DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

AUG 8 2000

FROM: HQ AFCESA/CES
139 Barnes Drive
Tyndall AFB FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 00-9: Airblast Protection Retrofit for Unreinforced Concrete Masonry Walls**

1. Purpose. This ETL provides guidance for retrofit upgrade of existing unreinforced non-loadbearing concrete masonry walls to provide protection from explosive airblast.

2. Application: All Air Force installations.

2.1. Authority:

- DoD 0-2000.12H, *Protection of DoD Personnel and Activities Against Acts of Terrorism* and Political Turbulence, February 19, 1993
- DoDI 2000.16, *DoD Combating Terrorism Program Standards*, July 21, 1997
- AFI 31-210, *The Air Force Antiterrorism/Force Protection (AT/FP) Program Standards*

2.2. Effective Date: Immediately.

2.3. Ultimate Recipients:

- MAJCOM Civil Engineering offices.
- Base Civil Engineering personnel.
- Responsible Army Corps of Engineers (USACE) and Naval Facilities Engineering Command (NAVFACENGCOM) offices acting as design/construction agents for Air Force projects or facilities on Air Force property.

2.4. Coordination: MAJCOM Civil Engineering offices.

3. References.

3.1. Air Force:

- AFMAN 32-1071V1, *Security Engineering - Project Development* (For Official Use Only)
- AFMAN 32-1071V2, *Security Engineering - Concept Design* (For Official Use Only)
- AFMAN 32-1071V3, *Security Engineering - Final Design* (For Official Use Only)

3.2. U.S. Army Corps of Engineers:

- CEGS-13700, *Mass Concrete*
- TM 5-855-1, *Design and Analysis of Hardened Structures to Conventional Weapons Effects*
- ETL 1110-3-495, *Estimating Damage to Structures from Terrorist Bombs*

- ETL 1110-3-501, *Windows Retrofit using Fragment Retention Film with Catcher Bar System*

3.3. American Concrete Institute (ACI):

- ACI 318-95, *Building Code Requirements for Structural Concrete*

3.4. American Society for Testing and Materials (ASTM):

- A615/A615M-00, *Steel Bars for Concrete Reinforcement, Deformed and Plain Billet*
- C881-90, *Concrete, Epoxy-Resin-Base Bonding Systems*

4. Definitions.

4.1. *Aramid: A* generic name for a tough synthetic yarn that is in the aromatic polyamide family. It consists of long molecular chains that are highly oriented with strong interchain bonding resulting in a lightweight, high-modulus material.

4.2. *Balanced Construction:* Equal parts of warp and fill in fiber fabric.

4.3. *Composite:* A material made from a fiber (or reinforcement) and an appropriate matrix material to maximize specific performance properties. The constituents do not dissolve or merge completely but retain their identities as they act in concert.

4.4. *Conventional Construction:* Building construction including walls, doors, windows, or manufacturers' components which is not designed to resist tools, weapons, or explosives, but is designed to resist common environmental conditions.

4.5. *End:* A strand of roving consisting of a given number of filaments gathered together. The group of filaments is considered an "end" or strand before twisting, a "yarn" after twist has been applied.

4.6. *Fiber-Reinforced Plastic (FRP):* A general term for a composite that is reinforced with cloth, mat, strands, or any other fiber.

4.7. *Fill:* Yarn oriented at right angles to the warp in a fabric.

4.8. *Matrix:* A material in which the fiber of a composite is embedded.

4.9. *Geotextile:* A planar, permeable, polymeric (synthetic or natural) textile material, which may be nonwoven, knitted, or woven. Geotextiles are primarily used in contact with soil/rock and/or any other geotechnical material in civil engineering applications.

4.10. *Knitted Fiberglass Fabric:* A fabric made from fiberglass ends, commonly used for aerospace and military applications. The warp and fill ends are not interlaced, but placed on top of each other at 90 degrees. A polyester knit yarn is used to form a plain jersey stitch that binds the warp and fill ends together. Knitted fiberglass fabric is lightweight, supple, moderately strong, and is tolerant of both damage and cyclical loading.

4.11. *Peel Strength:* Adhesive bond strength, measured in force per unit width, obtained by a stress applied in a peeling mode.

4.12. *Roving:* A number of yarns, strands, tows, or ends collected into a parallel bundle with little or no twist.

4.13. *Unreinforced Masonry Construction:* Construction composed of CMU lacking reinforcement embedded in such a manner that the two materials act together to resist forces. (Unreinforced masonry may be reinforced only for shrinkage or thermal change.)

4.14. *Warp:* The yarn running lengthwise in a fabric.

4.15. *Woven Kevlar® Fabric:* A high-strength, high-modulus fabric made from yarns of aramid fibers by interlacing the warp and weft ends. Kevlar® is a registered trademark of E.I. du Pont de Nemours and Company. Woven Kevlar® fabric is commonly used as reinforcement in fiber-reinforced composite materials where good stiffness, high abrasion resistance and light weight are required.

4.16. *Yarn:* An assemblage of twisted filaments, fibers, or strands, either natural or manufactured, to form a continuous length that is suitable for use in knitting, braiding, or weaving into textile materials.

5. Requirements.

5.1. Objective of Airblast Protection Retrofit. Recent terrorist attacks have demonstrated the vulnerability of U.S. military and civilian personnel and the facilities where they work and live. Moment-resisting frames with unreinforced infill CMU walls are a common type of exterior construction in many parts of the world. Unfortunately, unreinforced masonry walls provide limited protection against airblast due to explosions. When subjected to overload from airblast, unreinforced CMU walls typically break into pieces, which are then propelled into the interior of the structure, possibly causing severe injury or death to the occupants. This ETL provides three retrofit methods which greatly enhance the performance of unreinforced concrete masonry walls subject to airblast.

5.2. Existing Structure Description. The retrofit methods in this ETL apply directly to buildings with concrete moment resisting frames and non-load bearing CMU infill walls. Other applications of these retrofits to non-load-bearing unreinforced CMU walls must be evaluated on a case-by-case basis. Design criteria were developed based on an 8-inch (200-millimeter) nominal CMU thickness and a wall height of 12 feet (3.6 meters), and will be conservative for use with shorter walls and for walls with thicker CMU. Structural members that the CMU walls connect to at their top and bottom must allow for the attachment of the retrofit materials. This will require that the connecting members be either reinforced concrete slabs with a minimum thickness of 6 inches (150 millimeters), or beams that provide adequate edge distance for attachment anchors to develop the required shear capacity. Embedments necessary to develop the required anchor strength were determined based on a concrete compressive strength of 4,000 pounds per square inch (27.6 megapascals) and should be adjusted if the existing concrete strength is less.

5.3. Retrofit Types.

5.3.1. Geotextile Fabric Catcher System. A curtain of geotextile fabric is placed behind the CMU wall, but not directly attached to it; covering the entire inside face of the wall. In the event of an explosion, the fabric catches broken pieces of the wall, preventing them from flying into the protected space and injuring occupants. Criteria for the use of the geotextile fabric method are presented in Attachments 1 and 2. This retrofit method does not apply to walls with windows.

5.3.2. Composite Backing System. A field-made composite of fiberglass or aramid fabric in an epoxy matrix is bonded to the entire interior face of the CMU wall. The composite is extended beyond the CMU wall to overlap the concrete frame to resist the applied blast pressure. To enhance shear strength at the connections, additional composite made of aramid fabric and epoxy is used to reinforce the connection points. In the event of an explosion, the composite enhances the bending strength of the wall and prevents broken pieces of the wall from entering the protected space and injuring occupants. The composite can be painted or covered with wallpaper to provide an aesthetically pleasing interior wall surface. Criteria for the use of the composite method are presented in Attachments 3 and 4. This retrofit method currently does not apply to walls with windows.

5.3.3. Reinforced Concrete Backing. A 4- or 6-inch (100- or 150-millimeter) thick reinforced concrete backing wall is placed against the inside face of the CMU wall. There are two ways for the backing wall to add strength to the CMU wall: (1) it can either add its flexural strength to that of the CMU wall with the interface between acting like a slip plane; or (2) with proper surface preparation of the CMU wall, the two walls can be made to act composite, giving a much greater strength gain. Criteria for the reinforced concrete backing method are presented in Attachments 5 and 6. This retrofit method can be applied to walls with windows.

6. Point of Contact: Mr. Myron Anderson, HQ AFCESA/CESC, DSN 523-6470, commercial (850) 283-6470, Internet Myron.Anderson@tyndall.af.mil, FAX (850) 283-6219.

Michael J. Cook, Colonel, USAF
Director of Technical Support

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1. Geotextile Fabric Retrofit for Airblast Protection of Unreinforced Concrete Masonry Walls (Inch-Pound Units)
2. Geotextile Fabric Retrofit for Airblast Protection of Unreinforced Concrete Masonry Walls (Standard International Units)
3. Composite Retrofit for Airblast Protection of Unreinforced Concrete Masonry Walls (Inch-Pound Units)
4. Composite Retrofit for Airblast Protection of Unreinforced Concrete Masonry Walls (Standard International Units)
5. Reinforced Concrete Backing Wall Retrofit for Airblast Protection of Unreinforced Concrete Masonry Walls (Inch-Pound Units)
6. Reinforced Concrete Backing Wall Retrofit for Airblast Protection of Unreinforced Concrete Masonry Walls (Standard International Units)
7. Distribution List

GEOTEXTILE FABRIC RETROFIT FOR AIRBLAST PROTECTION OF UNREINFORCED CONCRETE MASONRY WALLS (Inch-Pound Units)

A1.1. General Description. A curtain of geotextile fabric is placed behind the CMU wall covering the entire inside face of the wall. In the event of an explosion, the fabric serves to catch broken pieces of the wall, preventing them from flying into the protected space causing injury to the occupants. This retrofit method is effective, relatively inexpensive, uses lightweight materials and is easy to install. It is not applicable to walls with windows, as the fabric must span continuously from floor to ceiling without interruption, nor is it an aesthetically pleasing solution. A cross-section with installation details is shown in Figure A1.1.

