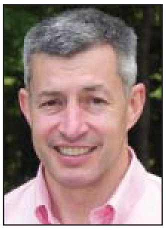
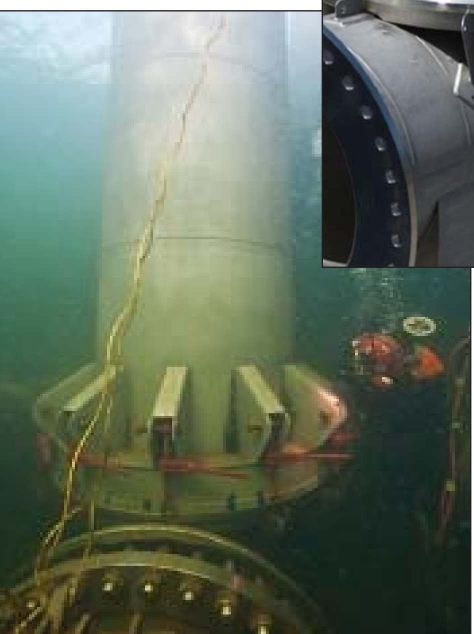
Tech Talk

PATRICK GRANDELLI AND JON HOLLAND



Grandelli Holland



PHOTOS BY MARK GAMBA

The Lake Oswego Interceptor Sewer's submerged, buoyant stainless-steel access points provide entry points to the pipeline without affecting boat navigation, and the installation of removable access caissons allows cleaning and inspection equipment to be inserted into for infrequently required maintenance.

Snake in a Lake—An Innovative Pipeline Design

With innovative modeling tools, high-performance materials, and original thinking, a first-of-its-kind pipeline project was recently completed that will protect the water quality of Oregon's Oswego Lake through seasonal changes in water temperature and in the event of an earthquake. The Lake Oswego Interceptor Sewer (LOIS) project was recently completed for the city of Lake Oswego. The project was undertaken to replace a 50-year-old corroded, undersized, and seismically vulnerable concrete cylinder sewer pipe under the lake with a larger, flexible, high-density polyethylene (HDPE) pipeline. LOIS is the first known buoyant gravity sewer in the world and was designed by a team led by Brown and Caldwell. The culmination of 10 years of careful planning, design, and construction was completed on schedule in May 2011 and under budget at a final total cost of $95 million. The project includes 17,000 feet of new HDPE pipeline, the majority of which has an outside diameter of 42 inches.

For nearly 50 years, the city of Lake Oswego relied on the original system, constructed of 24- to 36-inch-diameter bell-and-spigot concrete cylinder pipe supported on piles every 32 feet. However, overflows of untreated sewage to the lake during major rain storms, deterioration from corrosion, and seismic vulnerability to even a modest earthquake prompted the city to begin planning for the replacement project that began in 2002. The design team identified and evaluated a variety of alternatives to address these deficiencies, including rehabilitation of the existing pipeline and its supports, replacement using a buoyant system to hold the pipe at the correct underwater elevation, replacement of pile supports, tunneling under or around the lake, and replacement by pumping around the lake. Although the latter was recognized as a more conventional approach, it was ultimately rejected because of the costs and other challenges associated with siting, building, and maintaining six pumping stations and constructing nearly double the overall length of pipe.

UNIQUE CHALLENGES DRIVE INNOVATION

There was no shortage of issues to overcome for the successful completion of this difficult in-lake replacement project. These challenges included the following:

- Very deep, soft sediments (up to 200 feet) overlying bedrock required costly long, large-diameter, drilled and socketed piles or long ground anchors to ensure reliable capacity.
- Lake drawdown was not allowed by the management of the privately owned lake, so careful sequencing of multiple activities was required to meet the tight schedule.
- Limited access to the residential area with quiet, narrow streets required the purchase and demolition of two homes to provide additional access to the lake, dividing between two areas the noise and disruption of bringing heavy construction equipment, pipe, piles, and ground anchors to the lake.
- The nearly horizontal slope required tight placement tolerances of all pipe supports to prevent low spots in the finished pipeline profile.
- A wide range of lake temperature from 42 to 77°F at pipeline depth required special measures to accommodate significant thermal expansion and contraction of the pipeline.
- Lake drawdowns of up to 28 feet for future dredging and potential dam repair as well as the LOIS "lake down" phase of the project required special considerations and features.
- Prohibition by the lake owners of new above-surface access points required the development of new submerged access points and access caissons.
- Expense, visibility, permitting, and public acceptance issues required a 100-year plus design life.

To overcome these challenges, a buoyant pipeline system was developed for much of the project where lake depth beneath the pipeline grade was adequate. Pile supports were required in the shallower or buried reaches to support the pipeline should lake sediments liquefy during a seismic event. A thorough evaluation of steel, concrete, and plastic pipe materials led to HDPE as the prime candidate for the new in-lake pipeline.

