OUR CLIENT’S COMMENTS

“This has been an extremely low-cost dock for us, first in construction costs as well as in maintenance costs.”
- Warrenton Fiber Company

“PND has proven to be a dedicated team partner and a true steward of the environment. I believe that as word spreads, more environmental projects will see the benefits of the OPEN CELL SHEET PILE™ WIB for containing wastes in place as an alternative to risky excavation, transportation, and disposal efforts. I know they will have a good partner in PND on these projects.”
- AMEC Foster Wheeler

“The City of Nome now has three OPEN CELL bulkheads in its port system. These structures are exposed to the open ocean environment where waves can reach 14 feet and sea ice can be 5 feet thick! After 10 years of such exposure, the OPEN CELL bulkheads are performing well.”
- City of Nome

“PND was able to provide us with a unique solution for our new South Harbor that was both economical and effortless to construct. Thanks to PND and their creative design, the Port is ready to serve our region’s growth for the next 50 years.”
- America’s Central Port

“Cheniere is very pleased with the engineering effort provided to us by PND Engineers during the development of our LNG terminal at Sabine Pass. The OPEN CELL bulkhead helped us solve a challenging shoreline slope stability issue providing a very economical solution.”
- Cheniere Energy

“The OPEN CELL dock design provides an uncomplicated structure which saved considerable cost over the alternative tied-back cantilever wall system. The OPEN CELL dock is being used to load-out very heavy loads, 600-ton bridge segments, using a 545-ton carrier for the new East Span of Oakland Bay Bridge Skyway in California.”
- Kiewit/FCI/Manson (KFM)

“The structure has required no significant maintenance - even with our heavy use. Our pile driving crew had no previous OPEN CELL [construction] experience - construction was completed successfully without significant problems.”
- KFM

THE TECHNOLOGY

OPEN CELL™ technology is used for docks, heavy-load marine terminals, bridge abutments, and cofferdams. It is a cellular flat sheet pile structure in which each cell’s sheet piles are driven into the shape of a U when viewed from above. The system functions as a horizontally tied membrane relying solely on the vertical flat sheet pile anchor wall to restrain a curved flat sheet pile arch face. The bulkhead becomes a series of U-shaped vertical member structures that does not need toe embedment for stability.

First developed in the early 1980s, the OPEN CELL system has received recognition from national and international engineering institutions such as ASCE and PIANC. The system has been recognized by the US Army Corps of Engineers for specialty use in confining contaminated soils. Our projects utilizing OPEN CELL technology have won more than 30 awards.

NOVA AWARD

The OPEN CELL system was presented a NOVA award in 1988. The NOVA award, which has been referred to as the “Nobel Prize” for construction, is awarded annually by the Construction Innovation Forum, Inc. (www.cif.org) to revolutionary solutions, processes, or products that improve the quality, efficiency, and cost effectiveness of construction.

PATENTS

PND has spent years testing, observing, and refining the OPEN CELL system and holds all related information to be proprietary. The OPEN CELL system is patented, holding U.S. Patent No. 6,715,964 B2, No. 7,488,140 B2, and No. 8,950,981 B2.
ADVENTAGES

> **High Loads**
High vertical capacity for localized loads such as cranes or uniform loads from freight can be easily supported. Uniform loads of 10,000 pounds per square foot and concentrated loads of 6,000 tons have been accommodated. In addition, load capacity can be increased by simply extending tailwalls even after construction has been completed, if project requirements dictate.

> **Deep Draft**
The increasing draft of vessels throughout the world has required increased dredge depths. Vertical faces of over 95 feet have been constructed while still maintaining the highest load capacities.

> **Dense Soils & Shallow Bedrock**
A minimal required toe embedment of 10 feet below potential scour depth is a common design tip elevation. This is significantly less than other structure types.

> **Weak Soils**
OPEN CELL structures accommodate soft clay and silts, allowing high capacities while still maintaining local and global stability.

> **Coastal Erosion Protection**
The OPEN CELL system is scour insensitive because it derives its strength horizontally from its vertical tailwall and not through passive toe resistance.

> **Ice Conditions**
The OPEN CELL system has effectively proven itself against the ice prevalent throughout Arctic and subarctic regions.