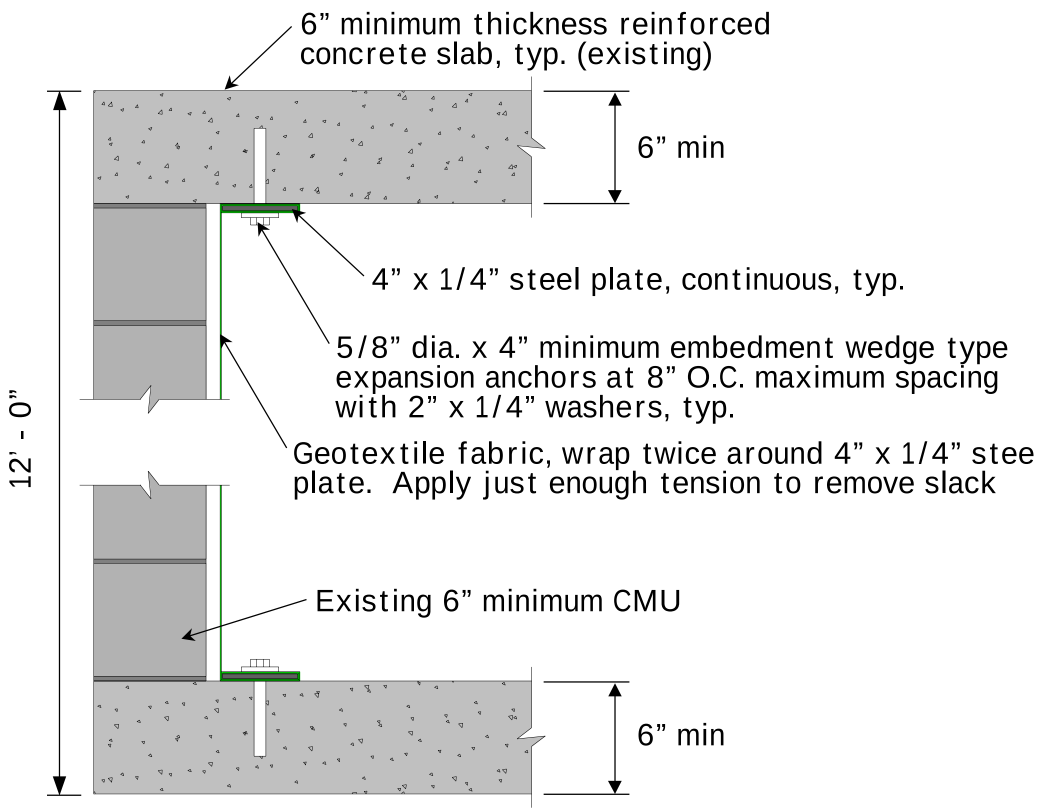

Figure A1.1. Geotextile Fabric Retrofit Cross Section

A1.2. Geotextile Fabric Properties.

A1.2.1. Geotextile fabric is a woven material with orthotropic strength properties. Fabric strength and stiffness is usually substantially greater in the primary or machine direction than in the orthogonal or cross direction. The strong direction of the fabric must be oriented vertically and the fabric securely anchored to a structural slab or beam at the top and bottom with just enough tension to remove slack.

A1.2.2. The effectiveness of this type of retrofit depends on the load versus strain behavior of the fabric as well as a secure attachment to an existing structure whose members have adequate strength. This ETL gives performance criteria for four different fabrics that may be used with this method. This is not a complete listing of fabrics that are suitable for this application; there are many others available. Information presented in this section will give an indication of the fabric property requirements. Load versus strain data for each of the four fabrics is presented in Table A1.1. Data for three of the fabrics was taken from manufacturers' data sheets, and data for the fourth fabric was obtained from independent material tests. Comtrac R 500 is a product of Huesker Inc. of Germany; Mirafi HS 1715 and HS 800 are products of the Nicolon/Mirafi Group of the U.S.; and UK Aramid is the W7660 fabric manufactured by Verseidag Indutex Limited of the U.K.

Table A1.1. Geotextile Fabric Load Versus Strain Data

Fabric ID	Load at 5% Elongation (lb/in)	Load at 10% Elongation (lb/in)	Ultimate Load (lb/in)	Ultimate Elongation (%)
Comtrac R 500 (M)	1050	…	2800	12
Comtrac R 500 (C)	…	…	400	12
HS 1715 (M)	650	1350	1715	12**
HS 1715 (C)	275	600	…	…
HS 800 (M)	300	800	800**	10**
HS 800 (C)	220	550	…	…
UK Aramid (M) *	537	…	675	7.4
UK Aramid (C) *	480	…	602	7.1

(M) Indicates machine (strong) direction.
(C) Indicates cross machine (weak) direction.
* No manufacturers' data available for this fabric; independent test results used.
** Assumed values used for analysis; not provided on manufacturers' data sheets.

A1.3. Anchorage to Existing Structure. The anchorage system shown in Figure A1.1 applies to all four fabrics. It was selected based on an assumed compressive strength for the existing concrete of f'_c = 4000 pounds per square inch. The 4-inch embedment depth shown provides adequate capacity to develop the full strength of all fabrics, however deeper embedment, up to 8 inches, should be used if the slab thickness allows. An 8-inch embedment length will assure ductile behavior of the anchors; shorter embedment lengths may result in brittle failures. Minimum embedment depth was set at 4 inches to accommodate a 6-inch minimum slab thickness, and thereby extend the usefulness of this system to as many structures as possible. If the anchors are to be embedded into a beam rather than a slab, the edge distance from the center of the anchors to the inside face of the beam must be at least 6 inches.

A1.4. Retrofit Blast Load Capacities. Blast load capacities for each of the geotextile fabric retrofits, presented in terms of charge weight versus standoff distance, are given in Figure A1.2. Charge weight is the equivalent weight of TNT and the standoff distance is the distance from the center of the charge to the outside face of the wall. The data used to create the curves shown in Figure A1.2 was generated using analytical methods. All loads used in the analyses were normal reflected pressures. The method used was verified by comparison with experimental results to give conservative estimates of the retrofit wall response to blast loading. The 8-inch thick CMU wall was modeled as a one-way span of 12 feet between simple supports at its top and bottom. The fabric acts as a tension membrane spanning between the structural members at the top and bottom of the wall and was modeled as being installed in contact or nearly in contact with the inside face of the wall. The response limit used was a midspan deflection equal to two-thirds of the deflection at which the fabric reaches its ultimate strain.

Masonry Wall Geotextile Fabric Retrofit
12-Foot High, Unreinforced 8-Inch CMU Block Wall
One-Way Span With Simple Supports at Top and Bottom

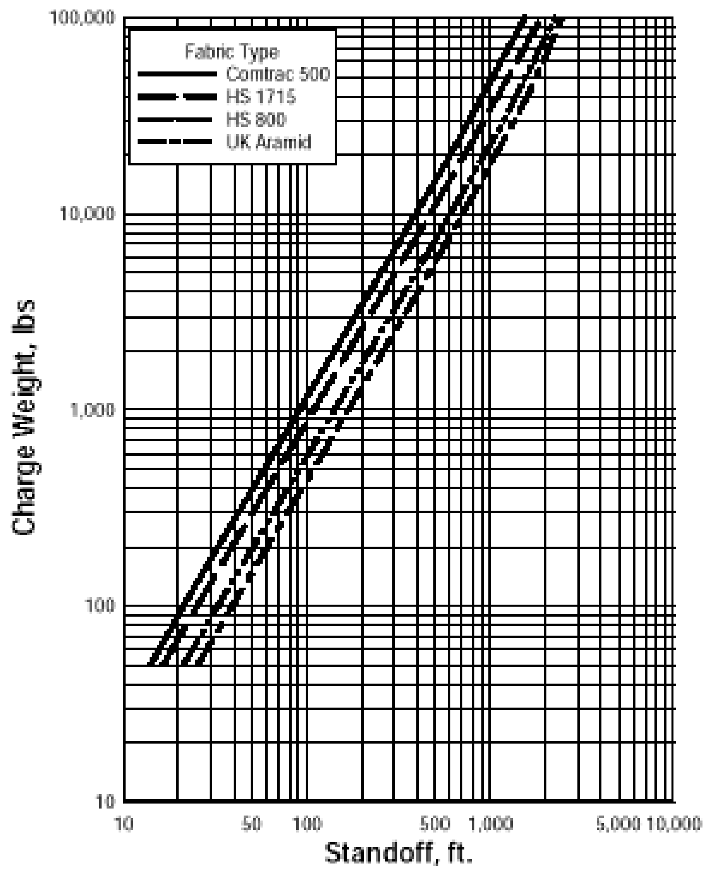

Figure A1.2. Charge Weight Versus Standoff for Geotextile Fabric Retrofit

A1.5. Cost Data for Geotextile Fabric Retrofits. Table A1.2 gives approximate costs for materials and installation of geotextile fabric retrofits. Labor and equipment requirements are also listed below. Note that the material cost for the fabrics is a small part of the total retrofit cost, so that the total cost does not depend greatly on the type of fabric. Costs given in the table are average values for construction in the United States in 1998.

Table A1.2. Geotextile Fabric Retrofit Cost Data

RETROFIT FABRIC	**COST (Per Linear Foot of Wall)***			
	Material and Equipment	Labor	Overhead and Profit	Total
Huesker Comtrac R 500	$32	$34	$18	$84
Mirafi HS 1715	$27	$34	$18	$79
Mirafi HS 800	$24	$34	$18	$76
UK Aramid	$40	$34	$18	$92

* Cost estimates are based on a wall height of 12 feet.

Labor required: Carpenters

Equipment required:
- Rotary hammer drill for drilling holes in concrete
- Miscellaneous hand and power tools

GEOTEXTILE FABRIC RETROFIT FOR AIRBLAST PROTECTION OF UNREINFORCED CONCRETE MASONRY WALLS (Standard International Units)

A2.1. General Description. A curtain of geotextile fabric is placed behind the CMU wall covering the entire inside face of the wall. In the event of an explosion the fabric serves to catch broken pieces of the wall, preventing them from flying into the protected space causing injury to the occupants. This retrofit method is effective, relatively inexpensive, uses lightweight materials and is easy to install. It is not applicable to walls with windows, as the fabric must span continuously from floor to ceiling without interruption, nor is it an aesthetically pleasing solution. A cross-section showing installation details is shown in Figure A2.1.

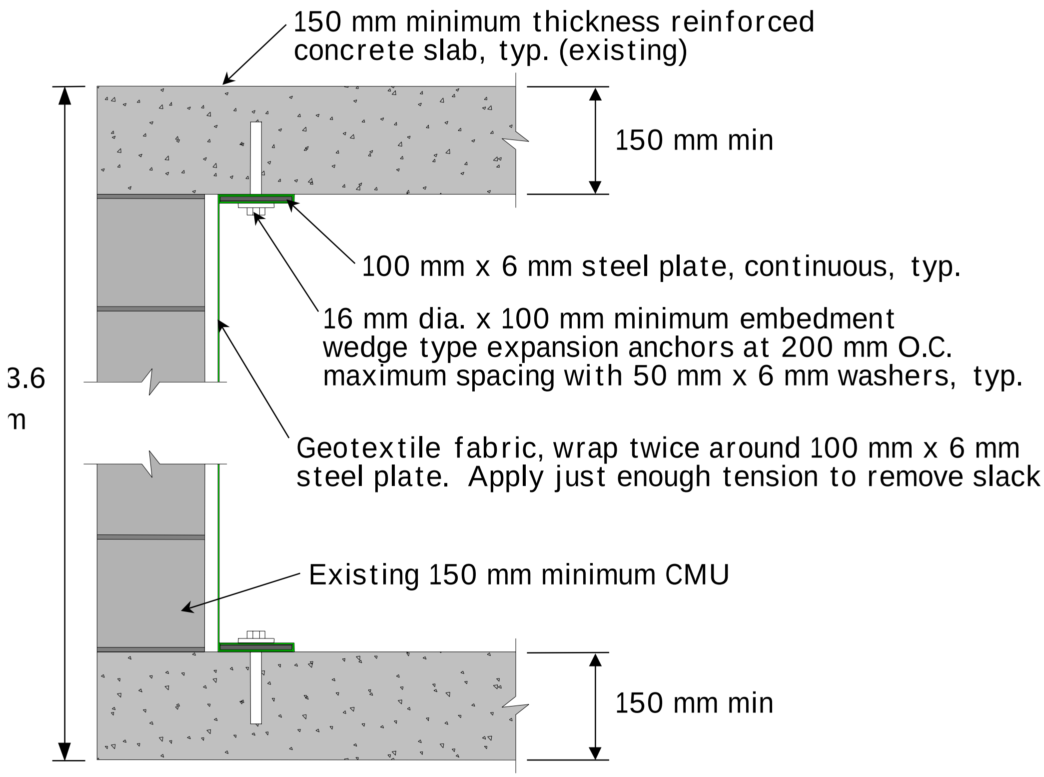

Figure A2.1. Geotextile Fabric Retrofit Cross Section

A2.2. Geotextile Fabric Properties.

