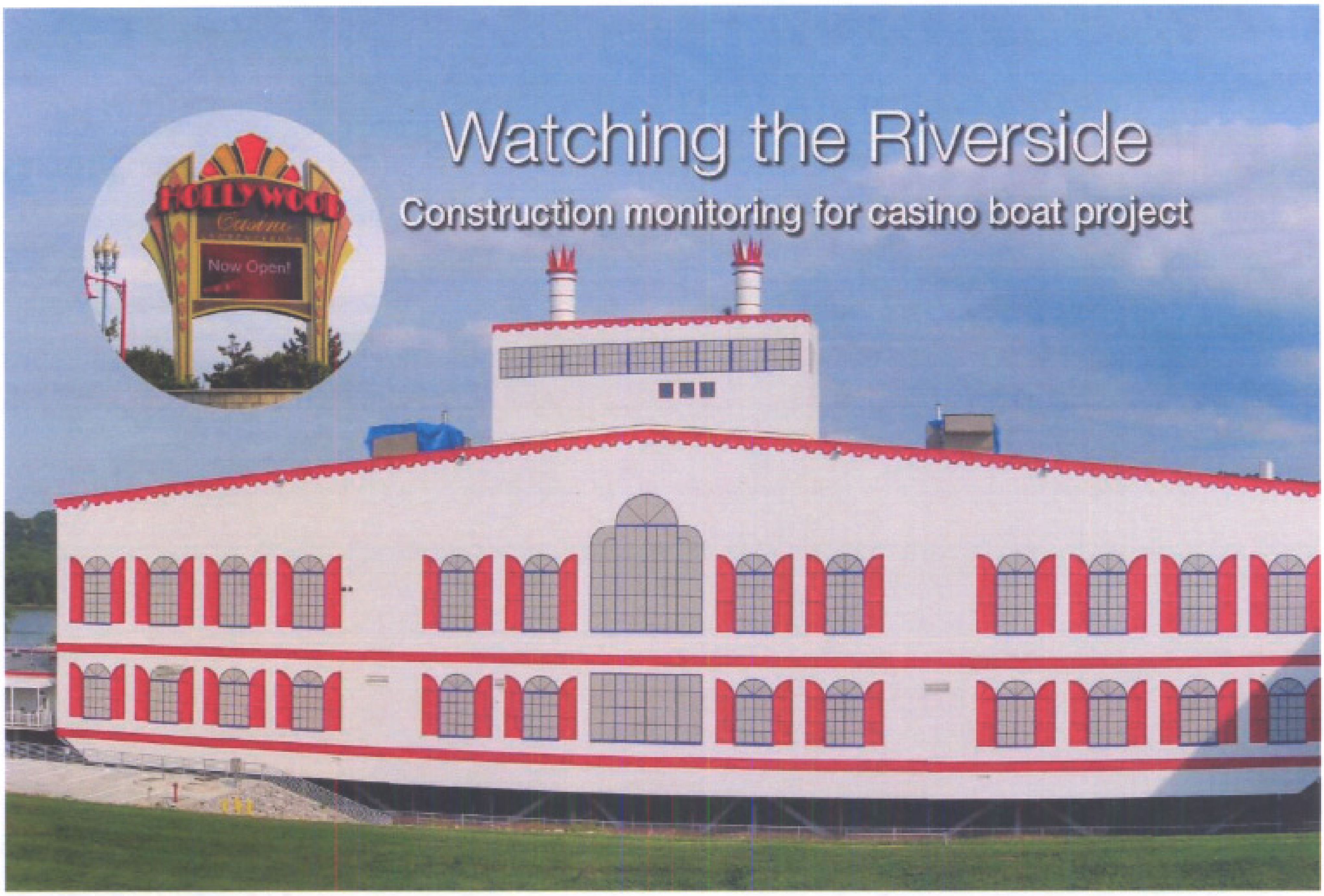
# Watching the Riverside

## Construction monitoring for casino boat project




by Peter Chou, PE, GE, MASCE, Bradley Frederick, PE, CSI, MASCE, and David Westendorf, EI
Photos courtesy David Westendorf

**THE HOLLYWOOD CASINO**, FORMERLY THE ARGOSY, IS LOCATED ALONG THE OHIO RIVER IN LAWRENCEBURG, INDIANA. IT RECENTLY UNDERWENT A MAJOR EXPANSION, WITH IMPROVEMENTS BOTH ON LAND AND WATER. WITH MAJOR WORK GOING ON ABOVE AND BELOW, AND CONCERNS WITH SITE CONDITIONS, MONITORING THE JOB DURING BACKFILLING BECAME CRUCIAL.

