

PRECAST CONCRETE OVAL ARCH STORAGE
MAGAZINE,

USACE STD. 421-80-05

OVERVIEW, DEPLOYMENT, AND CASE HISTORIES

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Abstract

The U.S. Army Corps of Engineers has developed an alternative design for the Army's Standard Earth Covered Ammunition Storage Magazine (ECM). The design combines the benefits of three-dimensional Finite Element Method (FEM) modeling with advanced, innovative manufacturing and installation techniques. The main feature of the new design is the use of precast concrete arch segments as an alternative to conventional pour-in-place concrete. The design utilizes *TechSpan™*, a precast concrete arch system manufactured by The Reinforced Earth Company. *TechSpan's* 3-hinge design is combined with the incorporation of backfill as an element of the FEM model. The optimized design model gives *TechSpan™* the inertia and flexibility to absorb explosive energy while remaining structurally intact. In addition, the new design satisfies DoD requirements for Lightning Protection by ensuring continuity of reinforcements throughout the structure. In addition to utilizing a precast concrete arch, the design includes variable alternative solutions for constructing the Magazine wing walls and protective walls. Mechanically Stabilized Earth (MSE) retaining walls are used for this application.

Deployment:

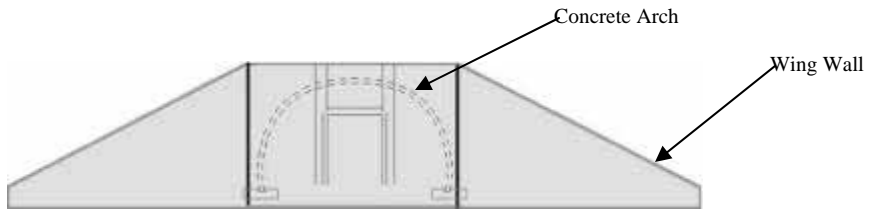
In 1996 the Corps' Engineering and Technical Support Center, Huntsville began a technical evaluation of RECo technologies, and in particular, the *TechSpan™* system. Their positive recommendation to the Army's Defense Ammunition Center (ADAC) launched a program to develop a new standard design using precast concrete components. The ADAC made its recommendations to the DoD Explosives Safety Board in support of the design concept. In September 1998 the design was approved by the DoD for deployment. The design is designated as USACE Std. 421-80-05, Magazine, Precast Concrete Earth Covered. The first installation of a *TechSpan* Arch Magazine occurred in May, 2001.

Case Histories:

To date, the new design has been constructed at six separate military installations. The Presentation will address government implementation procedures, variances in sizes and applications, and project-specific details of completed projects as well as future applications.

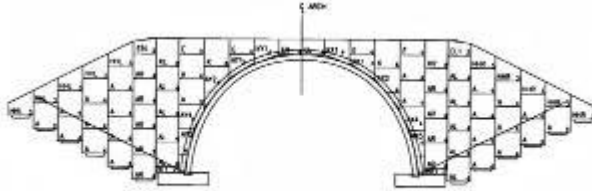
I. Overview of the Design

Two key components of conventional oval arch storage magazines, the arch and wing walls, are highly suited for construction with precast concrete technologies. The purpose of the new design is to offer Owners, Engineers, and Contractors a precast alternative to the cast in place method for constructing the arch and wing walls.



A Technical Paper presented by The Reinforced Earth Company (RECo) at the 28th DDESB Safety Seminar discussed the development of the design methodology and engineering software for the precast arch design. The paper, titled “Using 3-D Finite Element Method Modeling For Designing Prefabricated Concrete Protective/Containment Structures” concluded that a precast concrete arch storage magazine is a statically, dynamically, and economically efficient structure.

TechSpanTM is the name given to a precast concrete arch system designed and manufactured by The Reinforced Earth Company. Prior to being granted DDESB approval, TechSpan was employed almost exclusively for roadway infrastructure projects. The majority of these applications are large culverts and short-span bridges. The geometric similarities between a standard magazine and a typical TechSpan culvert are obvious. The new design succeeds in transforming the precast culvert-like design into an effective alternative for munitions storage magazines. Reinforced Earth Walls have been used as an alternative for magazine wing wall construction since the early 1980's.