A2.2.1. Geotextile fabric is a woven material with orthotropic strength properties. Fabric strength and stiffness is usually substantially greater in the primary or machine direction than in the orthogonal or cross direction. The strong direction of the fabric must be oriented vertically and the fabric securely anchored to a structural slab or beam at the top and bottom with just enough tension to remove slack.

A2.2.2. The effectiveness of this type of retrofit depends on the load versus strain behavior of the fabric as well as a secure attachment to an existing structure whose members have adequate strength. This ETL gives performance criteria for four different fabrics that may be used with this method. This is not a complete listing of fabrics that are suitable for this application; there are many others available. Information presented in this section will give an indication of the fabric property requirements. Load versus strain data for each of the four fabrics is presented in Table A2.1. Data for three of the fabrics was taken from manufacturers data sheets and data for the fourth fabric was obtained from independent material tests. Comtrac R 500 is a product of Huesker Inc. of Germany, Mirafi HS 1715 and HS 800 are products of the Nicolon/Mirafi Group of the U.S., and UK Aramid is the W7660 fabric manufactured by Verseidag Indutex Limited of the U.K.

Table A2.1. Geotextile Fabric Load Versus Strain Data

Fabric ID	Load at 5% Elongation (N/mm)	Load at 10% Elongation (N/mm)	Ultimate Load (N/mm)	Ultimate Elongation (%)
Comtrac R 500 (M)	184	…	490	12
Comtrac R 500 (C)	…	…	70	12
HS 1715 (M)	114	236	300	12**
HS 1715 (C)	48	106	…	…
HS 800 (M)	53	140	140**	10**
HS 800 (C)	39	96	…	…
UK Aramid (M) *	94	…	118	7.4
UK Aramid (C) *	84	…	105	7.1

(M) Indicates machine (strong) direction.
(C) Indicates cross machine (weak) direction.
* No manufacturers data available for this fabric, independent test results used.
** Assumed values used for analysis, not provided on manufacturers data sheets.

A2.3. Anchorage to Existing Structure. The anchorage system shown in Figure A2.1 applies to all four fabrics. It was selected based on an assumed compressive strength for the existing concrete of f'_c = 27.6 megapascals. The 100–millimeter embedment depth shown provides adequate capacity to develop the full strength of all fabrics; however, deeper embedment, up to 200 millimeters, should be used if the slab thickness allows. A 200-millimeter embedment length will assure ductile behavior of the anchors; shorter embedment lengths may result in brittle failures. Minimum embedment depth was set at 100 millimeters to accommodate a 150--millimeter minimum slab thickness, and thereby extend the usefulness of this system to as many structures as possible. If the anchors are to be embedded into a beam rather than a slab, the edge distance from the center of the anchors to the inside face of the beam must be at least 150 millimeters.

A2.4. Retrofit Blast Load Capacities. Blast load capacities for each of the geotextile fabric retrofits, presented in terms of charge weight versus standoff distance, are given in Figure A2.2. Charge weight is the equivalent weight of TNT and the standoff distance is the distance from the center of the charge to the outside face of the wall. The data used to create the curves shown in Figure A2.2 was generated using analytical methods. All loads used in the analyses were normal reflected pressures. The method used was verified by comparison with experimental results to give conservative estimates of the retrofit wall response to blast loading. The 200-millimeter-thick CMU wall was modeled as a one-way span of 3.6 meters between simple supports at its top and bottom. The fabric acts as a tension membrane spanning between the structural members at the top and bottom of the wall and was modeled as being installed in contact or nearly in contact with the inside face of the wall. The response limit used was a midspan deflection equal to two-thirds of the deflection at which the fabric reaches its ultimate strain.

Masonry Wall Geotextile Fabric Retrofit
3.6 Meters High, 200-Millimeter CMU Block Wall
One-Way Span With Simple Supports at Top and Bottom

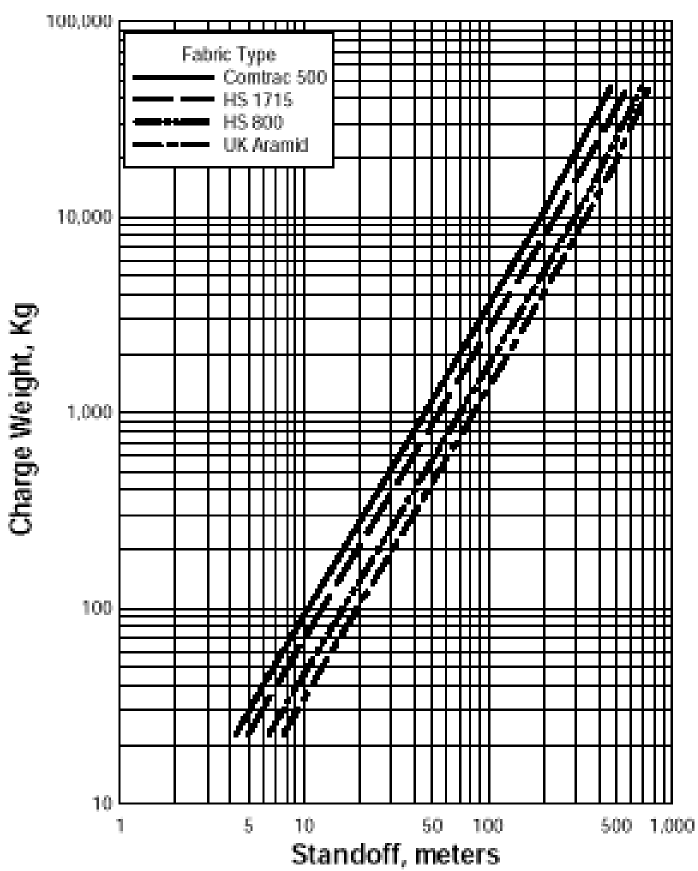

Figure A2.2. Charge Weight Versus Standoff for Geotextile Fabric Retrofit

A2.5. Cost Data for Geotextile Fabric Retrofits. Table A2.2 gives approximate costs for materials and installation of geotextile fabric retrofits. Labor and equipment requirements are also listed below. Note that the material cost for the fabrics is a small part of the total retrofit cost, so that the total cost does not depend greatly on the type of fabric. Costs given in the table are average values for construction in the United States in 1998.

Table A2.2. Geotextile Fabric Retrofit Cost Data

RETROFIT FABRIC	COST (Per Linear Foot of Wall)*			
	Material and Equipment	Labor	Overhead and Profit	Total
Huesker Comtrac R 500	$106	$112	$59	$227
Mirafi HS 1715	$89	$112	$59	$227
Mirafi HS 800	$79	$112	$59	$227
UK Aramid	$132	$112	$59	$227

* Cost estimates are based on a wall height of 3.6 meters.

Labor required: Carpenters

Equipment required:
- Rotary hammer drill for drilling holes in concrete
- Miscellaneous hand and power tools

**COMPOSITE RETROFIT FOR AIRBLAST PROTECTION
OF UNREINFORCED CONCRETE MASONRY WALLS
(Inch-Pound Units)**

A3.1. General Description. A field-made composite of fiberglass or aramid fabric in an epoxy matrix is bonded to the entire interior face of the CMU wall. The composite is extended beyond the CMU wall to overlap the concrete frame to resist the applied blast pressure. To enhance shear strength at the connections, additional composite made of aramid fabric and epoxy is used to reinforce the connection points. In the event of an explosion, the composite enhances the bending strength of the wall and prevents broken pieces of the wall from entering the protected space causing injury to the occupants. The composite can be painted or covered with wallpaper to provide an aesthetically pleasing interior wall surface. This retrofit method currently does not apply to walls with windows.

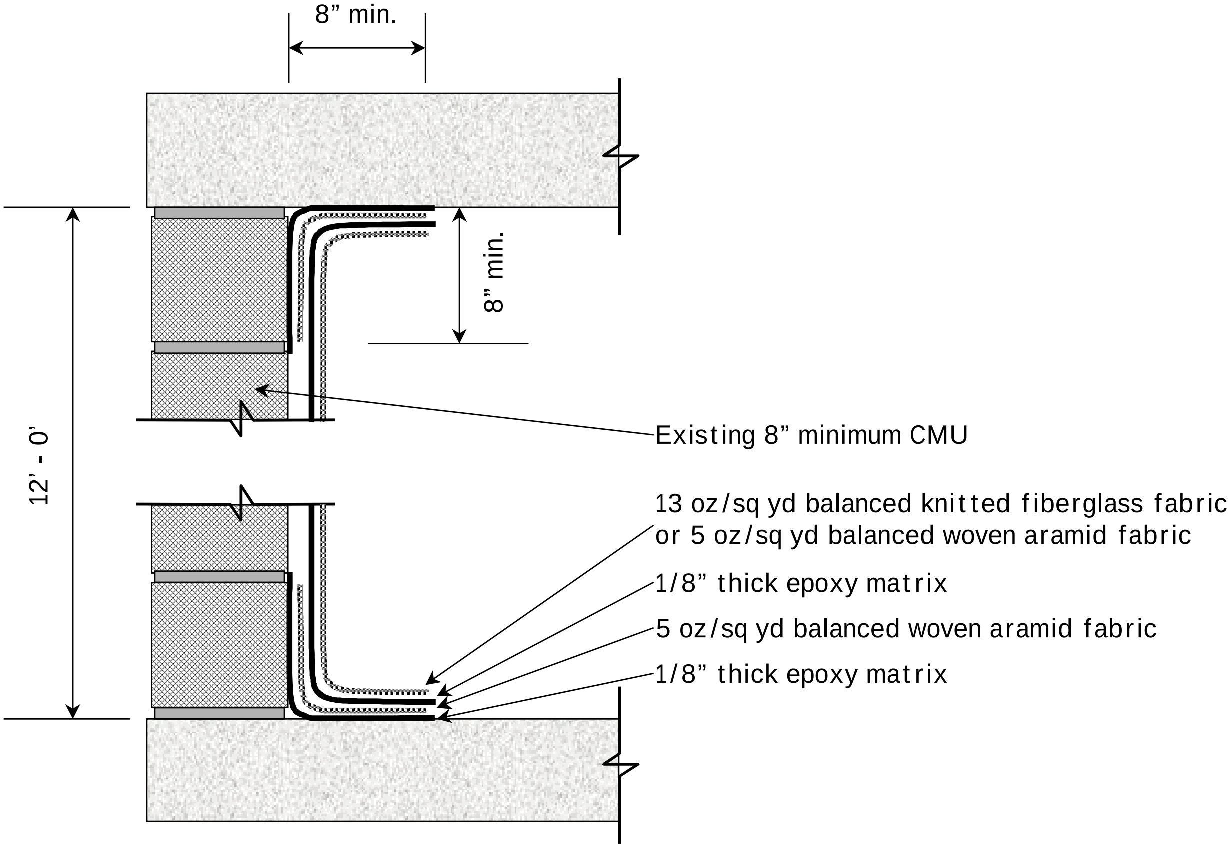

Figure A3.1. Composite Retrofit Cross Section

A3.2. Composite Properties.