The project included construction of a parking garage, surface parking, access roadways, and a pedestrian bridge, along with a new 25,084-$m^2$ (270,000-sf) riverboat casino and the associated riverside patron access and support facilities. The new boat will replace the 6968-$m^2$ (75,000-sf) Argosy VI. Able to handle more than 9000 visitors and employees, it will become one of the largest riverboat casinos in the country.

The authors' firms, H.C. Nutting–A Terracon Company and Core Fundamentals, worked together in monitoring the 82 x 158-m (270 x 520-ft) boat slip construction. This new harbor included:

- Open Cell wall—a proprietary bulkhead system that was composed of vertical, driven flat sheet pile-composed structures of variable geometry that act as retaining membranes;
- mechanically stabilized linked sheet pile earth wall; and
- associated utilities and access roads.

The subsurface profile that had been revealed by previous geotechnical test borings indicated the site became overlain by deposits of moderately to highly compressible, uncontrolled, manually placed random fill and relatively recent alluvium (*i.e.* soil or sediments deposited by a river or other running water). Therefore, the team anticipated significant immediate and post-construction settlement of the bulkhead wall backfill and within the underlying soft alluvial soils. Additionally, a jetty embankment boat slip for the existing Argosy VI was within the new boat slip area.

The construction work required significant excavation, on the order of approximately 7.3 m (24 ft), into the lime-stabilized existing embankment and soft alluvial deposits. Due to the large exposed wall height and deep excavation, the sheet pile walls were installed surrounding the new boat slip area as well as north of the existing boat slip where a behind-wall service road had been constructed to the west.

A mechanically stabilized earth (MSE) wall was built next to the northwest end of the bulkhead wall, connecting a service road above the wall to the new harbor area. Several hold-down anchors were incorporated in the structure to secure the new casino riverboat.

Due to the significant fill placement and deep excavation during the bulkhead system construction and other construction sequencing issues, wall and soil responses needed to be monitored during these actions.

A state-of-the-art instrumentation program—consisting of seven monitoring stations and enclosures—was designed along the bulkhead river walls and below the MSE wall. This data was then used to confirm project design assumptions and help minimize potential risk of construction failures that may otherwise cause delays or safety hazards.

The composite plan for Argosy Casino's harbor expansion.
Image courtesy Penn National Gaming

### Construction sequence

The Open Cell wall system, designed and patented by PND Engineers, was used primarily as the substructure for docks and bulkheads. Consisting of a series of linked sheet piles driven into the ground and formed U-shaped (*i.e.* open)

## MORE ON THE RIVERSIDE: THE HISTORY AND FUTURE OF MILL CREEK

Cincinnati's largest flood on record occurred on January 26, 1937, when the Ohio River crested at a level of 24.4 m (80 ft). In response to this devastating event, the Cincinnati Local Flood Protection Project was undertaken in the early 1940s to help protect the downtown area and Mill Creek Valley from the effects of similar floods in the future.

The protection system includes approximately 2.5 km (1.5 mi) of floodwall near downtown and the Mill Creek Barrier Dam Pump Station (Figure A). This facility was designed to pump the flow of Mill Creek into the Ohio River while preventing backwater from flooding upstream into the valley.

As the Ohio River approaches flood stage, eight large bulkheads [each 12.8 m [42 ft] long, 1.5 m [5 ft] high, and weighing 10 t [11 tons]) are lowered into place where Mill Creek flows through the floodwall. As many as six more bulkheads can be added, one at a time, if the Ohio River continues to rise. As soon as the initial bulkheads are placed, one or more of the eight pumps at the barrier dam station are activated to maintain Mill Creek at a safe level. Each of these vertical lift turbine pumps is capable of pumping more then 3.8 billion L (1 billion gal) of water daily; together the pump station is capable of pumping 34 billion L (9 billion gal) of water per day from the Mill Creek into the Ohio River.

