This paper describes the design and some construction aspects of three 55,000 barrel underground fuel storage tanks using precast, prestressed, segmental wall panels. The walls are post-tensioned circumferentially with the stressing tendons installed in ducts which are subsequently grouted.

The use of concrete for the construction of storage tanks, particularly underground tanks, has several attractive features, including durability, good resistance to lateral forces, and protection from fire and other external hazards. The use of precast prestressed concrete has the added advantages of better quality control and lower on-site labor cost than cast-in-place concrete, particularly at a remote site such as Adak (see map, Fig. 1).

Western Division, Naval Facilities Engineering Command (WESTNAV-FACENGCOM), is responsible for the design and construction of shore
Describes the design-construction features of three 55,000 barrel underground fuel storage tanks using precast prestressed concrete components which were manufactured and shipped some 2500 miles (4000 km) to the project.

Fig. 1. Location of underground fuel storage tanks in Adak, Alaska.

facilities for the Navy throughout the west coast of the United States, including Alaska. It also acts as a design-construction agent for other Department of Defense (DOD) activities, including those for the Defense Logistics Agency (DLA). In early 1981 DLA requested WESTNAVFACENGCOM to provide an additional 110,000 barrels of JP-5 storage.

Tryck, Nyman & Hayes of Anchorage, Alaska, was selected by WESTNAVFACENGCOM and awarded an engineering contract to provide the project design. Both the consultants and WESTNAVFACENGCOM concluded that the available budget would not allow construction of the required 110,000 barrels of underground storage, using conventional cast-in-place concrete tanks.

The decision facing DLA/WESTNAVFACENGCOM was to use a conventional DOD design for underground fuel storage tanks and provide approxi-
mately half the required storage volume or find a more economical alternative that provided safe, low maintenance, secure fuel storage, and still provide the full storage requirement.

Tryck, Nyman & Hayes performed an engineering study and recommended a design using precast prestressed concrete panels that would be manufactured "off-island," and barged to Adak. At the project site the precast components would be erected and post-tensioned. An economic analysis showed that the precast design was more economical than other building systems, allowing the construction of two 55,000 barrel tanks within budget.

DLA is pleased with the current project and has decided to take advantage of the cost effectiveness of this design and construct a third 55,000 barrel tank.

Project Location

The project is located on Adak Island, Alaska, midway along the Aleutian Chain in one of the most remote areas of the world (see Fig. 1). Adak is approximately 1150 miles (1840 km) southwest of Anchorage and 2500 miles (4000 km) from Seattle, Washington. There are no civilian communities on the island.

The existing underground tanks (in service for over 22 years) have proven satisfactory from the standpoint of operations and maintenance. Another advantage of buried fuel tanks at Adak is reduced maintenance due to fewer exterior surfaces exposed to the harsh climate. Further, because the fuel is maintained at a relatively cool and stable temperature, there is less fuel loss from evaporation and less accumulation of water from condensation.

The facilities are located on a treeless hillside with 20 to 30 percent natural slopes. Ground elevations vary from about 150 to 200 ft (46 to 61 m) above sea level. The area is vegetated by grass and other small plants. Surface expressions consist of hummocks extending about 20 in. (510 mm) above the existing ground surface.

Geology

Alaska is the most seismically active of all the American states. The Aleutian Island Arc, of which the Adak Island region is a part, is a convergent plate boundary between the Pacific and North American plates. Along this boundary, the majority of earthquakes register between 5.0 and 5.8 on the Richter scale, although many quakes have registered well over 6.2 and a few have been as high as 8.3.

Surface soils at the site consist of 1 to 2 ft (0.3 to 0.6 m) of peat or very fibrous organic silt overlying approximately 2.5 to 5.5 ft (0.8 to 1.7 m) of organic silt, silty peat or silt. The silty layer is probably volcanic in origin and contains abundant fibrous organics. A discontinuous layer of glacial till underlies the organic and fine grain surface soils. The till is composed of subrounded gravel, cobbles and occasional boulders in a matrix of fine to course grain soil. Beneath the surface soils lies a weathered basaltic tuff as shallow as 4 ft (1.2 m) to greater than 14 ft (4.3 m).

Tank Walls

Figs. 2 and 3 show a floor plan and elevation, respectively, of a typical underground fuel storage tank. A typical wall section is shown in Fig. 4.

The tank wall consists of 20 ft (6.1 m) high, 8 in. (203 mm) thick, prestressed segmental panels set in a keyway on a cast-in-place ring footing. Each tank has forty-four conventional panels and four buttress panels.