A3.2.1. The effectiveness of the composite retrofit depends on the load versus strain behavior of the composite and the integrity of the bond of the composite to the wall and frame. This ETL gives performance criteria for composites made from two different fabrics and a single matrix material. This is not a complete listing of fabrics or matrix materials that are suitable for this application; there are many others available. It is important that any fabric used to reinforce the composite must be of balanced construction. Information presented in this section will give an indication of the composite property requirements.

A3.2.2. Load versus strain data for both composites are presented in Table C-1. These data obtained from independent material tests. The aramid material is a balanced woven fabric of Kevlar 49® material manufactured by Fibre Glast Developments Corporation, of Brookville, Ohio. Kevlar® is a registered trademark of E.I. du Pont de Nemours and Company. The fiberglass (commonly referred to as E-glass) material is a balanced knitted textile manufactured by Collins Craft Composites of Walhalla, South Carolina. The two-component epoxy used is Hysol 9460 manufactured by the Hysol Corporation of Seabrook, New Hampshire.

Table A3.1. Composite Load and Strain Data

Composite	Peel Strength (lb/in)	Ultimate Load (lb/in)	Ultimate Elongation (%)
13 oz/yd^2 knitted fiberglass fabric with 1/8-inch thick epoxy*	350	425	1.5
5 oz/yd^2 aramid fabric" with 1/8-inch thick epoxy*	350	725	2.3

* No manufacturers' data available for this fabric; independent test results used.

A3.3. Application to Existing Structure. The manufacture and application of the composite material involves cutting the fabrics into the desired dimensions, thoroughly cleaning the surface to be retrofitted, placing the reinforcing strips at the intersections of the wall and frame, and placing the epoxy and fabric on the wall and frame. These steps are described in more detail below.

A3.3.1. Cut the fabric to the desired dimensions. The fabric should be cut so that there will be no less than an 8-inch overlap on the concrete frame. It is a good idea to purchase special scissors to cut the fabrics, as these fabrics tend to dull most scissors rather rapidly.

A3.3.2. The entire surface area over which the composite is to be applied must be cleaned thoroughly to ensure a good bond with the composite. Remove laitance and vacuum the entire wall surface as well as the corners where the CMU wall meets the concrete frame.

A3.3.3. Mix the two components of the Hysol 9460 epoxy in a 1:1 ratio. A good mix color will be a light gray shade. The working time of epoxy at 90 °F is approximately 30 minutes.

A3.3.4. Next, apply the aramid reinforcement at the intersections of the CMU wall with the concrete frame. Apply a 16-inch-wide ribbon of epoxy (8 inches on the wall, 8 inches on the frame) to a depth of 1/8-inch thick. A notched trowel performs this task adequately. Then apply a 16-inch-wide strip of aramid fabric, ensuring 8 inches of lap on the wall and concrete frame. Continue around the entire wall, making sure all connections are reinforced with the bonded aramid/epoxy composite material. Where strips of fabric must be joined, use at least a 9-inch lap joint, making sure that the epoxy thoroughly saturates both pieces of fabric at the joint.

A3.3.5. Finally, apply the fabric (either aramid or fiberglass) to the wall, lapping the fabric onto the concrete frame a minimum of 8 inches Apply a 1/8-inch-thick coat of epoxy to the entire surface of the wall. Apply strips of aramid or fiberglass fabric to the wall. Strips should be rolled on with a wax paper roller to ensure uniform penetration of the epoxy in to the fabric. Where strips of fabric must be joined (horizontally or vertically), use at least a 9-inch lap joint, making sure that the epoxy thoroughly saturates both pieces of fabric at the lap joint.

A3.4. Retrofit Blast Load Capacities.

A3.4.1. Blast load capacities for each of the composite retrofits, presented in terms of charge weight versus standoff distance, are given in Figure A3.2. Charge weight is the equivalent weight of TNT and the standoff distance is the distance from the center of the charge to the outside face of the wall.

A3.4.2. The data used to create the curves shown in Figure A3.2 were generated using analytical methods. All loads used in the analyses were normal reflected pressures. The method used was verified by comparison with experimental results to give conservative estimates of the retrofit wall response to blast loading. The 8-inch-thick CMU wall was modeled as a one-way span of 12 feet between simple supports at its top and bottom. The fabric acts as a tension membrane spanning between the structural members at the top and bottom of the wall, and was modeled as being installed in contact or nearly in contact with the inside face of the wall. The response limit used was a midspan deflection equal to two-thirds of the deflection at which the fabric reaches its ultimate strain.

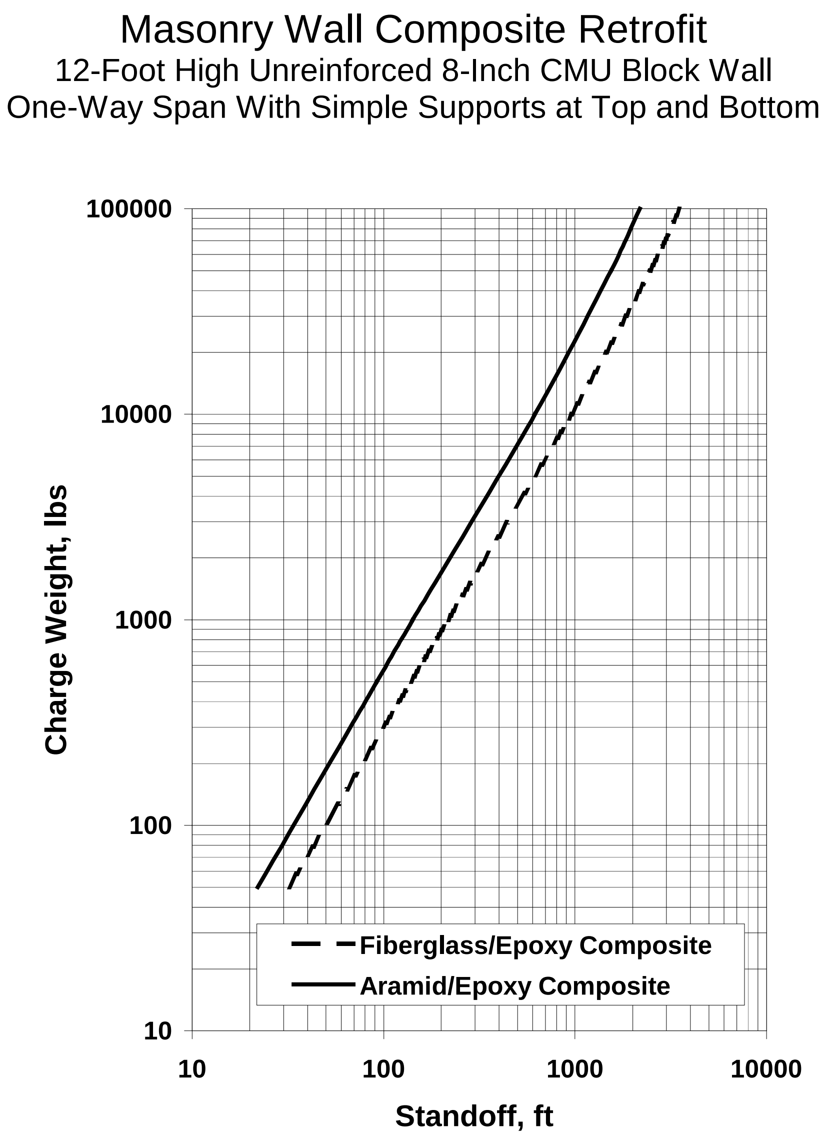

Figure A3.2. Charge Weight versus Standoff for Composite Retrofit

A3.5. Cost Data for Composite Retrofits. Table A3.2 gives approximate costs for materials and installation of composite retrofits. Labor and equipment requirements are also listed below. Note that the material cost for the fabrics is a small part of the total retrofit cost, so that the total cost does not depend greatly on the type of fabric. Costs given in the table are average values for construction in the United States in 1999.

Table A3.2. Composite Retrofit Cost Data

COMPOSITE	COST (Per Linear Foot of Wall)*			
	Material and Equipment	Labor	Overhead and Profit	Total
5 oz/sq yd knitted fiberglass fabric with 1/8-inch thick epoxy	$101	$36	$19	$156
13 oz/sq yd aramid fabric with 1/8-inch thick epoxy*	$133	$36	$19	$188

* Cost estimates are based on a wall height of 12 feet.

Labor required: Carpenters

Equipment required: Miscellaneous hand and power tools

COMPOSITE RETROFIT FOR AIRBLAST PROTECTION OF UNREINFORCED CONCRETE MASONRY WALLS (Standard International Units)

A4.1. General Description. A fabric composed of fiberglass or aramid fibers is bonded to the interior of the CMU wall using a high-strength epoxy forming a fiber-reinforced composite covering the entire inside face of the wall. The composite is extended beyond the CMU wall to overlap the concrete frame to resist the applied blast pressure. Additional aramid fabric strips are used to reinforce the connection points to provide enhanced shear strength at the connections. In the event of an explosion, the composite system enhances the bending strength of the wall and prevents broken pieces of the wall from entering the protected space causing injury to the occupants. The composite system can be painted or covered with wallpaper to provide an aesthetically pleasing interior wall surface. This retrofit method currently does not apply to walls with windows.