Figure A

The Mill Creek Barrier Dam Pump Station completed in 1948.
Image courtesy H.C. Nutting/Terracon

Before 1963, the pool level of the Ohio River at Cincinnati was maintained at an elevation of 134 m (441ft) by Lock and Dam No. 37. In the spring of 1963, the pool elevation of the river was raised to 139 m (455 ft) with the completion of the Markland Lock and Dam. This 5-m (14-ft) increase in water

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cells, it works as a horizontally tied membrane that relies on vertical tailwalls to restrain the arch face—conceptually similar to other types of mechanically stabilized earth retention systems. The bulkhead comprised a series of U-shaped vertical members, independent of toe embedment for stability. The entire system was constructed with flat sheet (PS) piles and connecting wye (Y) piles.

Once all sheets within one cell were driven, the bulkhead area was filled below water level with free-draining granular material and then compacted with vibro-compaction methods. Fill material above the water level was completed with onsite clayey material suitable as a structural fill. Since the entire sheet pile wall construction process was performed from the 'land side' of the project, the utilization of this system reduced the length of the harbor construction schedule and cost.

The structure's building sequence involved several steps. Initially, a construction platform consisting of granular soil below water and cohesive soil above water was built for the shore-based crane within the existing boat slip. The crane was set up at the locations where Wall 1 could be reached. Next, a single-level template was placed, and the cell sheets were driven, along with the wye pile. Following this, the template was moved to the next interior cell, and the tailwall and face sheets were driven until Wall 1 was completed.

For the Hollywood Casino project, the tops of tail sheets stepped down away from the walls and the lengths of tail sheets were shorter than that of face sheets. Wall backfill between Walls 1 and 2 was placed to Elevation 470 (*i.e.* 143 m) first, prior to commencement of Wall 2. Two pile-driving crews were mobilized for this project. Wall 1 was installed first, and then Wall 2 cell sheets were installed. After several cells were installed in this manner, backfill was placed in lifts within the cells.

Initially, backfill was placed to an elevation of approximately 143 m. Excavation then commenced in front of the walls down to Elevation 436 (*i.e.* 133 m). Backfilling then resumed, establishing the final design subgrade (approximately Elevation 480 [*i.e.* 146 m]). Following completion of the excavation and backfilling, the earth plug separating the new boat slip and river was removed.

### Instrumentation layout

Instrumentation was implemented at seven locations that were chosen to cover the different combinations of wall configurations. Instrumentation monitoring

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impacted the flow characteristics of Mill Creek and increased the silt accumulation in the forebay of the barrier dam.

To help provide continuous flow, the Mill Creek Low Flow Pump Station was installed and put into service in June 1964. The purpose of this station was to address degraded water quality in Mill Creek that occurred from slack water conditions during periods of low flow. Although not originally intended for this purpose, the low flow station was also employed as a means to remove accumulated sediment in the forebay of the barrier dam by using high-pressure water to flush the sediment into the low flow pumps and back out into the river.

A large amount of grit material was pumped through the low-flow station during this process and, by 1970, many internal pieces of the pumps had to be replaced due to excessive wear. Four years later, the pumps were again in need of major maintenance and replacement parts due to excessive wear from pumping grit and sediment. Consequently, the pump station was taken out of service at that time and has not been used since.

With the low-flow station out of service, the silt in the forebay has accumulated and not been removed for more than 30 years. This accumulation has formed a sediment delta upstream of the dam, shown in Figure B, that was estimated to be up to 6.7 m (22 ft) thick in some areas. With the sediment buildup, the barrier dam pumps have operated many times for more than 30 years with no apparent issues. However, the presence of the sediment could have negative effects on pump operation. As a portion (or all) of the accumulated sediment may need to be removed at some point in the future, the