Each panel is 20 ft 6 in. (6.2 m) long by 8 ft 9 in. (2.7 m) wide and 8 in. (203 mm) thick except the buttress panels which are thickened to accommodate the post-tensioning tendon anchors and higher stress concentrations. Adjacent panels are tied together by a 12 in. (305
Fig. 2. Floor plan of typical fuel storage tank.

Fig. 3. Elevation of typical fuel storage tank.
I. CONC. FILL

CAST-IN-PLACE CONCRETE

SEALANT

CONT. NITRILE BEARING PAD

8" PRECAST WALL PANEL

U-BARS TIED TO PRESTRESSING STRANDS T & B

2" POST-TENSIONING DUCT (TYP.) 14 EQUALLY SPACED

STUD (TYP.)

1/4" STEEL LINER

1/4" ANGLE & SEALANT

2 1/2" P.T. DUCT (TYP.)

WATERSTOP

6" CONC. FLOOR

1/4" STEEL LINER

NON-SHRINK GROUT

FOUNTATION RING

SHIMS

UNREINF. FOOTING

UNREINF. CONT. CONC. PAD

1/2" PVC

SAND

1/2" STD. PIPE

6 TURN SPIRAL BAR IN PANEL (TYP.)

Fig. 4. Typical section of fuel storage tank.
mm) wide cast-in-place pilaster.

The tank walls are designed to resist stress combinations resulting from fluid pressure (outward), soil pressure (inward), and seismic forces. The most severe loading condition occurs under seismic loading when the tank is empty.

Analysis of lateral earth loads included two static and one dynamic condition. The equivalent fluid method was used for the dynamic loading and one of the static loadings. A uniform load similar to sheeting and bracing was used for the second static load. This configuration was considered due to the deflection characteristics of the tank wall.

Unlike a typical retaining wall whose maximum deflection is at the top, the maximum deflection for the tank wall is near the center with virtually no deflections at the top and bottom. In all cases, a 300 psf (1464 kgf/m²) surcharge was applied to allow for construction and maintenance vehicle loads.

Vertical bending stresses are resisted by thirty ½-in. (12.7 mm) diameter, 270 ksi (1863 MPa), prestressing strands per panel. Hoop stresses are resisted by horizontal post-tensioning. A 200 psi (1.4 MPa) residual stress is maintained under all conditions except for vertical bending of the wall under seismic loads. A small tensile stress is considered acceptable under seismic loading due to its short duration. Under all load combinations, stresses are within the allowable limits specified in Section 18 of ACI 318-83.

Seismic forces were computed in accordance with Seismic Design for Buildings¹ and Nuclear Reactors and Earthquakes.² The analysis assumes that if the height of the tank is 1.5 times greater than the radius, then a portion of the contents acts as a constrained fluid and should be considered part of the tank mass. For the Adak tank geometry, there is no constrained fluid.

The contents were, therefore, analyzed dynamically, considering only impulsive and convective forces. The total effective mass used in computing the impulsive and convective forces is less than the mass of the tank contents. The lateral coefficient for the convective mass is less than that for determining base acceleration using rigid body theory. Shear friction is used to transfer lateral forces to the footings, while uplift is resisted by tensile reinforcement in the pilasters.

The walls were also analyzed for a thermal gradient of 40°F (22°C). With the prestress provided, a 40°F (22°C) gradient produces thermal cracks of 0.0005 in. (0.013 mm) in width. Crack widths of 0.004 in. (0.10 mm) or less were considered acceptable.³ For underground tanks, a 40°F (22°C) thermal gradient will probably occur only during the maintenance and cleaning operations. Once thermal equilibrium has been restored, prestressing in the tank walls will automatically close any thermal cracks.

Wall thickness was governed by placement requirements for reinforcement and post-tensioning ducts. A thinner wall was theoretically possible, but clearances would have required small post-tensioning ducts and an increase in the number of tendons. Forces in the walls of the tank did not justify tapering them.

Wall tendons consisting of six ½-in. (12.7 mm) diameter strands [270 ksi (1863 MPa)] are installed in 2-in. (51 mm) steel ducts extending 180 deg around the circumference of the tank. Jacking was phased 90 deg in order to maintain uniform prestress. The number of jacking buttresses is a function of jacking length for the selected strand size and tank radius.