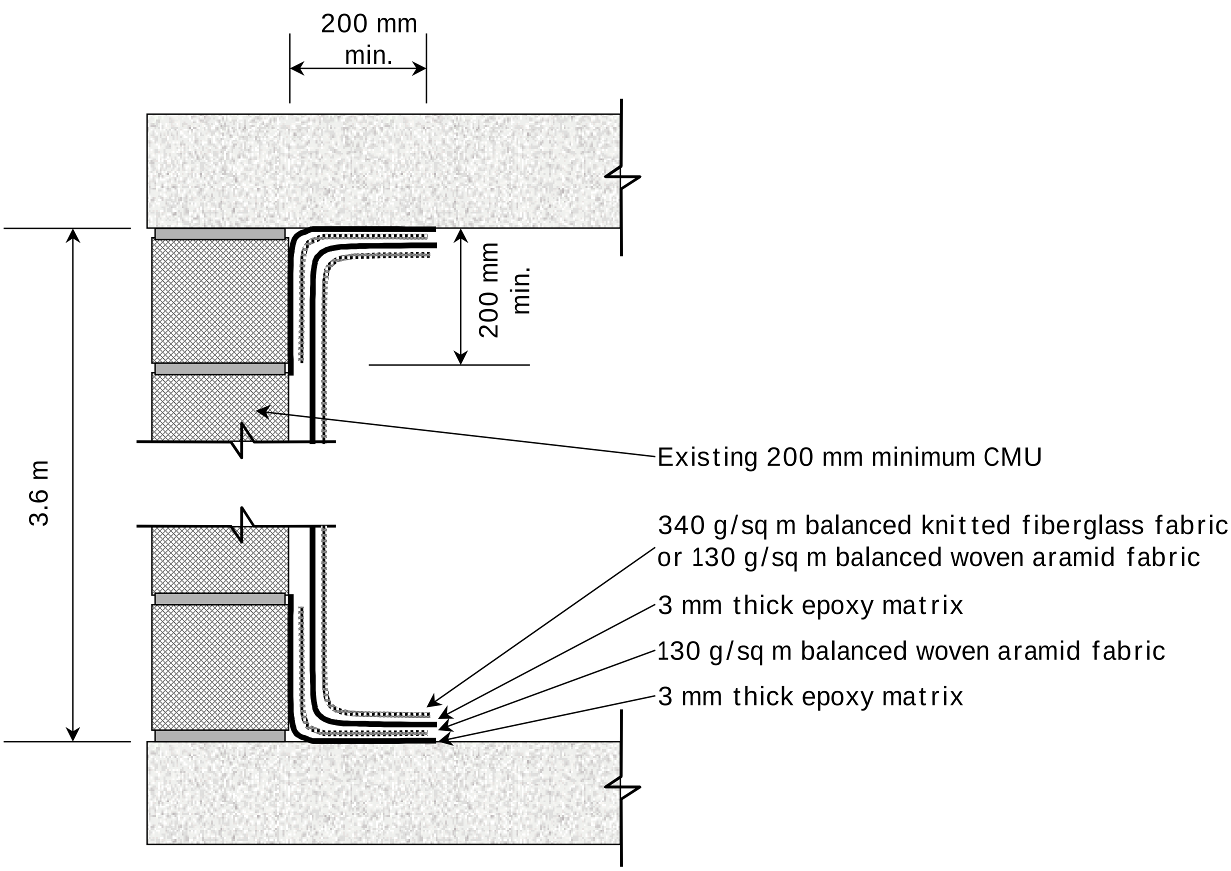

Figure A4.1. Geotextile Fabric Retrofit Cross-Section

A4.2. Geotextile Fabric Properties.

A4.2.1. The effectiveness of the composite retrofit depends on the load versus strain behavior of the composite and the integrity of the bond of the composite to the wall and frame. This ETL gives performance criteria for composites made from two different fabrics and a single matrix material. This is not a complete listing of fabrics or matrix materials that are suitable for this application; there are many others available. It is important that any fabric used to reinforce the composite must be of balanced construction. Information presented in this section will give an indication of the composite property requirements.

A4.2.2. Load versus strain data for both composites are presented in Table A4.1. These data were obtained from independent material tests. The aramid material is a balanced woven fabric of Kevlar 49® material manufactured by Fibre Glast Developments Corporation of Brookville, Ohio. Kevlar® is a registered trademark of E.I. du Pont de Nemours and Company. The fiberglass (commonly referred to as E-glass) material is a balanced knitted textile manufactured by Collins Craft Composites of Walhalla, South Carolina. The two-component epoxy used is Hysol 9460 manufactured by the Hysol Corporation of Seabrook, New Hampshire.

Table A4.1. Fiber-Reinforced Composite Load Versus Strain Data

Composite	Peel Strength (N/mm)	Ultimate Load (N/mm)	Ultimate Elongation (%)
340 g/m^2 knitted fiberglass fabric with 3-mm thick epoxy*	61	74	1.5
130 g/m^2 aramid fabric with 3-mm thick epoxy*	61	127	2.3

* No manufacturers' data available for this fabric; independent test results used.

A4.3. Anchorage to Existing Structure. The manufacture and application of the composite material involves cutting the fabrics into the desired dimensions, thoroughly cleaning the surface to be retrofitted, placing the reinforcing strips at the intersections of the wall and frame, and placing the epoxy and fabric on the wall and frame. These steps are described in more detail below.

A4.3.1. Cut the fabric to the desired dimensions. The fabric should be cut so that there will be no less than an 200-millimeter overlap on the concrete frame. It is a good idea to purchase special scissors to cut the fabrics, as these fabrics tend to dull most scissors rather rapidly.

A4.3.2. The entire surface area over which the composite is to be applied must be cleaned thoroughly to ensure a good bond with the composite. Remove laitance and vacuum the entire wall surface as well as the corners where the CMU wall meets the concrete frame.

A4.3.3. Mix the two components of the Hysol 9460 epoxy in a 1:1 ratio. A good mix color will be a light gray shade. The working time of epoxy at 32 °C is approximately 30 minutes.

A4.3.4. Next, apply the aramid fabric reinforcement at the intersections of the CMU wall with the concrete frame. Apply a 400-millimeter-wide ribbon of epoxy (200 millimeters on the wall, 200 millimeters on the frame) to a depth of 3 millimeters thick. A notched trowel performs this task adequately. Then, apply a 400-millimeter-wide strip of aramid fabric ensuring 8 inches of lap on the wall and concrete frame. Continue around the entire wall making sure all connections are reinforced with the bonded aramid/epoxy composite material. Where strips of fabric must be joined, use at least a 230-millimeter lap joint, making sure that the epoxy thoroughly saturates both pieces of fabric at the joint.

A4.3.5. Finally, apply the fabric (either aramid or fiberglass) to the wall, lapping the fabric onto the concrete frame a minimum of 200 millimeters. Apply a 3-millimeter-thick coat of epoxy to the entire surface of the wall. Apply strips of aramid or fiberglass fabric to the wall. Strips should be rolled on with a wax paper roller to ensure uniform penetration of the epoxy in to the fabric. Where strips of fabric must be joined (horizontally or vertically), use at least a 230-millimeter lap joint, making sure that the epoxy thoroughly saturates both pieces of fabric at the lap joint.

A4.4. Retrofit Blast Load Capacities.

A4.4.1. Blast load capacities for each of the composite retrofits, presented in terms of charge weight versus standoff distance, are given in Figure A4.2. Charge weight is the equivalent weight of TNT and the standoff distance is the distance from the center of the charge to the outside face of the wall.

A4.4.2. The data used to create the curves shown in Figure A4.2 were generated using analytical methods. All loads used in the analyses were normal reflected pressures. The method used was verified by comparison with experimental results to give conservative estimates of the retrofit wall response to blast loading. The 200-millimeter-thick CMU wall was modeled as a one-way span of 3.6 meters between simple supports at its top and bottom. The fabric acts as a tension membrane spanning between the structural members at the top and bottom of the wall and was modeled as being installed in contact or nearly in contact with the inside face of the wall. The response limit used was a midspan deflection equal to two-thirds of the deflection at which the fabric reaches its ultimate strain.

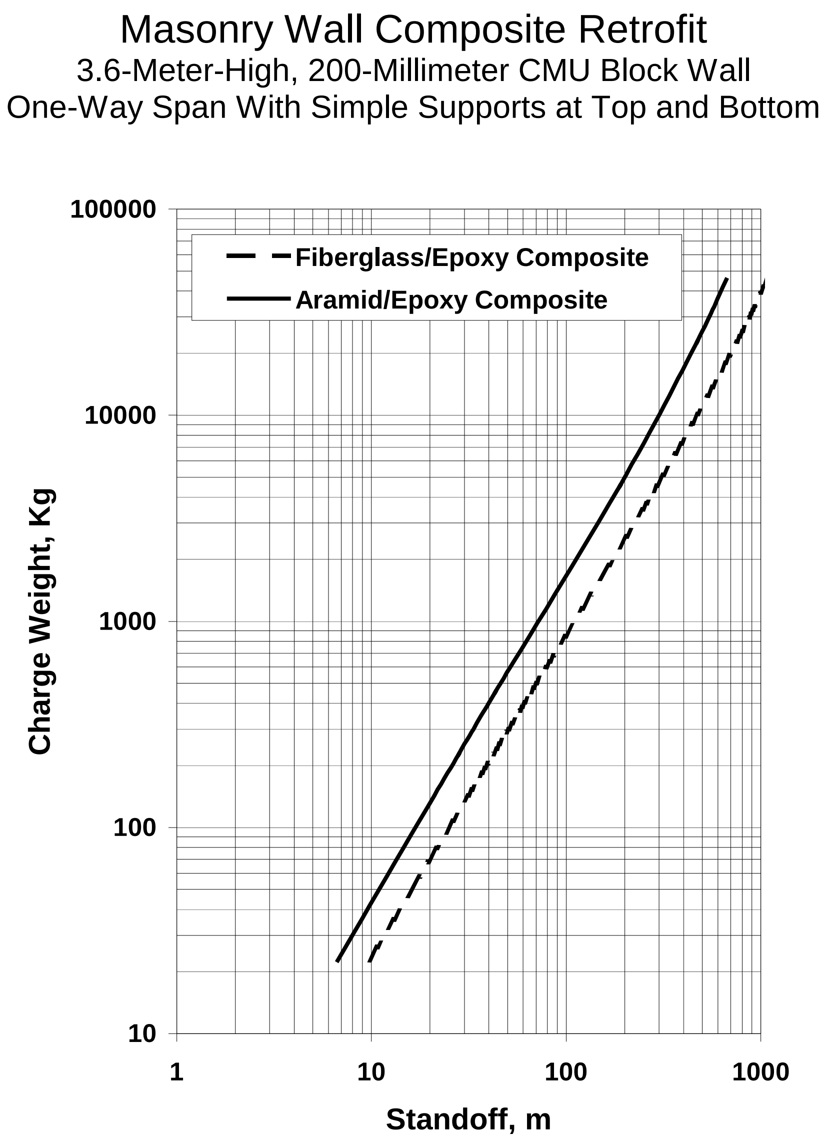

Figure A4.2. Charge Weight Versus Standoff for Composite Retrofit

A4.5. Cost Data for Composite Retrofits. Table A4.2 gives approximate costs for materials and installation of composite retrofits. Labor and equipment requirements are also listed below. Note that the material cost for the fabrics is a small part of the total retrofit cost, so that the total cost does not depend greatly on the type of fabric. Costs given in the table are average values for construction in the United States in 1999.

Table A4.2. Composite Retrofit Cost Data

Retrofit Fabric	Cost (Per Linear Meter of Wall)*			
	Material and Equipment	Labor	Overhead and Profit	Total
340 g/m^2. knitted fiberglass fabric with 3-mm thick epoxy*	\$331	\$118	\$63	\$512
130 g/m^2 aramid fabric with 3-mm thick epoxy*	\$435	\$118	\$63	\$616

* Cost estimates are based on a wall height of 3.6 meters.