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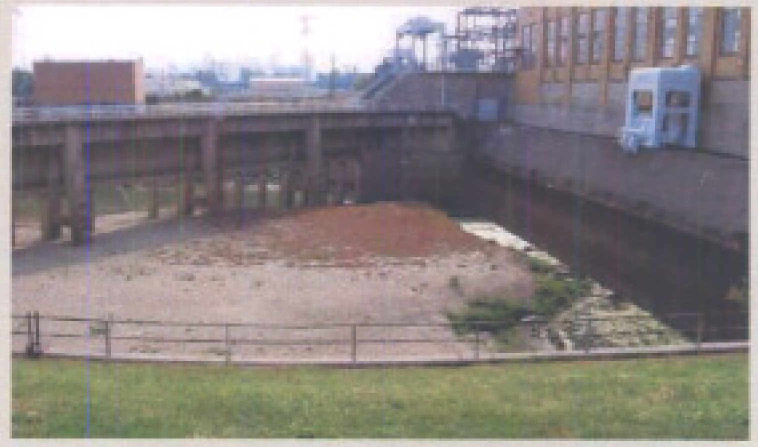
Figure B



Silt accumulation in the forebay of the barrier dam.
Image courtesy H.C. Nutting/Terracon

Aerial site photo of the Open Cell sheet pile wall construction (November 2007).
Image courtesy Messer Construction

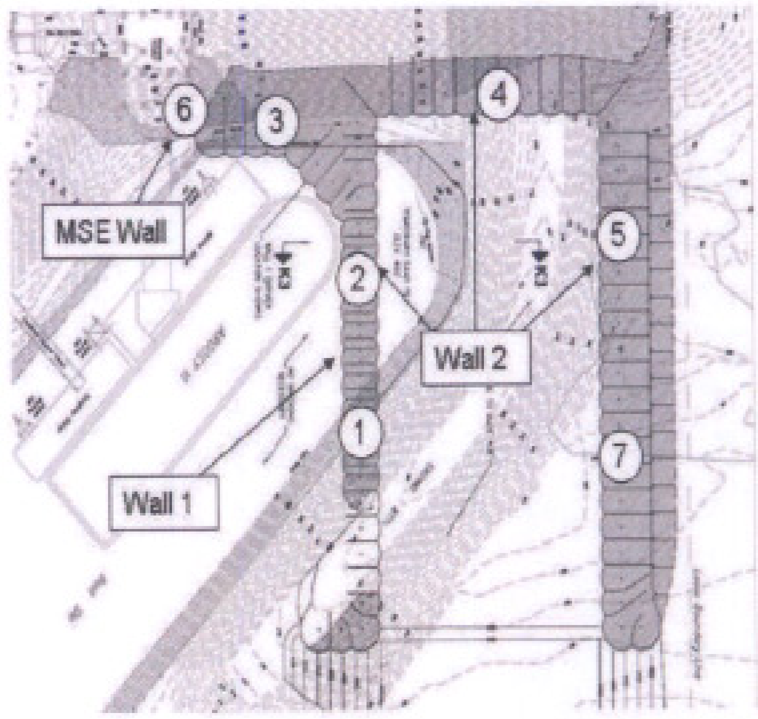
was installed behind the sheet pile wall and below the MSE wall. In addition to the instrumentation installed at the MSE wall location, short-range onsite wireless receiver and cellular transmitters were installed at this location. These devices were used to transmit data back to the office in Cincinnati.

In total, 150 individual sensors were originally installed at the site. Additionally, four strain gauges were added later to monitor a repair made to a damaged portion of the bulkhead wall. The flexibility of the automated system allowed these new sensors to seamlessly be added to the existing instrumentation. All the instrumentation locations were similar in the number and placement of the instruments, with a few exceptions. The typical location consisted of an inclinometer (for monitoring deformation or deflection), piezometers (for measuring pore water pressure within soil or rock), and a settlement-monitoring device.

At one instrumentation location on the Open Cell wall, 12 strain gauges were welded to the tailwall sheet piles. Welding of the strain gauges was completed on the ground before the sheet piles were driven. Steel channel was placed over the gauges for protection during driving.

Although precautions were taken, vibrations from pile driving and soil intrusion into the steel protection damaged several gauges. However, the surviving gauges still provided useful data. Several months after the initial instrumentation was installed and monitored, four additional strain gauges were installed on the wall at a second location to monitor a repair made to a damaged portion of the wall.