> **Seismic Protection**
OPEN CELL structures have survived hundreds of seismic events throughout the Pacific Rim. Not only have they survived, but they have remained in service with no damage noted.

PND is proud to present the OPEN CELL SHEET PILE system – a patented mechanically stabilized wall with a multitude of purposes and applications. The OPEN CELL system is more versatile and provides greater cost savings than comparable alternatives. PND continually works to improve this technology for all in-situ conditions and uses. We are confident that you will agree with us that the OPEN CELL system is a time-tested system that allows you to build a vertical wall higher, with larger load capacity, and in more challenging soil conditions than any other retaining wall structure.

Jim Campbell, P.E.
President

APPLICATIONS

> Retaining walls
> Module loading piers (MOF and TOF)
> Deep-draft berths
> Cofferdams and heavy shoring
> Contaminated soils containment and disposal
> Cruise ship terminals
> Soil erosion protection
> High capacity bridge abutments
> Offshore man-made islands
> Man-made reefs and levees
> Tsunami safe haven berms, islands, and platforms
The OPEN CELL system utilizes a flat-web sheet pile and welded or extruded connectors. The simplicity of the design and durability of the materials allow PND to adapt the OPEN CELL system to many uses and conditions.

On average, the OPEN CELL wall is a lower-cost option to typical wall types, including z-sheet pile walls, and combi-walls. The overall cost per foot remains competitive in structures, particularly those over 30 feet tall, due to the way the OPEN CELL structures are designed.
Clients

OPEN CELL structures built to date total 231 as of 2017. The system has been utilized by public and private entities throughout the United States and internationally. Below is a partial list of our clients:

- ExxonMobil
- ConocoPhillips
- City of Nome
- BP plc
- Iberia Parish
- American President Lines (APL)
- Petersburg Borough
- Chevron Corporation
- Cheniere Energy, Inc.
- America’s Central Port
- Horizon Lines
- City and Borough of Juneau
- Minnesota Power
- Matson
- Sasol Limited
- Haliburton Company
- Iraqi Navy
- U.S. Army Corps of Engineers
- Foss Maritime
- U.S. Navy

Contractors

OPEN CELL structure construction is standardized by the use of driving templates and industry-standard equipment. Provided the contractor has an established means and methods procedure, the system can be installed by any skilled construction team. Professional contractors with experience constructing OPEN CELL SHEET PILE structures include, but are not limited to the following:

- Cajun Deep Foundations • Ruskin Construction LLC • Kiewit Construction Co.
- Manson Construction • Pacific Pile & Marine, L.P. • Lash Corporation • Kelly-Ryan, Inc.
- Boh Bros. • Berry Bros. • Swalling Construction Co. • Traylor Bros. • JF Brennan Co.
- Orion Marine Constructors • Alaska Interstate Construction • Advanced American Co.
- Richard Goettle, Inc. • M.R. Pittman Group • CJ Mahan • BoMac
HEAVY LOADS

High load capacity for localized loads such as cranes or uniform loads from freight can be easily supported. Uniform loads of 10,000 pounds per square foot and concentrated module loads of 6,000 tons have been accommodated. In addition, load capacity can be increased by simply extending tailwalls even after construction has been completed, if project requirements dictate.

> Module Offload Facility (Alaska)
Underlying soft marine sediments were encountered at the site designated for prefabricated oil field modules. An OPEN CELL bulkhead provided the dock structure to support transfer of 2,500-ton modules onto barges.

> Module Offload Facility (Russia)
This 665-foot-long OPEN CELL pier was constructed with 240-foot-long fendered berthing face. The pier is used for the live offload of 3,000-tonne pre-assembled, self-propelled modules. PND provided finite element modeling for this unique facility, which is able to withstand over 100KN during module offload. Design considerations included: variable seismic criteria, soil properties, ice loading, and a 8.5-foot scour allowance.