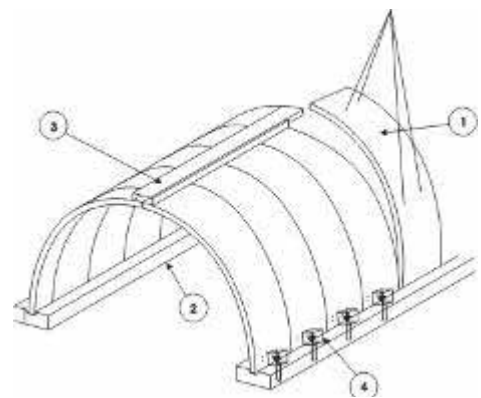


Typical TechSpan Culvert and Wing Walls

TechSpanTM Arch:

The TechSpan magazine arch is comprised of the following components:

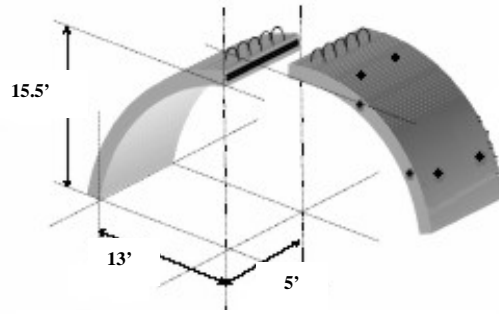
1. Quarter quasi-semicircular precast arch panels
2. Pour in place footings and grouting
3. Pour in place crown beam
4. Pour in place footing blocks



Precast Magazine Arch Components

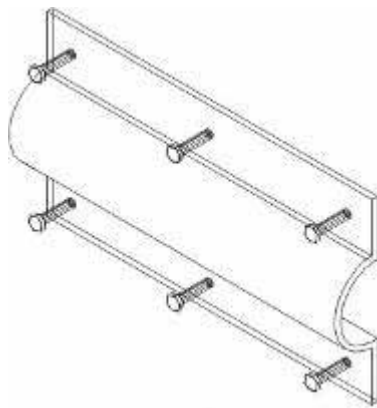
Precast Arch Panels

The standard precast arch panels are nominally sized 5-feet wide, 8-inches thick, and 23.7-feet long along the inside face. Each panel weighs approximately 12,200 pounds. Panels are cast to meet a minimum compressive strength of 4,000 psi in 28 days. Four lifting anchors are embedded along the back face for lifting and placing. Two lifting inserts are embedded along one side edge for handling during shipping and storing. A steel crown plate is embedded along the top edge to form the crown joint. The top edge of the panel and the crown plate are formed as “males” and “females”, interlocking with one another when assembled. Half-size precast panels are used to complete the arch tunnel at each end of the magazine. These panels are 2.5-feet wide and weigh approximately 6,100 pounds.

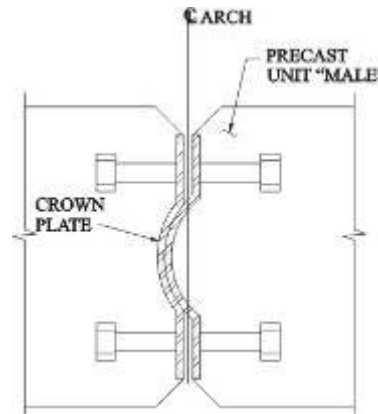


Standard Arch Panel Nominal Dimensions

A steel crown plate is embedded along the top edge to form the crown joint. The top edge of the panel and the crown plate are formed as “males” and “females”, interlocking with one another when assembled. Half-size precast panels are used to complete the arch tunnel at each end of the magazine. These panels are 2.5-feet wide and weigh approximately 6,100 pounds.



Typical Crown Plate (Female shown)



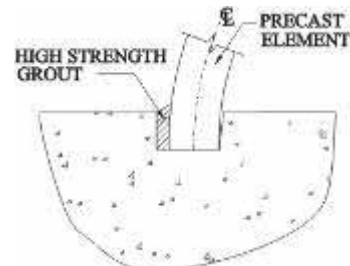
Arch Panel Joint at Crown

Pour-in-place Footings and Grouting

The pour in place strip footings are configured with keyways. The keyways define and secure the location of the arch and facilitate alignment during erection. Once the panels are placed and properly aligned, grout is poured along the keyway to secure the panel in place.