Labor required: Carpenters

Equipment required: Miscellaneous hand and power tools

REINFORCED CONCRETE BACKING WALL RETROFIT FOR AIRBLAST PROTECTION OF UNREINFORCED CONCRETE MASONRY WALLS (Inch-Pound Units)

A5.1. General Description. A four- or six-inch thick reinforced concrete backing wall is placed against the inside face of the CMU wall. The backing wall is reinforced with a single layer of reinforcement midway through its thickness. Equal vertical and horizontal bars are used with the vertical bars placed toward the inside of the wall relative to the horizontal bars. Attachment at the top and bottom of the new wall is achieved by drilling into existing slabs or beams and placing anchors that lap with the vertical wall reinforcement. The anchors can be either through-bolts or reinforcing bars epoxy-grouted into the existing structure. This retrofit method is very effective. It can also be used on walls that have windows, as described in A5.6. The concrete backing wall does add significant dead load to the structure and its effect on the conventional static and seismic design must be checked.

A5.2. Bonded Versus Unbonded. The reinforced concrete retrofit can be designed as bonded or unbonded. For the unbonded option, no special preparation is done to the surface of the CMU wall before placing the backing wall. Without surface preparation, the quality of the bond between the CMU and the concrete backing will not be reliable and the walls must be considered as acting separately, with the interface between them acting as a slip plane. The backing wall adds its strength to that of the CMU with no enhancement from composite action. If the surface of the CMU wall is properly prepared before placement of the concrete, a strong reliable bond will develop at the interface and the two walls will act as a composite unit, giving a substantial strength increase over the unbonded wall. The bonded wall surface should be prepared according to the guidance given in CEGS-03700, *Mass Concrete,* for preparation of concrete surfaces to which concrete is to be bonded.

A5.3. Backing Wall Configurations. Four combinations of backing wall thickness and reinforcing ratio are presented for both the bonded and the unbonded backing wall options. A backing wall thickness of 4 inches is used with either number three bars at 12 inches or number three bars at 6 inches; and a backing wall thickness of 6 inches is used with either number 3 bars at 10 inches or number three bars at 6 inches. Detailing options for the installation of the backing wall retrofits are presented in Figures A5.1 and A5.2. Figure A5.1 shows the through-bolting method for anchorage to the existing structure, and Figure A5.2 shows the use of epoxy resin grouting for anchorage. The use of epoxy resin grouting for anchorage is an alternative that can be used when access for through-bolting is difficult or impractical.

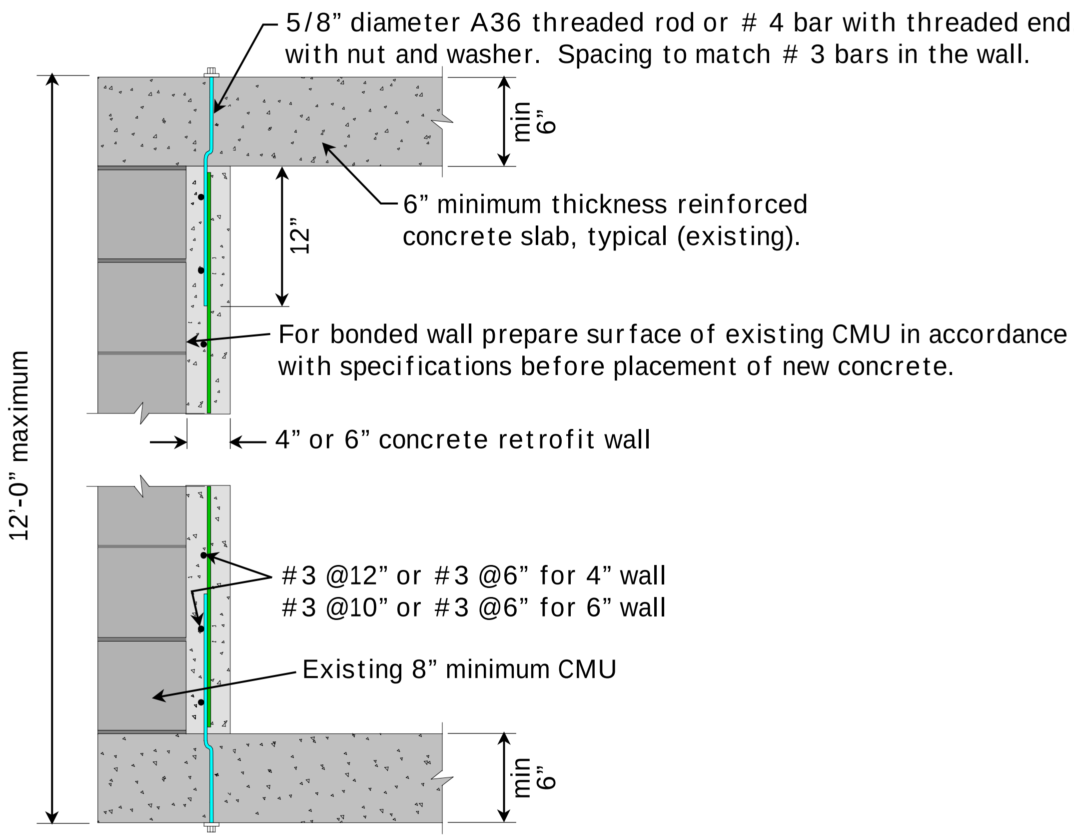

Figure A5.1. Four- or Six-Inch Backing Wall with Through-Bolt Anchorage

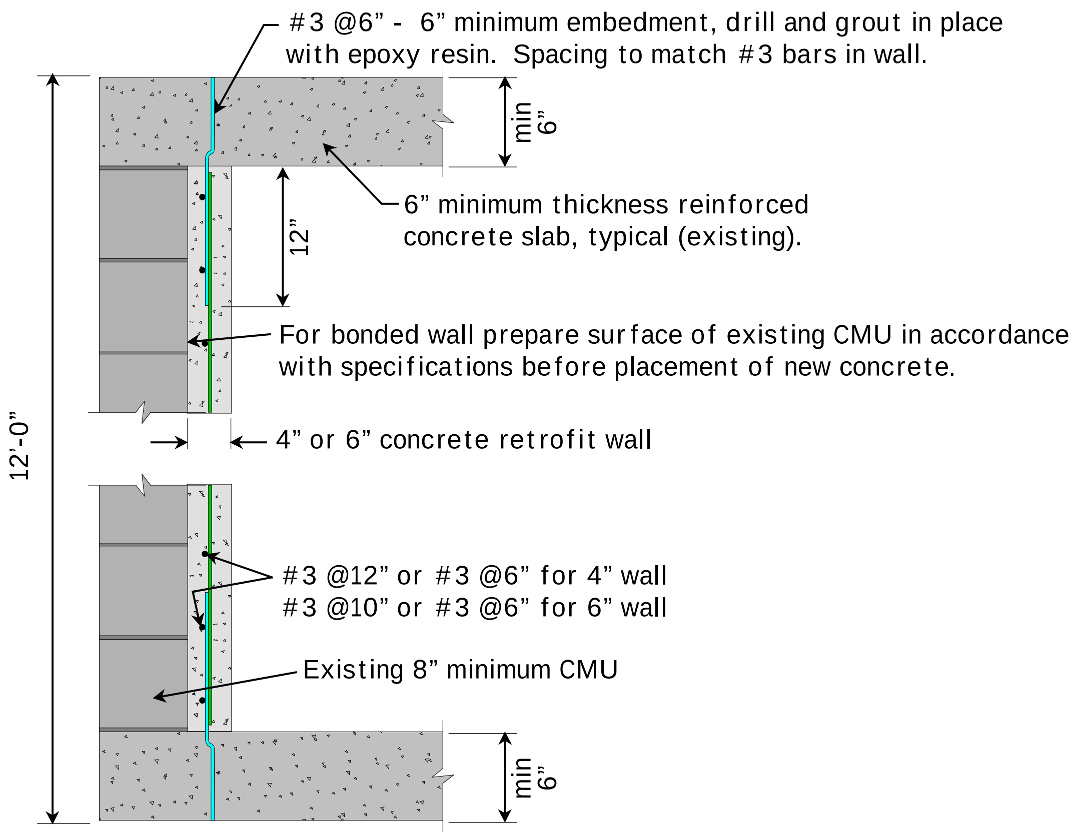

Figure A5.2. Four- or Six-Inch Backing Wall with Epoxy Resin Anchorage

A5.4. Material Properties. Material properties used in the development of these retrofits were a concrete compressive strength of f'_c = 4,000 psi and reinforcing steel meeting ASTM-A615/A615M-00, *Steel Bars for Concrete Reinforcement, Deformed and Plain Billet*, Grade 60. Epoxy-resin used for drilled and grouted reinforcing bar anchorage must meet ASTM-C881-90, *Concrete, Epoxy-Resin-Base Bonding Systems*, Type IV and be of the appropriate grade and class for installation conditions.

A5.5. Retrofit Blast Load Capacities.

A5.5.1. Blast load capacities for each of the reinforced concrete backing wall retrofits, presented in terms of charge weight versus standoff distance, are given in Figures A5.3 and A5.4.

A5.5.2. Charge weight is the equivalent weight of TNT and the standoff distance is the distance from the center of the charge to the outside face of the wall. The data used to create the curves shown in these figures were generated using analytical methods in accordance with TM 5-855-1. All analyses used normal reflected airblast. The method used was verified by comparison with experimental results to give conservative estimates of the retrofit wall response to blast loading.

Unbonded Reinforced Concrete Backing Wall
Retrofit for 12-Foot High Unreinforced 8-Inch CMU Block Wall
Block Wall Simply Supported at Top and Bottom

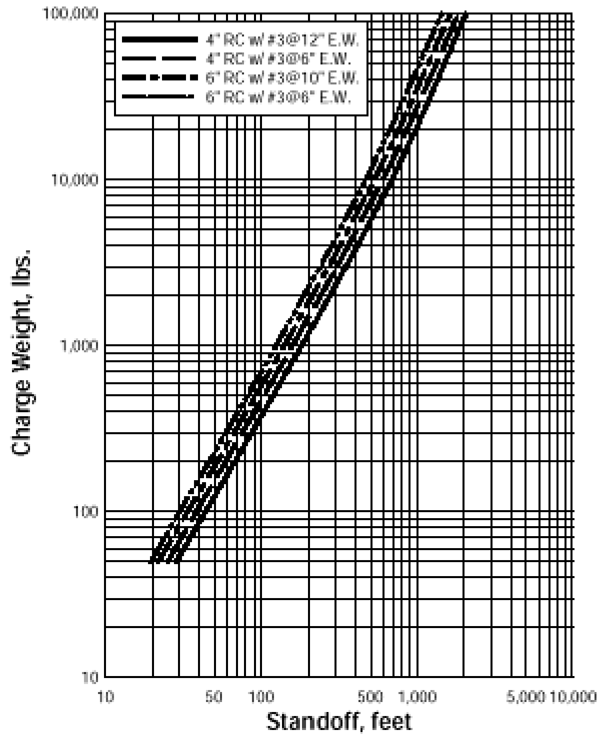

Figure A5.3. Charge Weight Versus Standoff for Unbonded Concrete Backing Wall Retrofit