Madison Harbor Barge Terminal | St. Louis, IL
On the shore of the Mississippi River, the Madison Harbor bulkhead consists of a 400-foot-long, 65-foot-tall bulkhead with a paved surface to be used as a bulk cargo transport on and off river barges using both mobile and fixed cranes. PND also designed a pile-supported fendering system and mooring structures that include three closed cells and four mooring dolphins.
**Baffinland Iron Mines Bulkhead - Nunavut, Canada**

Milne Inlet ore dock supports development of an open-pit iron ore mine. The new dock and loading facilities allow the loading of ore carriers during the open-water season at Milne Port and are expected to ship 3.5 million tonnes per annum of high-grade iron ore. PND designed the marine structures to withstand the expected heavy ice loads that occur yearly at Milne Port. In addition to the main dock structures, PND designed an onshore mooring point.

**Deep Draft**

The increasing draft of vessels throughout the world has required increased dredge depths. Vertical faces of over 70 feet have been constructed while still maintaining the highest load capacities.

**Container Terminal**

The dock structure is a 330-foot-long pile-supported pier supporting a modern 100-foot gauge container crane. The site has a deep layer of very soft soils requiring piles to be socketed into bedrock. PND designed the structure to accommodate large container-handling forklifts with 100-ton axle loads. The lateral resistance system utilizes an innovative sheet pile system to drag lateral loads into the fill behind the dock structure. Dolphin structures extend the dock to more than 600 feet.
**Dense Soils & Shallow Bedrock**

Zero to minimal required embedment of the face sheets allow construction directly on bedrock. Often face sheet embedment is limited to the potential scour depth. This advantage allows OPEN CELL structures to potentially be constructed without the costs related to pre-dredging or pre-drilling.

**Kloosterboer Marine Terminal Bulkhead - Unalaska, AK**

Designed as a 100-year facility in a highly active seismic area, the terminal provides a dramatic advance in seafood trans-loading and cold storage technology for Dutch Harbor, the largest seafood producing port in the US. The OPEN CELL system was determined to be 50% less expensive than alternatives. The dock, which features 96-foot-long sheet piles, provides 46 feet of vessel draft and a high-capacity freight dock, and created over 3 acres of usable uplands in the mountainous area.

**Owensboro Riverport General Cargo Dock - Owensboro, KY**

PND provided planning and design services for a new OPEN CELL general cargo dock on the Ohio River for the Owensboro Riverport Authority of Kentucky. Services for this port development project included geotechnical review, bid support, and fabrication inspection. The new general cargo dock is 212 feet long, with four mooring cells and an upland operating area. PND designed the dock for use with mobile cranes, bulk cargo storage, and heavy truck traffic.
Weak Soils

OPEN CELL structures have proven to be an excellent solution to stabilize fill placement over weak underlying soils. The system works like a mechanically stabilized earth (MSE) wall to confine and strengthen a soil mass. This provides local and global stability. If settlement occurs behind an OPEN CELL structure, the material will settle evenly preventing the types of failures seen in tied-back and combi-wall systems.

PND designed an OPEN CELL SHEET PILE bulkhead system with an adjoining floating pier for the USACE. The project was constructed for the Iraqi Navy at the Umm Qasr Naval Base. The new facility, the only one of its kind in the area, was designed to retain up to 45 feet of fill over soft underlying silt and clay. The bulkhead utilized both land- and marine-based construction.

Sabine Pass LNG Terminal - Cameron Parish, LA

PND provided design for this 1,500-foot OPEN CELL bulkhead at the Sabine Pass LNG Terminal. The bulkhead was designed so that it could be dredged or experience scour to elevation -45 feet, creating a wall height of 55 feet. The OPEN CELL bulkhead system was chosen for this site to deal with local soft clays, clearance issues to an adjacent pipeline rack, and for the significantly lower cost over shoreline revetment.

Petro-Chemical Plant - Lake Charles, LA

This bulkhead provides flood protection and assists with the owner’s land reclamation project. The 19-foot-tall wall is more than 2,000 feet long and was constructed through layers of weak organic soils, soft to stiff clay, and dense sand.