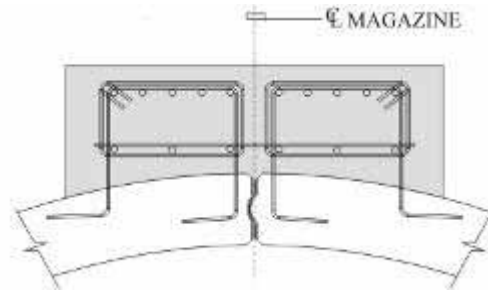
Pour-in-place Strip Footings With Keyway



Grouting along keyway

Pour-in-place Crown Beam

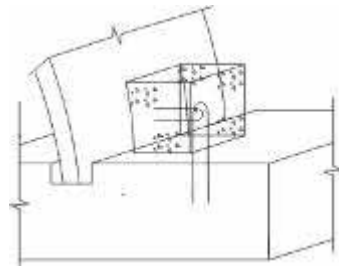
Each full-size arch panel is cast with six stirrups, protruding from the top of the outside surface, three stirrups for half-size panels. The stirrups facilitate a pour-in-place crown beam. The crown beam ties the individual panels together longitudinally while allowing for a degree of articulation along the crown hinge during backfilling and loading.



Pour-in-place Crown Beam

Pour-in-place Footing Blocks

Each precast panel is cast with a single stirrup protruding from the outside face. The stirrup serves to connect the panel with the footing for the purpose of electrical continuity or lightning protection. A 1-foot square concrete block is poured around the connection as a protective cover.

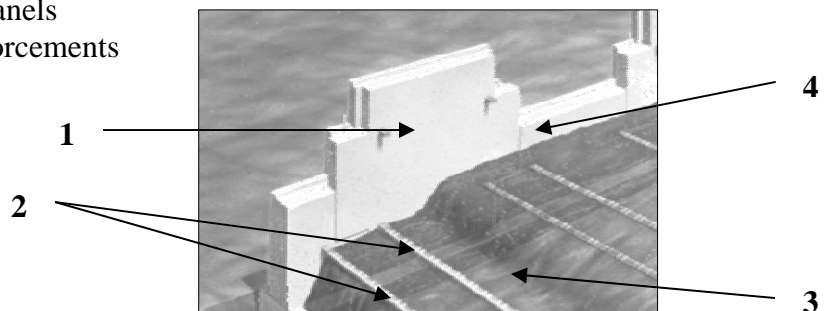


Footing Block Detail

Reinforced Earth[®] Walls:

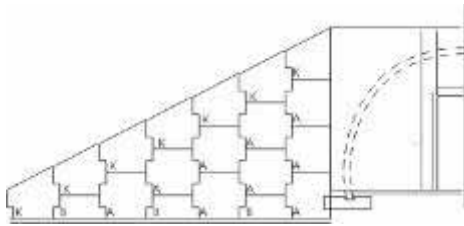
The Reinforced Earth wing walls are comprised of the following components:

1. Precast concrete facing panels
2. Linear metallic soil reinforcements
3. Granular backfill
4. Joint Materials

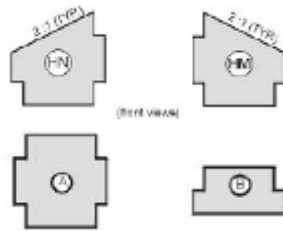


Precast Reinforced Concrete Facing Panels

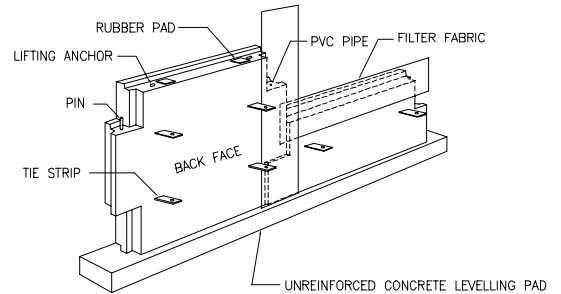
The Corps' standard design for modular wing walls depicts cruciform-shape precast facing panels. While alternative shapes may be used, the cruciform panel has been used successfully for magazine wing walls since the early 1980's. The precast facing panels vary in size as smaller panels are used along the bottom of the walls and larger panels are used along the top. Panels are cast to meet a minimum compressive strength of 4,000 psi at 28-days. Each panel is 5.5-inches thick weighing between 900 pounds and 2,400 pounds each. The panels are cast with a lap joint along all edges. The lap joints facilitate interlocking between adjacent panels when installed. Each panel is cast with two lifting anchors embedded along the top edge. Connection devices called Tie Strips are embedded and protrude from the back face of each panel. Depending on the size of the panel, between two and five tie strips are required for each panel. Tie strips serve to connect the panel to the soil reinforcements.