HDPE is noted for its toughness, corrosion resistance, and leak-free joints. However, it is also very flexible compared with other pipeline materials. With only 7 feet of fall over nearly 2 miles, the new system can accommodate very little variation in grade without resulting in low spots where material might accumulate. With no existing track record anywhere for a buoyant gravity sewer with tight grade control, some fundamental questions had to be answered for the design team, the city council, and the public to confidently support moving forward with the new concept: Where has this been done before? Will it work? Will it last? Can we maintain it?

PHOTOS BY MARK GAMBA

This westward view of Oswego Lake (top) shows construction on the interceptor sewer project during the 24-foot drawdown phase during which pipe-bending operations (left) achieved the pipeline's sinusoidal shape with the use of internodal cables.

Makai Ocean Engineering, a firm specializing in subsea HDPE pipelines, was selected to model and analyze the HDPE pipe and advise on its configuration and constructability. The proposed system was analyzed with state-of-the-art modeling tools, allowing engineers to realistically simulate the pipeline's response to changes in temperature, seismic events, and future lake drawdowns. Makai's analysis showed that the dramatic new concept would behave rather undramatically: The buoyant pipeline, anchored every 25 feet and with built-in thermal expansion loops, allowed grade to be controlled to a tolerance of plus or minus a half inch. The flexibility was critical to ensuring the pipe design could accommodate stresses from earthquakes, expansion and contraction from temperature changes, and lake drawdown events. A turnbuckle could be installed on each tether to precisely adjust the grade of the pipeline, with a key consideration being that the slope of the system is tightly controlled so that operation and maintenance will be kept to a minimum. Armed with these findings, the design team and Joel Komarek, Oswego Lake's LOIS project director, used a variety of forums to describe for ratepayers and the city council the benefits and manageable risk of the proposed buoyant system. Evidence that this system was the lowest-cost option and that its key components were well-tested in other applications helped stakeholders make their final decision.

BENT OUT OF SHAPE

A manageable but inconvenient property of HDPE is its high coefficient of thermal expansion. The wide seasonal temperature variation in the lake causes the main reach of the system, more than 9,000 feet, to grow and shrink by approximately 14 feet from the midpoint of the temperature range. As shown in Figure 1, the pipe would bow or bend laterally to accommodate this extra length and violate the tight grade tolerances needed.

To address this design challenge, a sinusoidal "S-shape" concept was devised to allow the pipeline to expand and contract without significant lateral, and corresponding vertical, displacement. The pipeline would be permanently held in a horizontal sinusoid, like a long serpent. This design takes advantage of the series of arcs along the pipe that act like springs, absorbing motion and thermal expansion. As shown in

FIGURE 1 Lateral deflection caused by expansion of straight, unrestrained HDPE causes excessive vertical grade change, even with long tethers

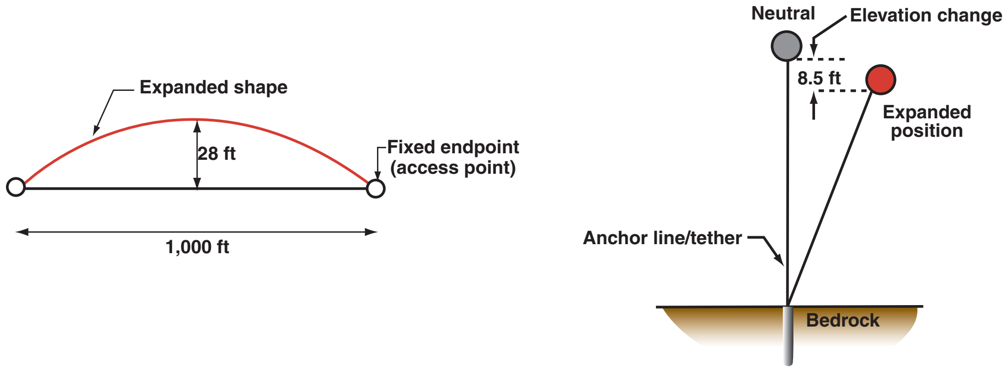


Image courtesy of Brown and Caldwell

HDPE—high-density polyethylene

FIGURE 2 Sine wave alignment limits lateral deflection and controls vertical grade, even with short tethers