Umm Qasr Seawall - Umm Qasr, Iraq

PND designed an OPEN CELL SHEET PILE bulkhead system with an adjoining floating pier for the USACE. The project was constructed for the Iraqi Navy at the Umm Qasr Naval Base. The new facility, the only one of its kind in the area, was designed to retain up to 45 feet of fill over soft underlying silt and clay. The bulkhead utilized both land- and marine-based construction.
**Coastal Erosion Protection**

Due to its resilience in a variety of soil conditions, OPEN CELL technology may be utilized to support eroding slopes. In the marine environment the system is scour insensitive as it derives its strength horizontally from its vertical tailwall not through passive toe resistance. Outside the marine environment, major slope stability is another of the OPEN CELL system’s versatile uses.

Chevron Wall - Nikiski, Alaska

Fuel spills on upland property began leaking into Cook Inlet, AK, which is subject to severe wave and ice conditions. An OPEN CELL SHEET PILE structure was driven into an underlying clay layer with the top of the wall above high-tide wave action. An oil-collection system was installed behind the erosion-control bulkhead to capture migrating contaminants.

Owensboro Riverwalk - Owensboro, KY

When the City of Owensboro, Kentucky, began the redevelopment of its downtown waterfront on the Ohio River, two objectives were desired: stabilize a chronically sloughing bluff and create more park area.

The City Engineer reassessed the situation and allowed value-engineered alternative design bids from contractors. One of the bidders, Richard Goettle, Inc., used PND’s OPEN CELL system as a substitute earth-retention system, offering nearly $13 million in cost savings and reducing the amount of steel by 30%, as well as saving six to eight months of wall construction time.
Nome Port Breakwater Bulkheads - Nome, Alaska
PND has designed five separate waterfront structures around City of Nome property. Three of these are dock facilities, each approximately 200 feet long. These OPEN CELL structures are designed to withstand and be overrun by 4-foot-thick sea ice floes (insert) and resist 16-foot waves. The most recent, the middle of the three structures above, was completed in 2015. The other bulkheads date back more than twenty years.

Northstar Offshore Island - Prudhoe Bay, Alaska
This project incorporated a 360-foot-long OPEN CELL bulkhead at the south end of the original Northstar Island (insert). The dock provides deep-water access to the island while still providing ice resistance and scour protection. More than ten years after the first OPEN CELL bulkhead was installed, the owner chose to expand the southeast corner of the island, connecting the existing structure with the new bulkhead. The dock allows for direct offload of 3,500-ton modules and provides protection against severe ice, wave, and wind conditions. The project included long-term erosion protection; a high-capacity module barge dock designed for 4,500-ton sea-lift module offload; seawater intake system and cofferdam; offshore dredging; armor rock erosion protection; and an emergency vehicle egress ramp.

Ice Conditions
The OPEN CELL system has effectively proven itself against the ice prevalent throughout Arctic and subarctic regions.
SEISMIC STABILITY

Many of our OPEN CELL projects are located in the highly seismic Pacific Rim area. Since construction of the first OPEN CELL structure in Alaska in the early 1980s, there have been more than thirty large-magnitude earthquakes in Alaska alone. PND has constructed approximately 230 OPEN CELL structures in high-seismic areas during this time, and none of them have experienced any seismic failure or damage.

STRUCTURAL STABILITY

Rigorous structural analysis is performed on every structure we design and can include multiple methods involving both classic analysis and numerical methods.

OPEN CELL SYSTEM VS. INDUSTRY STANDARD

It is not uncommon to see or read about catastrophic failures of industry-standard bulkhead designs due to overloading ground settlement, corrosion, and seismic events. At right is the typical failure mode of a combi-wall bulkhead in Seward, Alaska. The failure occurred after a large earthquake, which caused extensive damage and required significant restoration to the waterfront.

Below is an OPEN CELL bulkhead supporting a waterfront hotel in Seward that has been subjected to equivalent seismic forces. This structure and other similar OPEN CELL bulkheads in Seward have experienced no failures or damage due to seismic activity.

▲ Designed by others: failure of a z-sheet combi-wall bulkhead

▲ American President Lines Dock - Dutch Harbor, AK

Built to support the expanding Bering Sea fishing industry, this 350-foot-long OPEN CELL bulkhead was constructed to support heavy-load operations from the fishing industry as well as heavy cargo. The proposed facility provided container crane access to all holds on the largest APL ships and about 6 acres of new, and much needed, container storage space.
Vertical Confined Disposal Facilities

Conventional Confined Disposal Facilities (CDF) are typically constructed using an earthen or rock dike, but these structures are porous and permeable. Flow through the OPEN CELL bulkhead decreases to a point where a watertight barrier is formed, thus preventing containment transport. A VCDF, employing OPEN CELL technology, will require less space for dike construction and can therefore have a larger dredged material capacity for the same areal footprint when compared to conventional CDFs using conventional dikes.