Typical Elevation of Reinforced Earth Wing Wall



Typical Reinforced Earth Facing Panels



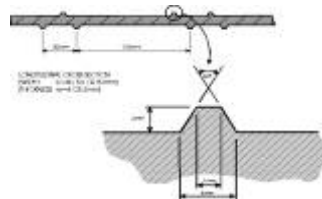
Typical Arrangement of Wing Wall Panels

Linear Metallic Soil Reinforcements

Linear metallic soil reinforcements, commonly known as reinforcing strips are connected to the back face of the precast panels by nuts and bolts. The reinforcing strips are embedded in alternating layers within compacted granular backfill. It is the friction that is created between the reinforcing strips and the backfill that gives the wall its stability. Reinforcing strips are made from hot rolled steel bars and are normally galvanized for corrosion protection. The strips are deformed with alternating ribs along the top and bottom surfaces. Reinforcing strips measure 50mm (2-inches) x 4mm (3/16-inch) thick with a bolt hole pre-punched at one end to facilitate a 3/4-inch nut, bolt, and washer connection. Reinforcing strips are shipped in bundles of between 50 and 100 pieces.



Soil Reinforcing Strips measure 50mm wide x 4mm thick



A ribbed surface enhances the pullout capacity of the soil reinforcements



Soil reinforcements are shipped To the jobsite in bundles

Granular Backfill

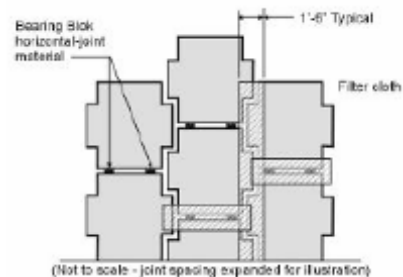
Granular backfill is placed in successive lifts and compacted within the limits of the Mechanically Stabilized Earth (MSE) backfill volume. The MSE volume extends from the back face of the facing panel to the free end of the linear metallic soil reinforcements. The granular backfill is a free-draining material reasonably free of organic materials. Limits for plasticity, soundness, and electrochemical characteristics are also included in the specifications for MSE retaining walls.

Select Backfill Requirements (AASHTO Specification - Reference 1)	Test Method (AASHTO)	Test Method (ASTM)
Geotechnical		
Particle size \leq 150 mm (6 in)	T 27	D 422
Amount passing the 0.075 mm (No. 200) sieve \leq 15%	T 27	D 422
Plasticity index \leq 6	T 90	D 4318
Angle of internal friction $\phi \geq 34^\circ$	T 236 *	D 3080
The material shall be essentially free of organic and other deleterious materials	None	D 2974
The material shall be essentially free of poor durability particles, and the magnesium sulfate soundness loss shall be less than 30% after four cycles	T 104	none
Electrochemical		
pH between 5 and 10	T 289-91 I	G51
Resistivity (at 100% saturation) $>$ 3000 ohm-cm	T 288-91 I	G57
Water soluble chloride content $<$ 100 ppm	T 291-91 I	D512
Water soluble sulfate content $<$ 200 ppm	T 290-91 I	D516

Backfill Specification for MSE Wing Walls

Joint Materials

Joint materials used with Reinforced Earth Walls comprise of Bearing Pads and Filter Fabric. Bearing pads are used along horizontal joints to space panels apart and to provide a joint that can absorb energy in compression. Filter cloth is used to cover horizontal and vertical joints between panels. The filter cloth retains fine particles of backfill that otherwise could migrate through the open joints and create unwanted voids in the MSE volume.