Several innovative instruments were employed to improve the instrumentation's capability to accommodate difficult construction activities and challenging sequences, and reduce risk of sensor damages, increasing program monitoring life. The developed technologies relate to instrumentation installation, data recording, data transmission, and data publishing.



Argosy Harbor's Open Cell system construction sequence.
Image courtesy HC Nutting/Terracon

*Industrialized data acquisition system*

Thirty-four industry-standard data acquisition (DAQ) modules were installed in seven customized water-resistant monitoring enclosures. These DAQ modules, including both analog and vibrating wire models, were selected for this harbor construction project due to their ease of installation, high resolution, and compatibility to the communication output modules.

*Relay/timer output module and power system*

Similar to other harbor or offshore constructions, it was unfeasible to install permanent site power supply during the initial construction phase of the project, particularly during pile-driving and soil backfilling.

The selected DAQ and relay output modules had built-in timers programmed to take measurements every 60 minutes. The engineer could specify duration and frequency of data recording and sleep time of the instrumentation sensors using the relay

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question arose as to its environmental status and the ultimate requirements for removal and disposal of the material.

To assist in characterizing the silt material, the City of Cincinnati retained this author's firm to drill six borings through the sediment delta and collect samples for environmental testing. During late summer, the surface of the sediment delta is generally dry and above the water level of Mill Creek. Due to the relatively low density of the sediment, a low-ground-pressure drill rig was needed to operate safely and effectively on the sediment. Additionally, due to limited access to the forebay area of the barrier dam, the only way to get the rig onto the sediment delta was by lowering it via crane from the concrete fender wall extending out into the forebay area (Figure C).

A 5897-kg (13,000-lb) track-mounted drill rig was employed for drilling and sample collection. This low-ground-pressure rig was large enough to obtain samples at the depths required, but light enough to operate safely on the sediment surface. All six borings were drilled in one day and the drill rig was removed the same evening. Sediment samples were taken in steel tubing at 1.5-m (5-ft) intervals of depth and delivered to a laboratory for chemical analysis.

Figure C

Lowering of the drill rig onto the sediment delta.
Image courtesy H.C. Nutting/Terracon

Results from the sediment sampling will be used by the city and regulatory agencies to assist in determining a proper removal and disposal plan should this be required.

–Jeff Oxenham, PE (senior engineer with the City of Cincinnati), and Fred W. Erdmann, PE, PG (senior consultant with H.C. Nutting–A Terracon Company) **CS**

output module inside each remote monitoring enclosure. These parameters could be set up and updated from the remote office.

Only one 55W to 85W solar panel and one backup 12V deep-cycle marine battery were required to enable continuous operation throughout inclement weather conditions at each monitoring platform (*i.e.* enclosure).

### *Short-range wireless routers between monitoring stations*

Deploying sensors and transmitting data without the necessity to hard-wire them in place greatly enhanced the monitoring capability and reduced instrumentation installation time. Short-range wireless routers sent data between each instrumented location and the core monitoring location. If a direct connection between a monitoring location and the core monitor was not available, the system relayed the signal through the other monitoring locations to the core.

Data from each monitoring location was wirelessly transmitted to the core monitor through the onsite network. A commercial cellular-to-Ethernet network bridge (general packet radio service [GPRS] in this case) inside of the core monitoring enclosure connects to the core monitor and provides a stable, secure connection to the remote office computer.