Bonded Reinforced Concrete Backing Wall
Retrofit for 12-Foot High Unreinforced 8-Inch CMU Block Wall
Block Wall Simply Supported at Top and Bottom

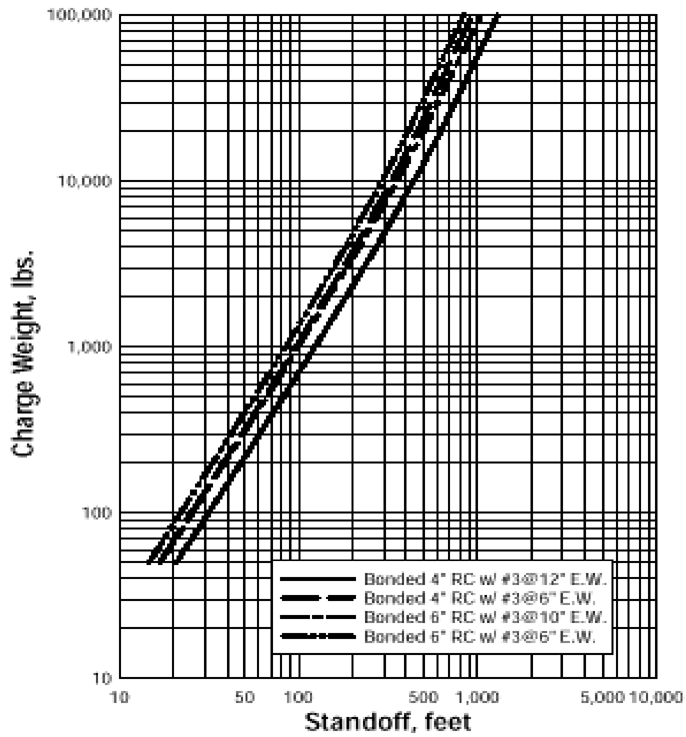

Figure A5.4. Charge Weight Versus Standoff for Bonded Concrete Backing Wall Retrofit

A5.6. Walls With Windows. In many cases, a reinforced concrete backing wall retrofit can be applied to walls with windows. The presence of a window opening weakens a wall, and this weakening effect must be accounted for in the retrofit design. After selection of the retrofit backing wall design from Figures A5.3 or A5.4, the following additional requirements must be satisfied to allow the backing wall to compensate for the weakening effects of a window opening.

(1) The width of the window opening must not exceed 80 percent of the vertical span of the retrofit wall.

(2) The concrete backing wall must be placed behind any CMU wall above and below the window as well as on both sides.

(3) Additional vertical reinforcing bars must be placed in the backing wall on each side of the opening. The amount of additional vertical reinforcing must equal or exceed the amount of vertical reinforcing interrupted by the opening, with half placed on each side. The additional bars should be distributed evenly in the backing wall close to the opening and over a wall width such that the reinforcing ratio in that width does not exceed 75 percent of the balanced strain reinforcing ratio (per ACI 318-95, *Building Code Requirements for Structural Concrete*). The additional bars must

extend the full height of the wall and be anchored into the existing structure in the same manner as the other bars.

(4) If the width of wall between any two window openings is insufficient for placement of the additional reinforcing required in (3), these two windows and the space between must be considered as a single opening width in (1).

For windows wider than specified in (1) above, use of this procedure is not recommended and more detailed considerations beyond the scope of this ETL are appropriate. Application of these retrofit measures to a wall with windows presupposes that the windows are also upgraded to a similar airblast protection level.

A5.7. Cost Data for Reinforced Concrete Backing Wall Retrofits. Table A5.1 gives approximate costs for materials and installation of the reinforced concrete backing wall retrofits. Labor and equipment requirements are also listed below. The difference in cost between epoxy grout anchored dowels and threaded rods with nuts and washers is negligible; thus, they are not given separate prices in the cost table. Costs given in the table are average values for construction in the United States in 1998.

Table A5.1. Reinforced Concrete Backing Wall Retrofit Cost Data

Retrofit Description	**Cost (Per Linear Foot of Wall)***			
Unbonded Reinforced Concrete Backing Wall	Material and Equipment	Labor	Overhead and Profit	Total
4” Backing Wall With #3@12”	$30	$52	$23	$105
4” Backing Wall With#3@6”	$37	$71	$31	$139
6” Backing Wall With #3@10”	$37	$57	$26	$120
6” Backing Wall With #3@6”	$42	$73	$32	$147
Bonded Reinforced Concrete Backing Wall				
4” Backing Wall With #3@12”	$38	$64	$29	$131
4” Backing Wall With #3@6”	$46	$82	$37	$165
6” Backing Wall With #3@10”	$46	$69	$33	$148
6” Backing Wall With #3@6”	$50	$84	$39	$173

* Cost estimates are based on a wall height of 12 feet.

Labor required:

- Rodmen to place reinforcing steel
- Carpenters for formwork
- Cement finishers
- Skilled workers to drill holes in concrete and install dowels
- Equipment operators for concrete pump, boom truck, generator and air compressor with sandblasting attachments

Equipment required:

- Concrete pump and 75-foot boom with truck
- Concrete vibrator
- Air compressor with attachments for sandblasting (needed for bonded backing walls only)
- Rotary hammer drill for drilling holes in concrete
- Miscellaneous hand and power tools

REINFORCED CONCRETE BACKING WALL RETROFIT FOR AIRBLAST PROTECTION OF UNREINFORCED CONCRETE MASONRY WALLS (Standard International Units)

A6.1. General Description. A 100 -or 150-millimeter-thick reinforced concrete backing wall is placed against the inside face of the CMU wall. The backing wall is reinforced with a single layer of reinforcement midway through its thickness. Equal vertical and horizontal bars are used with the vertical bars placed toward the inside of the wall relative to the horizontal bars. Attachment at the top and bottom of the new wall is achieved by drilling into existing slabs or beams and placing anchors that lap with the vertical wall reinforcement. The anchors can be either through-bolts or reinforcing bars epoxy-grouted into the existing structure. This retrofit method is very effective. It can also be used on walls that have windows, as described in A6.6. The concrete backing wall does add significant dead load to the structure, and its effect on the conventional static and seismic design must be checked.

A6.2. Bonded Versus Unbonded. The reinforced concrete retrofit can be designed as bonded or unbonded. For the unbonded option, no special preparation is done to the surface of the CMU wall before placing the backing wall. Without surface preparation, the quality of the bond between the CMU and the concrete backing will not be reliable and the walls must be considered as acting separately, with the interface between them acting as a slip plane. The backing wall adds its strength to that of the CMU with no enhancement from composite action. If the surface of the CMU wall is properly prepared before placement of the concrete, a strong reliable bond will develop at the interface and the two walls will act as a composite unit, giving substantial strength increase over the unbonded wall. Prepare the surface of the bonded wall according to the guidance given in CWGS-03305 for preparation of concrete surfaces to which concrete is to be bonded.

A6.3. Backing Wall Configurations. Four combinations of backing wall thickness and reinforcing ratio are presented for both the bonded and the unbonded backing wall options. A backing wall thickness of 100 millimeters is used with either a nominal 10-millimeter-diameter bar (10ϕ) at 305 millimeters, or 10ϕ at 150 millimeters; and a backing wall thickness of 150 millimeters is used with either 10ϕ at 250 millimeters or 10ϕ at 150 millimeters. Detailing options for the installation of the backing wall retrofits are presented in Figures A6.1 and A6.2. Figure A6.1 shows the through-bolting method for anchorage to the existing structure and Figure A6.2 shows the use of epoxy resin grouting for anchorage. Epoxy resin grouting can be used for anchorage when access for through-bolting is difficult or impractical.