Wing Wall Panel Joint Materials

II. Key Features of the Design

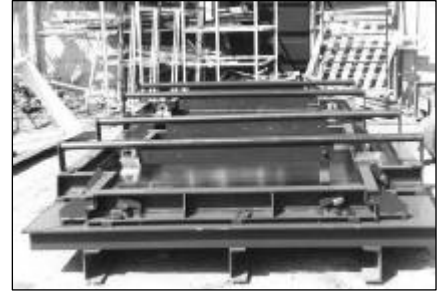
- The design includes provisions for lightning protection. Steel reinforcement and embedded items in the arch are interconnected for electrical continuity. Reinforcement bars in the TechSpan Arch panels are tied or welded together. The arches crown beam is not only designed to connect the arch panels longitudinally but also provides electrical continuity. Stirrups are used to connect the arch panels to the footings and floor slabs all of which are connected to conventional grounding rods.
- During inclement weather that prohibits earthworks and concreting in the field, precasting and manufacturing of the arch and wall components can continue uninterrupted. In addition, precast segmental structures are particularly well suited for construction in seismically active regions. Precast segmental structures provide the high degree of structural damping needed to absorb large energy releases associated with earthquakes.
- TechSpan Arch and Reinforced Earth Walls are much more flexible than rigid pour in place structures. Most of the stress normally applied to and “attracted” by buried rigid structures is transferred to the surrounding fill materials. Footing sizes are minimized and the need for pile-supported foundations is reduced.
- The precast design provides a higher quality of workmanship than the pour in place method. RECo has secured fixed precast formwork specific to the precast magazine dimensions. Form molds are regularly maintained by the company as part of its quality control programs. Before reaching the project site, all prefabricated components are inspected and certified to meet the project specifications. The need for onsite testing and inspection is reduced.
- Dismantling, salvage and remediation work is easier and more environmentally-friendly than the pour in place design. Precast panels can be removed and transported offsite without the need for destructive removal.

III. Fabrication and Construction



TechSpan Arch forms are fixed to the dimensions of the magazine

RECO furnishes the necessary precast formwork, either to a local precaster or to the Contractor if casting onsite. The formwork is fixed to the shape of the arch and wing wall panels required for the specific project.



Reinforced Earth Wall precasting forms



Precast panels are stripped from the forms daily and stored until sufficient concrete strength is reached

Precast panels are cast face down. Forms are lined with a smooth steel skin. A three-person crew can cast between two and four arch panels and ten or more wing wall panels in a single shift.

Typically while precasting is underway the Contractor is preparing the site. After the ground is cleared and graded, footings are formed and poured. The precast arch and wing wall panels, including soil reinforcements and joint materials are shipped to the jobsite in truckloads. Preferably, materials are offloaded and sorted in order of assembly.



The arch footings are formed and poured in place



3 arch panels comprise a truckload, while 20 to 30 wing wall panels comprise a truckload



Panels are normally stored onsite in order of placement

Erection of the precast arch panels is rapid. A four-person crew with the aid of a crane can erect an 80-foot long arch tube, 33 panels, in an eight-hour shift. After the arch panels are assembled and aligned they are grouted into the footing keyway.

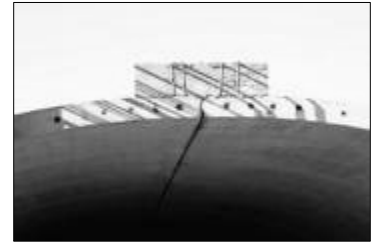


A standard 80-ft long magazine arch can be erected in one day



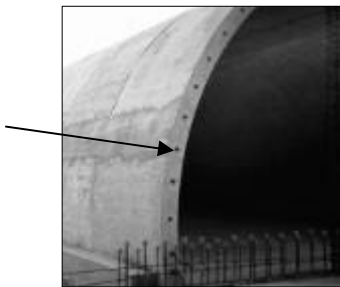
Completed TechSpan Arch

Next the crown beam is formed and poured in place. Floor slabs can be formed anytime following installation and grouting of the arch.

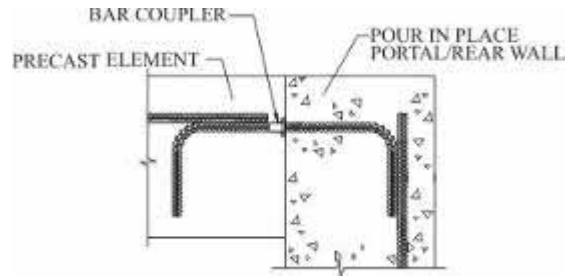


Poured in place crown beam

The Contractor is now ready to form and pour the portal wall and rear wall. The cast in place walls adjoin the precast arch with the rebar replacement inserts. For those panels that comprise the end units, a rebar coupler is cast into the outside edge. When joining the precast arch to the portal wall and rear wall a threaded rebar is attached and then embedded into the pour-in-place wall sections.



Rebar Couplers along edge of end



Dowel Bar Replacement Detail

Prefabricated modular forms or built-in-place forms with scaffolding is used to form the portal wall.



