed, and tested to determine if the projected denial times are accurate. All attack methods should be considered, including explosives. If the results do not confirm the expected attack resistances then another phase may be necessary to improve the barrier design and performance.

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