The OPEN CELL VCDF:

- Reduces or eliminates contaminant migration under the containment structure.
- Is constructible in poor soil conditions and deeper water.
- Provides a vertical face and the ability to dredge directly in front of the containment wall.
- Eliminates seepage through the containment structure.
- Able to encapsulate existing structures.

(Photo at right: Tampa, Florida).

Alternative Containment Method Review by USACE

The OPEN CELL system has been reviewed by the USACE to determine its acceptability as a Vertical Confined Disposal Facility (VCDF). The USACE Environmental Laboratory at the Engineer Research and Development Center in Vicksburg, Mississippi, concluded in its final report that the OPEN CELL system, “...can be effective for controlling environmental risk for containment of dredge material.”

The USACE report is available at www.pndengineers.com.

Alameda Point OPEN CELL Waste Isolation Bulkhead, near Oakland, CA

The bulkhead encapsulated contaminated soils, preventing them from leeching into San Francisco Bay. The project – which utilized the OPEN CELL system design – won the 2014 Chief of Naval Operations (CNO) Environmental Restoration Award.
PERMANENT CANAL CLOSURES AND PUMPS (PCCP) PROJECT COFFERDAMS

Permanent Canal Closures and Pumps (PCCP) is the keystone project that closes the Hurricane Risk Reduction System around the City of New Orleans. PCCP Constructors (A Joint Venture between Kiewit, Traylor Brothers, and M.R. Pittman) selected PND Engineers to develop the OPEN CELL SHEET PILE system for pump station cofferdams and permanent pump intake retaining walls.

The OPEN CELL system proved to be well suited for these challenging soil conditions. The OPEN CELL cofferdam design provided a free field of construction for the pump station since no internal bracing was required to support the cofferdam walls – all the wall loading was supported by the tailwalls. The PCCP pump station cofferdams are among the largest cofferdams ever constructed on the U.S. Gulf Coast.

The OPEN CELL SHEET PILE system retains 48 vertical feet of soil plus 20 vertical feet of differential water pressure. The bottom of the cofferdams was approximately 50 feet below sea level. The plan area of the cofferdam varied up to 160 feet wide by 250 feet long.

The design of the OPEN CELL SHEET PILE system was thoroughly reviewed, vetted, and authorized for construction by the USACE and third-party reviewers. The system saved the Design-Builder tens of millions of dollars on construction and provided a significant schedule advantage by not needing to construct the pump stations around internal bracing within the cofferdam.

OPEN CELL LEVEES

The OPEN CELL system is an innovative technology for rehabilitating and upgrading levees.
**Bridge Abutments**

Bridge abutments utilizing OPEN CELL technology are resistant to scour and are able to support heavy loads. Additionally, OPEN CELL bridge abutments may be constructed very quickly.

**Kuparuk Low Water Crossing - North Slope, AK**

With an overall length of 700 feet, this causeway bridge over a breach in a previously earth-filled ocean causeway is supported by two in-water conical pile-supported piers and features abutments protected by OPEN CELL SHEET PILE bulkheads. The breach is designed for up to 38-foot scour below existing seabed, and the design ice load on the piers is 500 kips.

**Endicott Causeway - Prudhoe Bay, AK**

High current flows and ice created potential scour depths in excess of 40 feet through the causeway breach. OPEN CELL technology was used to protect the abutments for this critical transportation link.

**Cornelius Pass Bridge - Burlington, OR**

The creek crossing was bridged with a combination of OPEN CELL pile abutments and a recycled bridge section, which came from a nearby abandoned line. The OPEN CELL abutments were necessary to keep fill slopes out of the creek and within the right-of-way.