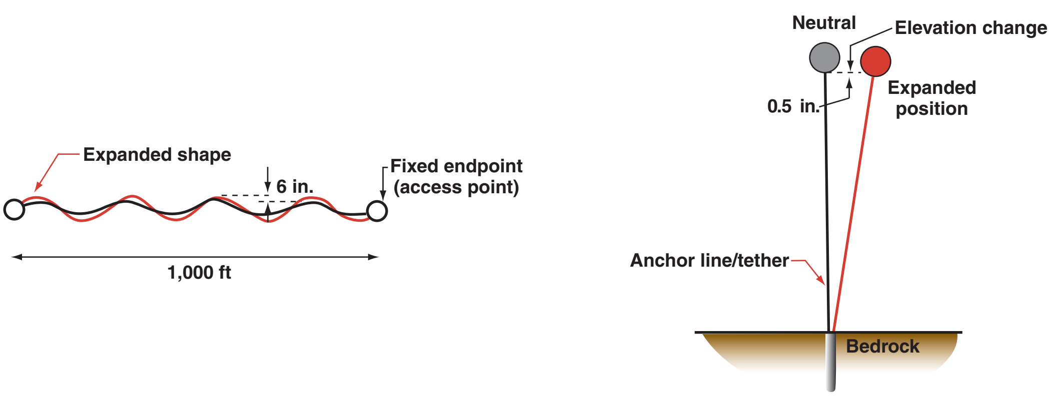


Image courtesy of Brown and Caldwell

FIGURE 3 Finite element modeling of the Lake Oswego Interceptor Sewer allowed prediction of movement and stresses from temperature change, seismic events, and lake drawdowns

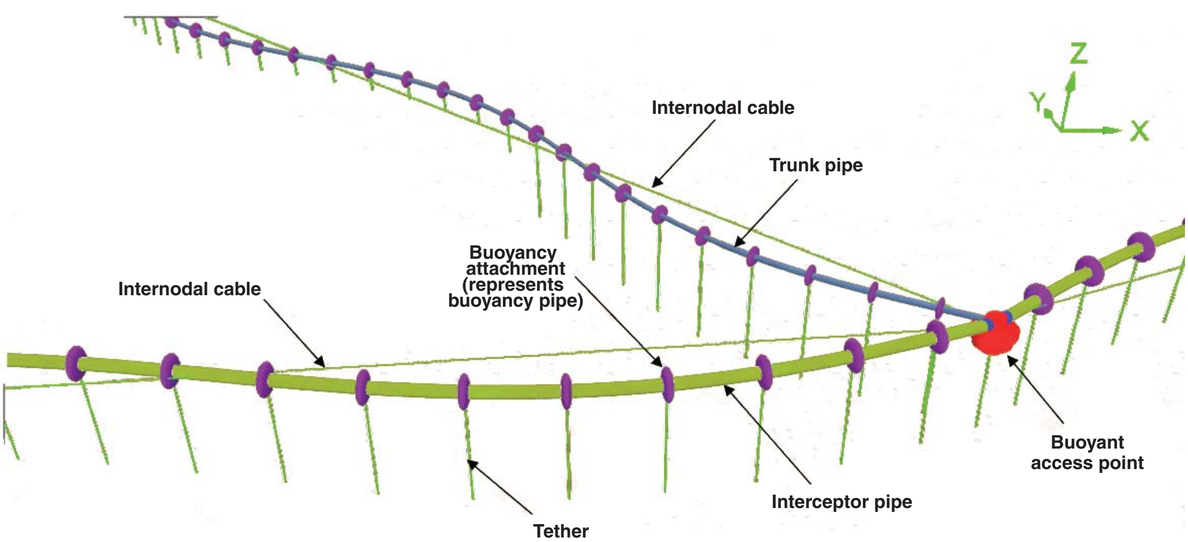


Image courtesy of Makai Ocean Engineering, Inc.

Figure 2, because the pipeline is already "bowed out" at each arc, an expansion in length causes a much smaller lateral displacement than would be experienced by a straight pipeline.

The wavelength and amplitude of the sine wave were optimized with the aid of a finite-element modeling program normally used in the offshore industry. The optimum wavelength-to-amplitude ratio was approximately 20:1. For the main interceptor, a wavelength of 400 feet and an amplitude of 18.5 feet were selected. The modeling showed that pipeline movements are small with the nearly 40° temperature swings, and peak stresses in the pipe caused by the movement are well below allowable limits for HDPE.

Because the pipeline is not a straight line, the overall length of the pipeline increased slightly—less than 2%. Careful pipe measurement and adjustment for temperature were required, along with tight tolerances on locations of the drilled-in ground anchors to ensure the two patterns closely matched the design alignment. Pipe length measurement for 1,200 foot strings was required to be accurate to within ±6 inches while accounting for its curving alignment and changing length because of daily variation in air temperature. Additionally, despite working in up to 50 feet of water and with anchors up to 200 feet long and with piles up to 160 feet long, horizontal positioning tolerance for the tops of piles and anchors was only ±6 inches.

TO BOW OR NOT TO BOW

Another problem for the design team to tackle was how to get a straight HDPE pipeline to stay in a sinusoidal shape. One early concept was to use mitered joints to join straight pipe sections and closely simulate a sine wave. This concept has the advantage of building a pipe that remains in its desired shape without the aid of any external forces. However, this method was judged too expensive, if not physically impossible to fabricate within the required tolerances.