Built-in-place formwork



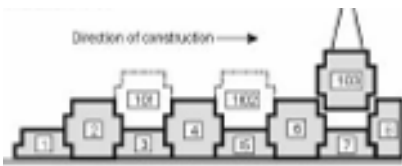
Prefabricated modular formwork



Completed Portal Wall

Waterproofing methods and materials are normally specified by the Owner or the Engineer. Waterproofing may consist of geomembranes, liquid-applied coatings, flashing, or a combination thereof.

Construction of the Reinforced Earth wing walls progresses with placement and compaction of the magazine backfill. A cast in place or precast leveling pad serves as a level foundation for the initial course of precast facing panels. The first course of panels is braced temporarily while alternating layers of granular backfill and soil reinforcements are installed. The successive lifts of panels are installed as the backfill reaches the top of the arch. Facing panels interlock by way of a lap joint formed along the edges of the panels.



Wing Wall panel construction sequence



Reinforcing Strips are bolted to the facing panels



Backfill is spread and compacted



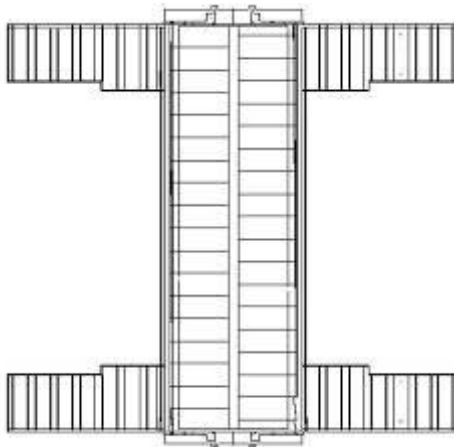
Erosion control blanket installed prior to final earth cover

Impermeable earth cover (clay), erosion control blankets, vegetation, or a combination thereof is applied as a cover to the granular backfill.

Typically the final construction sequence includes installation of ventilation, lighting, security, communications, and other appurtenances and fixtures as require.

Additional information and step-by-step installation instructions can be found in the Construction and Quality Control Manuals for TechSpan and Reinforced Earth Walls available from The Reinforced Earth Company.

IV. Case Histories



Special design for back-to-back portal walls

Edwards AFB, CA – N47408-00-D-8115

This project consists of a single igloo, 90-feet long. In early 2000 NAVFEC found that they had special needs for munitions storage at Edwards AFB. The existing steel arch magazine had collapsed and needed replacing. After discussing their needs with The Reinforced Earth Company (RECo) NAVFEC decided to use the precast design. In August, 2000 the NAVFEC issued a request for proposals to replace the magazine. In order to expedite the bidding process quickly, and without the need to hire an outside consultant, NAVFEC issued the standard drawings, site adapted by RECo, to the bidders. After the award,

RECo furnished the contractor with final, for-construction drawings, materials, and onsite assistance. The magazine was special in that a portal wall and blast door was constructed at both ends of the magazine. The contractor installed the 90-ft long arch in less than two days. Site adaptation was performed by RECo. General Contractor: Sergent Mechanical Systems, Oxnard, CA.

New Ammunition Supply Point (ASP), Fort Dix, NJ - DACA27-00-C-0067

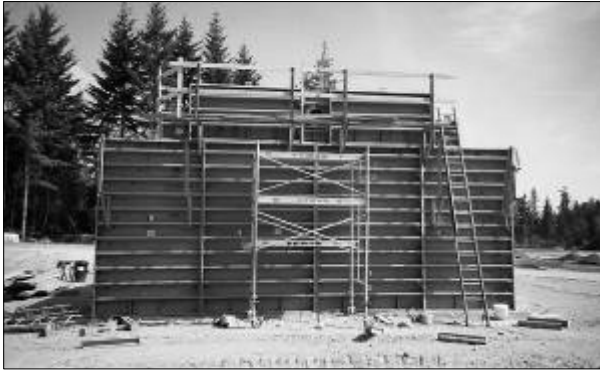


Built-in-place formwork slows construction of the end walls

This project consists of ten igloos, 80-feet long each. Following a 40-year effort to replace the cramped and crowded ASP that served the post since World War II, the new ASP opened in February 2003. The Corps' Louisville District coordinated the design and acted as Program Manager while the Philadelphia District managed the construction. The contract documents included drawings and specifications for both cast-in-place arch and wing walls as well as the precast alternative. Labeling the precast alternative as a "Contractor's Option", the contract bidders were encouraged to make careful

comparisons and evaluations of each of the two alternatives. In the end the successful low-bidder, Pyramid Enterprises, Columbus, NJ chose to use the precast alternative. While construction of the arches went smoothly and rapidly, constructing the portal walls proved more demanding. Pyramid chose to construct then deconstruct the portal wall formwork at each magazine, one at a time, rather than use prefabricated formwork. This process slowed production, although the project was delivered on time. A lesson learned that prefabricated formwork may be the most effective approach when constructing multiple magazines. Site adaptation was performed by Mason & Hangar Group, Lexington, KY. General Contractor: C. Pyramid Enterprises, Columbus, NJ.