**‘C’ Street Bridge at Ship Creek - Anchorage, AK**

This 136-foot-long bridge over the tidally influenced Ship Creek is located on soft marine sediments. OPEN CELL bulkhead abutments were used to provide a stable erosion-protected surface for a cast-in-place footing for the box girder bridge.
INSTALLATION METHODS FOR THE OPEN CELL SYSTEM

Construction of the OPEN CELL system is typically performed from a barge or from shore. Land-based is more common than marine-based construction and often the most cost effective. Utilization of the OPEN CELL system’s simple design allows a contractor to gain efficiency and shortens the overall duration of construction. We have broken up the installation methods of the OPEN CELL system into five steps: site preparation; set pile driving template; drive wye piles; drive sheet piles; and compact backfill and finalize deck face.

STEP 1: SITE PREPARATION
The first step in OPEN CELL structure installation is site preparation. This includes preparing a crane pad for land-based construction, or assembling a barge if construction is marine-based.

STEP 2: SET PILE DRIVING TEMPLATE
The cells are formed using a pile template to guide the flat sheet piles into place. Templates typically consist of two steel platforms, matching the shape of the arc and the straight tailwall.

STEP 3: DRIVE WYE PILES
Construction usually begins at a wye pile driven at an end cell. A surveyor locates the position of the wye pile and it is partially driven with adjacent sheet piles in both the tailwall and structure face.
**Step 4: Drive Sheet Piles**

Flat sheet piles are threaded into an adjacent pile interlock, similar to z-sheet piles. Each pile is driven to stable embedment, supported by the driving template. Installation involves a vibratory hammer to advance the sheet pile into position. Care is taken to maintain location and plumbness and to not advance a single sheet pile more than 5 feet ahead of the adjacent sheet pile.

**Step 5: Finishing and Appurtenances**

> Fill height differential between two adjacent cells must be kept within 5 feet to avoid bending of the tailwalls.
> The fill below the water level is consolidated using vibracompaction. Fill above the water level is roller compacted. Lastly, the dockside edge is finished with deck fixtures such as fenders, bollards, and surfacing.
FENDERS & APPURTENANCES

After an OPEN CELL structure is constructed and backfilled, the top is finished with either rock surfacing or pavement of the client’s choice. Various types of edge finishing can be employed to obtain a linear face on which to moor and operate. Continuous or intermittent steel or concrete beams have been utilized. In some cases structures have been designed to accommodate concrete panel facades. In addition to finishing, there are many different types of fender and bollard systems that may be used. PND’s engineers determine the mooring systems based on the design criteria of the structure and the intended uses.
PND can provide immediate support to our clients to identify if an OPEN CELL bulkhead alternative will provide value and cost savings to their project. We offer our services to develop concept-level drawings and cost estimates at a level we call ‘white papers’. With an understanding of your project goals and basic site information, such as local geotechnical conditions, we can produce drawings and estimates in a matter of days. With this information our clients can determine if the project is feasible or more cost effective than other alternatives.

The process of developing a white paper and seeing it through to construction and final completion of a project is very exciting. The Bermuda South Basin Land Reclamation project is one such project. Located at Sandy’s Parish in Bermuda, the new 1,345-foot-long bulkhead will form two of the four sides of the new 9-acre reclamation area in the South Basin. PND initially performed a value engineering analysis for the project’s contractor, Cashman Dredging and Marine Contracting, from Quincy, MA. The original proposed bulkhead type was a combi-wall system. Based on the value engineering analysis, PND determined that it was neither a practical nor cost-effective way to create this large a reclamation area. After an analysis of the total area and the owner’s intended use of the bulkhead, the OPEN CELL system was determined to provide a substantial cost savings and a full 50% reduction in the quantity of steel as compared with the original bulkhead design.

The nine reclaimed acres was initially used as a staging area and village for the 2017 America’s Cup sailing race. Since the races were completed in summer 2017, the bulkhead will be utilized by the owner as additional waterfront property to benefit the densely populated island community.
Providing Comprehensive Civil/Structural Services Since 1979

PND is a civil/structural engineering firm specializing in civil infrastructure, ports and harbors, coastal engineering, Arctic engineering, geotechnical, and construction engineering for more than 35 years. Visit us online at www.pndengineers.com.