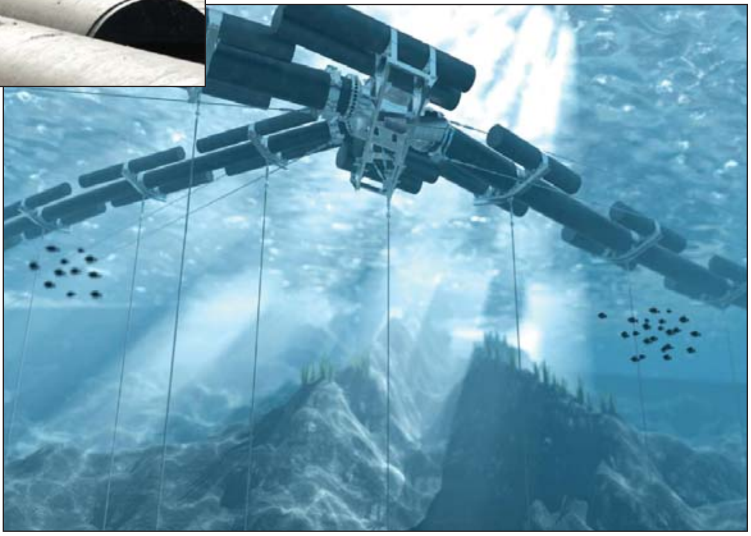
The concept selected was to fuse a 1,224-foot straight pipeline, then bow it into its S-shape and maintain an 18.5-foot amplitude sinusoid using six 200-foot stainless steel "internodal" cables to act as the "bowstrings" (Figure 3). The next bow would be bent in the opposite direction. Each cable would act as a bowstring for its section of the bowed pipeline and would be secured to the pipe by steel clamps at the "nodes." One complication to this wired design is that the internodal cables introduce a stiff tension member into a system that is otherwise very flexible when subjected to earthquake motions. However, analysis showed that wire tensions would still be acceptable during the design earthquake, so the concept was adopted for the pipeline. The photograph on page 37 shows the pipe-bending operation.

RISING TO THE TOP

Although the pipeline is buoyant even when filled with water, supplemental buoyancy was needed to support the

PHOTOS BY MARK GAMBA

Twin buoyancy pipe modules keep the pipe afloat and transition piles and slings protect the pipe during infrequent major lake drawdowns (left). The artist's rendering (bottom) shows the completed Lake Oswego Interceptor Sewer from below the surface of the lake looking up.



RENDERING BY EARL WILSON, BROWN AND CALDWELL

metallic hardware and any accumulated sediment inside the pipeline. An allowance was even made for invasive mussels should they infest Oswego Lake. Several options were considered to increase the buoyancy of the pipeline, including attaching an entirely separate "buoyancy pipe" to the underside of the sewer pipeline. However, concern for the stability of the pipeline during the lake drawdown portion of the work led engineers to incorporate numerous catamaran-style brackets using two smaller sealed HDPE pipes as the buoyancy hulls. In addition, during infrequent major lake drawdowns, the pipe must transition smoothly from its pile-supported reaches to the buoyant system floating on the surface. The photograph on this page (above left) shows the system of cradles and slings used to make the transition as well as the twin buoyancy pipe layout.

MAINTENANCE A MUST

Custom-made buoyant, submerged stainless-steel pipeline access points and removable portable aluminum access caissons (shown in the photographs on page 36) were designed to avoid boating hazards while still enabling access for cleaning and video inspection of the pipe interior. More accessible onshore debris sumps were installed to collect sand and gravel where it can be easily removed before reaching the in-lake pipeline. These sumps are expected to greatly reduce the required frequency of cleaning for LOIS.

COMPLETION AND RECOGNITION

The final design was completed in early 2009, and work started on the project in the spring of that year. The "lake down" portion of the project was constructed by general contractor James W. Fowler Company. The lake drawdown portion of the work is complete, the lake has been refilled, and the system is operating as designed. The artist's rendering (above right) of the completed LOIS system shows this first-ever combination of rugged, well-tested components. The Plastics Pipe Institute designated the project as its Municipal Project of the Year for 2010, and Advanced American Construction, the general contractor for the "lake full" portion of the project, was recently presented the Grand Award from the Association of General Contractors.

—Patrick Grandelli is a design engineer for Makai Ocean Engineering Inc. and directed the modeling work for the city of Lake Oswego's buoyant pipeline. He is the Ocean Thermal Subcommittee chairman for the American Society of Civil Engineers' Marine Renewable Energy Committee. Jon Holland, jrholland@brwncald.com, is a vice-president with Brown and Caldwell. A member of AWWA, Holland was the project manager for LOIS from the outset of planning in 2002 through completion of construction in 2011.