Post-tensioning ducts are placed so that prestress forces mirror the corresponding hoop stresses. Prestressing is assumed to increase linearly from 200 psi (1.4 MPa) at the top of the tank wall, to the point of maximum hoop stress and then remains constant from there to the base.
Manufacture and Erection of Precast Components

The precast concrete components were manufactured by Concrete Technology Corporation in Tacoma, Washington. Under these controlled factory conditions, it was possible to insure high quality products with precise dimensional tolerances. Such accuracy was needed to successfully carry out the segmental operations.

Table 1 provides the details of the number and principal dimensions of the precast components produced per tank. The precast components were loaded on a barge (see Fig. 5) in Tacoma and shipped 2500 miles (4000 km) to Adak. Figs. 6 and 7 show typical wall and buttress panels, respectively, in storage at the precasting yard.

Panel erection proceeded very rapidly, requiring about 2 to 2 1/2 days per tank. Erection time includes unloading the barge, loading the truck (two panels per load), driving to the construction site, unloading the truck and setting, plumbing and bracing the panels on the ring footing. Figs. 8 and 9 show progressive phases of the panel erection.

Foundation and Floor Slab

The foundation consists of spread footings supporting columns and a ring foundation supporting the tank walls and a tributary area of the roof. The entire foundation is cast-in-place concrete (see Fig. 9). The ring footing is reinforced conventionally to resist bearing loads and post-tensioned longitudinally to resist hoop stresses resulting from the transfer of wall base shears. A keyway is cast in the ring footing to accommodate the wall panels.

Note that the keyway remains ungrouted until post-tensioning is completed to allow for radial shortening without developing base moments. The keyways are detailed with one side higher than the other to prevent accidental over filling with grout and permit application of a sealant in a groove along the inside of the wall. PVC drains, having a 1/8-in. (12.7 mm) diameter, are placed in the keyway to provide drainage during construction.

The tank floor is a 6-in. (152 mm) thick cast-in-place concrete slab-on-grade. It is conical with a 2.5 percent grade to provide positive drainage to the center sump. Where they abut, the top of the slab is held flush with the tops of the ring and spread footings. A PVC waterstop and sealant are provided between all construction joints and an unreinforced concrete strip footing is placed beneath all joints to mitigate differential settlement.

On-site labor costs were minimized by limiting the number of joints and using heavy wire mesh reinforcement in place of individual bars. The slab could not be cast until the ring foundation had been post-tensioned.

All conventionally reinforced concrete used for fuel containment has been designed by the working stress method to control cracking.

Roof

The roof system consists of prestressed hollow-core panels supported by precast prestressed concrete roof
Fig. 5. Precast elements loaded on barge in Tacoma, Washington, for 2500-mile (4000 km) voyage to Adak.

Fig. 6. Typical wall panels.

Fig. 7. Typical buttress panels.
Fig. 8. Wall panels 90 percent erected.

Fig. 9. Ring footing with wall panels 50 percent erected.

Fig. 10. Tank with 90 percent of roof panels set.
beams which are in turn supported by steel tube columns on spread footings (see Fig. 10). A structural topping slab is placed over the hollow-core panels (see Fig. 11). The use of prestressed roof beams eliminates the need for shoring.

The roof is designed to support the weight of 3 ft (0.91 m) of soil (390 psf (1900 kgf/m²)), snow [30 psf (150 kgf/m²)], and an AASHTO H15-44 truck; full snow and truck loads were not assumed to act concurrently. Snow loads governed the column design, while truck loads controlled the design of roof beams and panels. Capacity to resist the relatively high shears encountered in the roof panels at the supports is provided by grouting the panel cores to a point where the panels alone are sufficient.

The roof is designed to be continuous across the beams, with the roof panels resisting positive moment and the topping slab resisting negative moment. The use of a topping slab also provides for placement of transverse temperature reinforcement. Horizontal shear transfer between the panels and the topping slab required a broom finish on the panels. Particular attention was given to soil loads which result in high, long-term stresses and accompanying loss of prestress.

The infill strip between roof panels (over the beams) acts compositely with the precast roof beams. The beams were analyzed for construction loads without the infill and for service loads with the infill. Between the column and the beam are nitrile butadieneline bearing pads. Thermal movement in two directions is accommodated by strain in the pads and oversize bolt holes. Sliding of the roof under lateral loading is prevented by reinforcement projecting from the wall panels into recesses in the roof.

Precast concrete pump pits are located on the roof, at the center of each tank. Positive drainage is provided from the center of the roof towards the perimeter by varying the column heights. The structural topping slab also provides a waterproof surface.