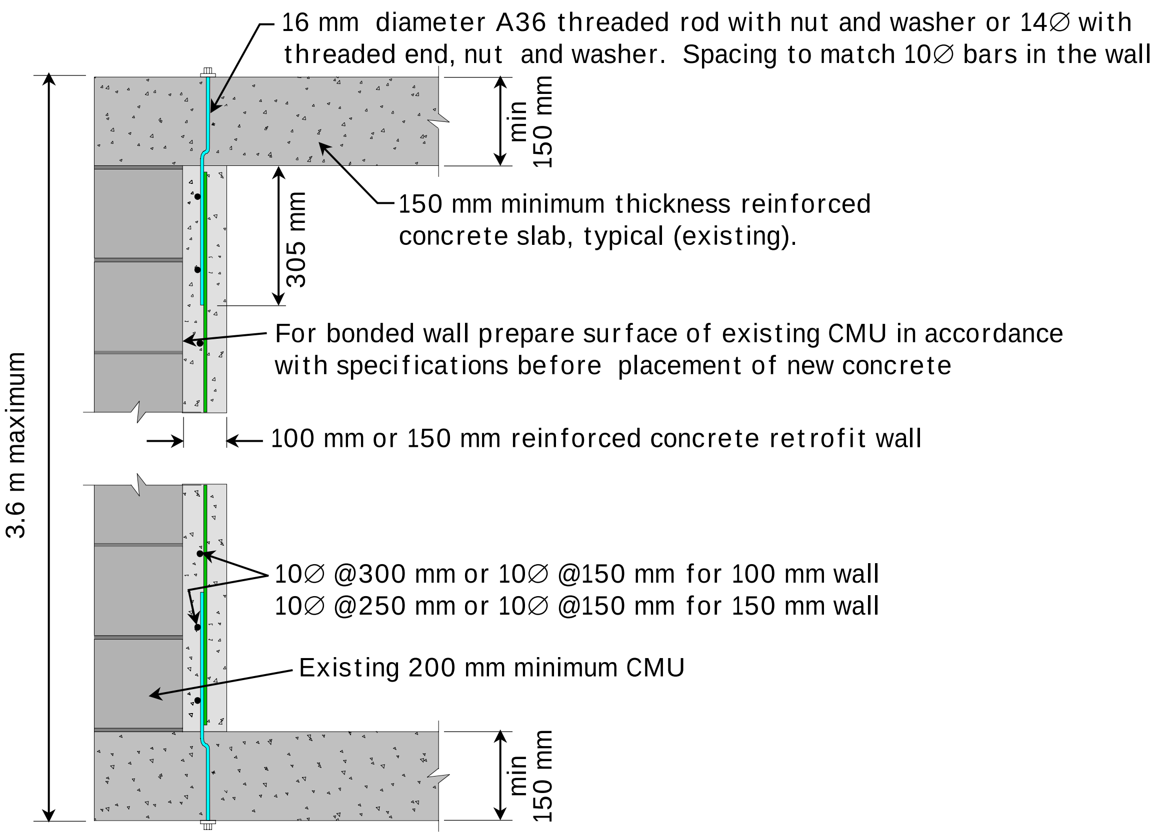

Figure A6.1. 100- to 150-Millimeter Backing Wall with Through-Bolt Anchorage

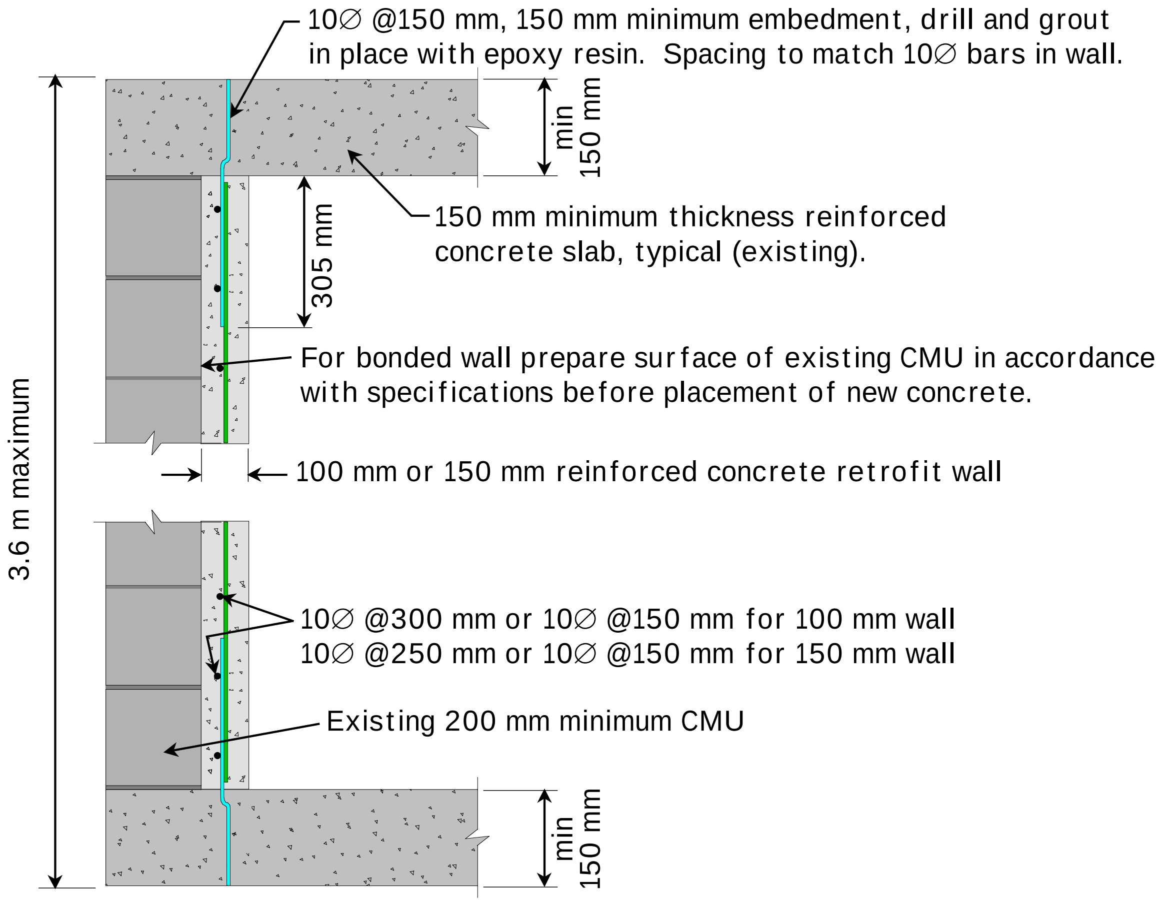

Figure A6.2. 100- to 150-Millimeter Backing Wall with Epoxy Resin Anchorage

A6.4. Material Properties. Material properties used in the development of these retrofits were a concrete compressive strength of f'_c = 27.6 megapascals and reinforcing steel meeting ASTM-A615/A615M-00 Grade 400. Epoxy-resin used for drilled and grouted reinforcing bar anchorage must meet ASTM-C881-90 Type IV and be of the appropriate grade and class for installation conditions.

A6.5. Retrofit Blast Load Capacities. Blast load capacities for each of the reinforced concrete backing wall retrofits, presented in terms of charge weight versus standoff distance, are given in Figures A6.3 and A6.4. Charge weight is the equivalent weight of TNT and the standoff distance is the distance from the center of the charge to the outside face of the wall. The data used to create the curves shown in these figures was generated using analytical methods in accordance with TM 5-855-1. All analysis was done using normal reflected airblast. The method used was verified by comparison with experimental results to give conservative estimates of the retrofit wall response to blast loading.

Unbonded Reinforced Concrete Backing Wall

Retrofit for 3.6 meters high unreinforced 200-millimeter CMU block wall
(Block wall simply supported at top and bottom)

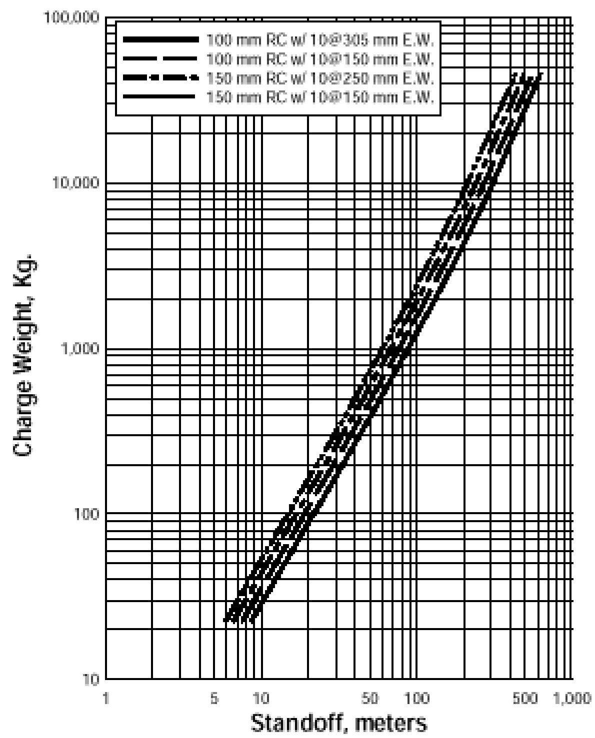

Figure A6.3. Charge Weight Versus Standoff for Unbonded Concrete Backing Wall Retrofit

Bonded Reinforced Concrete Backing Wall

Retrofit for 3.6 meters high unreinforced 200-millimeter CMU block wall
(Block wall simply supported at top and bottom)

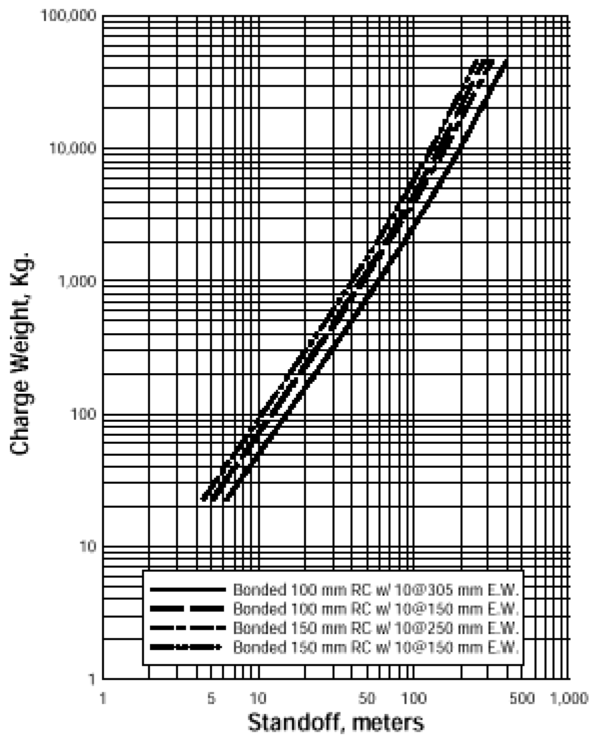

Figure A6.4. Charge Weight Versus Standoff for Bonded Concrete Backing Wall Retrofit

A6.6. Walls With Windows. A reinforced concrete backing wall retrofit can be applied to walls with windows in many cases. The presence of a window opening weakens a wall and this weakening effect must be accounted for in the retrofit design. After selection of the retrofit backing wall design from Figures A6.3 or A6.4, the following additional requirements must be satisfied to allow the backing wall to compensate for the weakening effects of a window opening:

(1) The width of the window opening must not exceed 80 percent of the vertical span of the retrofit wall.

(2) The concrete backing wall must be placed behind any CMU wall above and below the window as well as on both sides.

(3) Additional vertical reinforcing bars must be placed in the backing wall on each side of the opening. The amount of additional vertical reinforcing must equal or exceed the amount of vertical reinforcing interrupted by the opening, with half placed on each side. The additional bars should be distributed evenly in the backing wall close to the opening and over a wall width such that the reinforcing ratio in that width does not exceed 75

percent of the balanced strain reinforcing ratio (per ACI 318). The additional bars must extend full height of the wall and be anchored into the existing structure in the same manner as the other bars.

(4) If the width of wall between any two window openings is insufficient for placement of the additional reinforcing required in (3), these two windows and the space between must be considered as a single opening width in (1).

For windows wider than specified in (1) above, use of this procedure is not recommended and more detailed considerations beyond the scope of this ETL are appropriate. Application of these retrofit measures to a wall with windows presupposes that the windows are also upgraded to a similar airblast protection level.

A6.7. Cost Data for Reinforced Concrete Backing Wall Retrofits. Table A6.1 gives approximate costs for materials and installation of the reinforced concrete backing wall retrofits. Labor and equipment requirements are also listed below. The difference in cost between epoxy grout anchored dowels and threaded rods with nuts and washers is negligible; thus, they are not given separate prices in the cost table. Costs given in the table are average values for construction in the United States in 1998.

Table A6.1. Reinforced Concrete Backing Wall Retrofit Cost Data

Retrofit Description	**Cost (Per Linear Meter of Wall)***			
Unbonded Reinforced Concrete Backing Wall	Material and Equipment	Labor	Overhead and Profit	Total
100 mm backing wall w/10ϕ @ 305 mm	$99	$172	$76	$347
150 mm backing wall w/10ϕ @ 250 mm	$122	$234	$102	$458
150 mm backing wall w/10ϕ @ 250 mm	$122	$188	$86	$396
150 mm backing wall w/10ϕ @ 150 mm	$139	$241	$106	$486
Bonded Reinforced Concrete Backing Wall				
100 mm backing wall w/10 @ 305 mm	$125	$211	$96	$431
100 mm backing wall w/10 @ 150 mm	$152	$271	$122	$545
150 mm backing wall w/10 @ 250 mm	$152	$228	$109	$489
150 mm backing wall w/10 @ 150 mm	$165	$277	$129	$571

* Cost estimates are based on a wall height of 3.6 meters.

Labor required:

- Rodmen to place reinforcing steel
- Carpenters for formwork
- Cement finishers
- Skilled workers to drill holes in concrete and install dowels
- Equipment operators for concrete pump, boom truck, generator and air compressor with sandblasting attachments

Equipment required:

- Concrete pump and 22.7-meter boom with truck
- Concrete vibrator
- Air compressor with attachments for sand blasting (needed for bonded backing walls only)
- Rotary hammer drill for drilling holes in concrete
- Miscellaneous hand and power tools

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