Ammunition Supply Point (ASP) Expansion, Fort Lewis, WA, -DACA67-02-C-0203



Modular formwork speeds construction of the portal walls

This project consists of fourteen igloos, 80-feet long each, the largest project undertaken using precast arches thus far. Designed by the Corps' Seattle District, the contract documents originally included drawings and specifications for pour-in-place concrete only. During the early stages of the design phase the Corps commissioned a Value Engineering study to be undertaken by an independent Consultant, Olympic Associates, Seattle. The purpose of the VE study was to evaluate the potential for cost savings should the precast

alternative be included and then chosen for use by the successful Contractor. The VE study concluded that the precast alternative was practical and should be included as a "Contractor Option". The implementation process was accomplished by adding language to the specifications. Additional engineering was not required. Following the February 2002 bid opening, the successful contractor elected to use the precast alternative. RECo furnished the contractor with site-adapted drawings, materials, and onsite assistance for the project. In addition to using precast arches and wing walls, the contractor chose to use prefabricated formwork for the portal walls. This choice proved successful as the magazines were completed ahead of schedule allowing the magazines to open for storage before the completion of other major works on the project. The contractor received an Outstanding Performance Rating from the Corps for their work on the project. Site adaptation was performed by the Corps Seattle District. General Contractor: Pease Construction, Lakewood, WA.

Ammo Supply Point (ASP), Fort Hunter-Liggett, CA -GSA GS-09P-01-KYC-0028



This project currently consists of three new magazines 80-feet long each, replacing the existing units that were put into service in the 1950's. The project is managed by the Ft. Hunter-Liggett Department of Public Works (DPW). The DPW, through GSA funding is able to secure materials and construction simply by soliciting bids for the work as depicted on the standard drawings and

specifications, no deviations are necessary. The funding schedule allows the DPW to secure one magazine per calendar year. While this schedule would normally require recurring consultant and inspection fees, RECo provides construction oversight, material certifications, and onsite assistance throughout the duration of the project, incidental to supplying the precast materials. Site adaptation performed by The Reinforced Earth Company, Vienna, VA. General Contractor: J&P Construction, Santa Maria, CA.

Replace Joint Munitions Storage Complex, Buckley AFB, CO, CRWU 909731



This project is comprised of two side-by-side TechSpan igloos, 67.5-feet long each. Early into the project the contractor recognized the potential to reduce costs if the portal walls and rear walls were able to be constructed ahead of and absent of the precast arch. The contractor requested that RECO design an alternate detail for connecting the portal wall and rear wall to

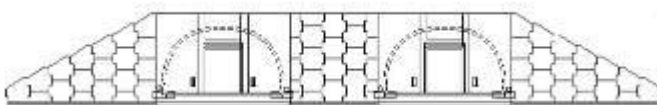
the precast arch. The alternate connection detail consists of a series of bolted angles installed along the connection joint. After being bolted in place, the angles are interconnected with steel cables and grounded for lightning protection. Site adaptation was performed by KPFF Consulting Engineers and VSLA Architects & Planners, both of Phoenix, AZ. General Contractor: Shauer Construction, Colorado Springs, CO.



Alternative solution for connecting end walls to the precast arch

Replace Munitions Storage Complex, Battle Creek ANG Base SOL MBMV9989082

This project consists of two side-by-side integral igloos 65-feet long each, connected by Reinforced Earth Walls. Site adaptation performed by URS Corporation, Grand Rapids, MI. General Contractor: L.D. Docsa, Kalamazoo, MI.