**Fuel Leakage Containment for Detection System**

Primary fuel containment is provided by a \( \frac{1}{4} \) in. (6 mm) thick steel liner plate, which also protects against contamination of fuel from contact with the concrete. Should the steel liner develop a leak, secondary containment is provided by a reinforced chlorinated polyethylene alloy membrane (RCPM) which extends under the tank and up the
sides to the roof. Except at the base of the tank, the membrane is installed against the tank walls.

Damage to the membrane from backfilling is prevented by a 1 in. (25 mm) layer of rigid insulation placed between the membrane and the walls; a construction fabric is layered between the backfill and the membrane. The RCPM also covers the top of the tank and is lapped up the sides of the pump pit.

The use of prestressing in the walls has the advantage of theoretically providing an uncracked section, thus providing a third fluid tight barrier. For the Adak tanks this was not considered. Prestressing was only for structural purposes. If prestressing had been implemented for containment purposes, the tank floor would have required post-tensioning.

A 6 in. (152 mm) corrugated steel pipe between the membrane and the tank, near the base, collects any leakage. To reduce the effort required to locate leaks, inspection pipes isolate the tank into quadrants. Any fuel leaking through the steel bottom liner will flow by gravity along the sloping (2.5 percent) bottom until it is collected in shallow channels cast in the slab. The channels segregate the bottom into five areas, thereby facilitating the location of leaks in the bottom lining. Fuel collected in the channels and perimeter drains is directed to pipes discharging into a manhole for visual inspection. From this point the fluids are diverted to an oil/water separator.

**Design Details**

Special attention to detail is required to ensure that the conditions assumed during design are achieved in the field. Allowing wall movement during post-tensioning was a primary concern in maintaining the assumed design condition. By allowing the wall to move independently of the ring footing, undesirable stresses due to differential shortening during prestressing were avoided. An oversize keyway and greased steel shims under the wall panels permit wall movement.

Movement at the pilaster is complicated by the presence of reinforcement tying the ring footing to the pilaster. To accommodate movement, a blockout was formed at the base of the pilaster and a corrugated metal sleeve placed in the footing. This detail permits the reinforcement to deflect without overstressing the bar or the concrete. After the tank and the wall are post-tensioned the keyway, blockout, and sleeves are grouted. The ring footing was cast on a layer of sand over a non-reinforced concrete mud slab to insure movement.

To facilitate assembly, the wall panels were cast integrally with the liner plate. The liner is held in place with ¼ in. (6.3 mm) diameter studs. The panels can be designed to act compositely or noncompositely with the liner. If the designer chooses to use a composite panel, consideration should be given to the possible need of removing (replacing) the liner in the future.

Noncomposite panels were used in the Adak tanks. When using noncomposite panels the design should provide for stress relief at the wall/liner interface, to prevent undesirable shrinkage stresses and possible damage to the liner due to shearing of the studs.

**Instrumentation**

Strain gauges have been installed in the ring footing, in two regular wall panels located at 90 deg. to one another, and in one buttress panel. The gauges are oriented vertically and horizontally, depending on their locations, and are read by a digital recording device. They are monitored while testing the tank with water (without backfill), backfilling the tank (without water), and during filling of the tank with fuel. The gauges
will also be monitored at predetermined intervals following construction.

The authors anticipate publishing the results of that program once the data becomes available and has been analyzed.

Costs

The bidding for this project was extremely competitive. Over 300 sets of plans were distributed to contractors, subcontractors, and suppliers. Altogether, 18 bids were received. The low bid was $7,693,000.

Work at Adak is extremely expensive due to weather conditions, travel time, shipping, camp costs, and overtime pay. In general, construction costs at Adak are three times greater than costs in the Seattle area for similar work.

Concluding Remarks

Construction of the underground fuel tanks began in March 1984 and the project is scheduled for completion in October 1985. This time span includes a 101-day winter shutdown from December to April.

The use of precast prestressed concrete is an economical and functional method for constructing underground fuel storage structures. Local labor, material, and transportation costs, including tank size, are factors which affect the economic viability of precast systems. Precast prestressed concrete has the advantage of better quality control and lower on site labor cost than cast-in-place concrete.

The design-construction experiences gained from this project have been valuable. The prospects of additional precast prestressed concrete tanks being built in Alaska or other remote areas appear promising.

Credits

Owner: United States Navy.
Designer: Tryck, Nyman & Hayes, Anchorage, Alaska.
Precast Concrete Manufacturer: Concrete Technology Corporation, Tacoma, Washington.

REFERENCES


Discussion of this paper is invited. Please send your comments to PCI Headquarters by January 1, 1986.