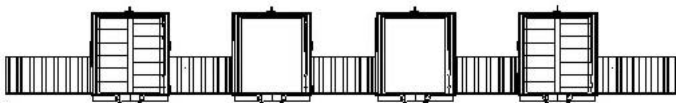
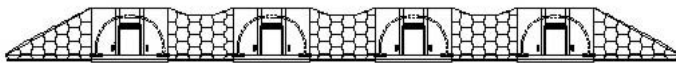
Integral Magazines connected with precast walls



NGIC Foreign Munitions Storage Facility, Aberdeen Proving Ground, MD

DACA31-02-C-0040

This project consists of four integral “cubicle” igloos 30-feet long each, connected by Reinforced Earth Walls. This is the first pure design-build project utilizing the precast arch design. Site adaptation performed by RECO. General Contractor: Baltimore Contractors, Inc., Baltimore, MD. Construction will begin in the Fall of 2004.



First use of precast arch “cubicles”

V. Specifying the Design

Owners and Consultants can specify the new design simply by incorporating the standard drawings and specifications into the contract bid documents. RECo will furnish pricing and quantities to the bidding contractors during the bid phase. Following the contract award, RECo will furnish professionally engineered site-adapted drawings to the successful contractor. The cost for engineering services performed by RECo are incidental to the cost of the precast materials.

If a project has already been fully designed or nearly completed using a cast-in-place design, and time precludes adding the Corps' standard, precast drawings then the engineer can amend the existing documents with "contractor option" language. The following are examples of language used successfully by the Corps to call attention to the alternative design:

“THE CONTRACTOR MAY PROPOSE AN ALTERNATE DESIGN USING PRECAST ARCHES AND WING WALLS AS DEPICTED IN USACE STD. 421-80-05, MAGAZINE, PRECAST CONCRETE EARTH COVERED STANDARD DESIGN. ANY DESIGN CHANGES REQUIRED TO “SITE ADAPT” THE ALTERNATE DESIGN TO THIS PROJECT WILL BE THE RESPONSIBILITY OF THE CONTRACTOR AND MUST BE APPROVED BY THE CONTRACTING OFFICER”

Or

“A SIMILAR DESIGN USING PRECAST ARCHES AND WING WALLS MAY BE PROPOSED BY THE CONTRACTOR IF THE DESIGN HAS BEEN PREVIOUSLY APPROVED BY THE CORPS OF ENGINEERS.”

Or

THE SET OF DRAWINGS INCLUDED IS SUFFICIENT FOR USE ON THIS PROJECT. THESE ACCURATELY DEPICT THE NEEDS OF THE GOVERNMENT AND ARE APPROVED FOR USE BY THE DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD. OTHER PRIVATE SYSTEMS ALSO EXIST WHICH ARE ALSO APPROVED BY THE EXPLOSIVES SAFETY BOARD, ONE EXAMPLE BEING BY THE REINFORCED EARTH COMPANY, MAGAZINE, PRECAST CONCRETE EARTH COVERED STANDARD DESIGN 421-80-05. AT THE CONTRACTOR'S OPTION ANY OF THESE SYSTEMS MAY BE USED PROVIDED ALL OF THE FOLLOWING REQUIREMENTS ARE SATISFIED:”

VI. Future Enhancements to the Design

RECo is developing several enhancements to the design:

- Following the successful installation of the igloos at Buckley AFB, RECo intends to develop a standard detail for an alternative connection between the precast arch panels and the cast-in-place portal wall and rear wall. In some cases, it is more cost effective to allow the contractor to construct the two end walls prior to placing the arch.



RECo is developing alternative solutions to speed construction of the end walls

- RECo is developing alternative solutions for the wing walls and rear walls using modular full-height precast panels. This development will speed erection of these components.



Full-height precast wing wall panels speed construction

- RECo intends to investigate the pros and cons of offering TechSpan Arch and Reinforced Earth Wall components under a GSA schedule.

VII. Conclusion

As the needs change for secure munitions storage facilities so can the design for precast arch igloos. A key aspect of the TechSpan Arch system is its adaptability to different loading criteria and function. The design theory using Finite Element Modeling determines the optimum shape and reinforcement needed for each particular application. What was once considered proprietary technology, modular formwork and casting beds are gaining popularity with mainstream manufacturers of concrete products. This advancement allows engineers to develop solutions with precast concrete construction in mind from the start of the project. Applications for precast tunnel technologies are being evaluated in fields including nuclear materials and buried protective tunnels. While not all owners, consultants, and contractors prefer the precast method over the cast-in-place method, it is the inherent benefit of choice that makes the new design a success.



Modular formwork for precast arches produces a wide variety of shapes and sizes