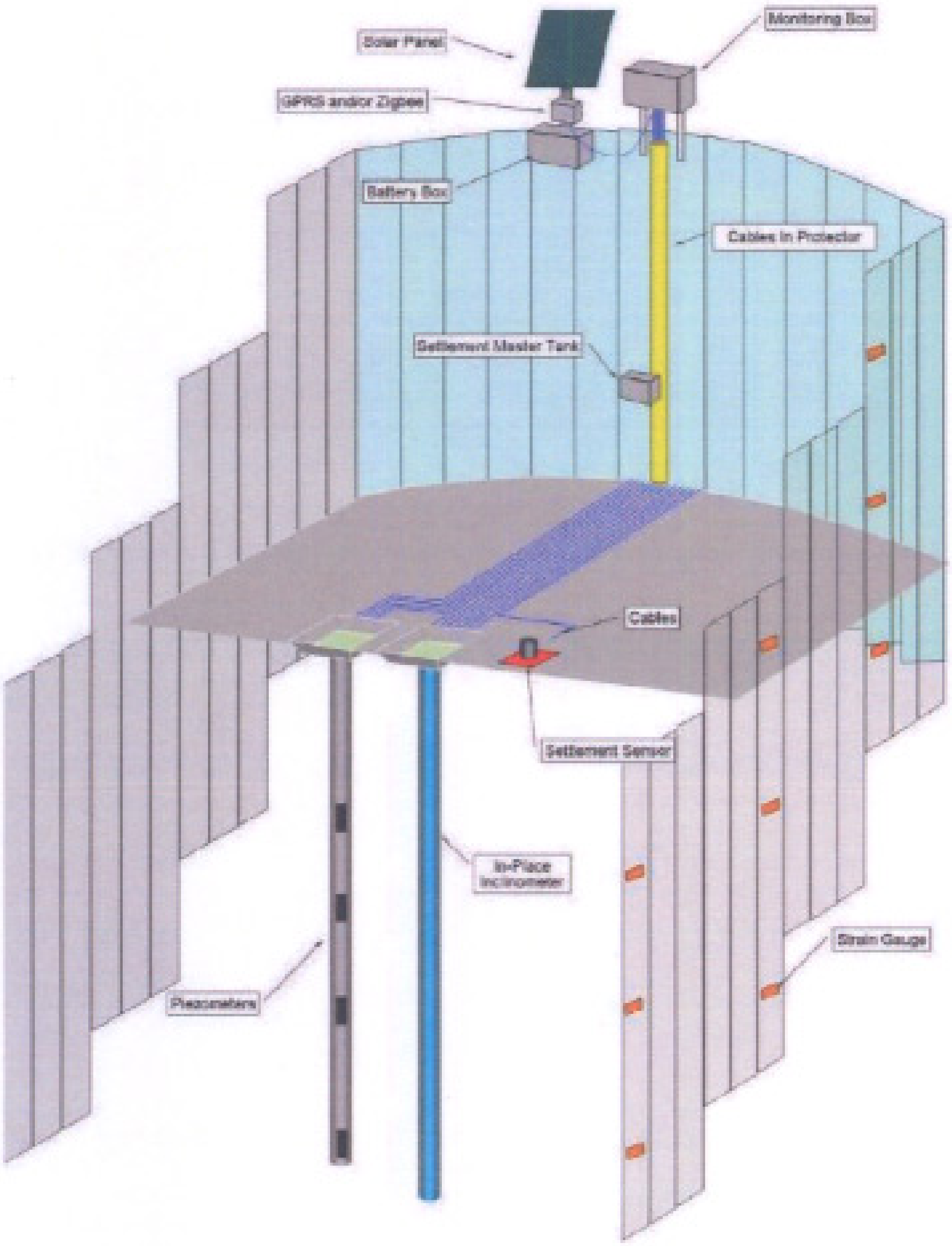
### *GPRS and core monitoring enclosure*

Internet service was unavailable at the jobsite during the initial stage of harbor construction. A commercial cellular-to-Ethernet router was employed to provide a reliable cellular data connection between the instruments and remote office computer.

The core monitoring enclosure, which included a GPRS, acted as a gateway for information transmission with a back-end remote server in the office. Long-range communication was achieved by a GPRS wireless connection via GSM (*i.e.* Global System for Mobile Communications) cellular networks. GPRS was able to provide bi-directional control and information flow, command, data export, and recording.

### *Office data collecting and Web-based publishing program*

Once all data is transmitted to the office computer through the Internet, calculations are performed by the software and measurements are available for real-time viewing and interpretation. The remote computer center, located at the engineering firm's




Typical instrumentation layout and location.
Image courtesy HC Nutting/Terracon

Cincinnati office, was developed using the LabVIEW software program. This office computer had access to a static TCP/IP address to which each core monitoring enclosure/station could connect to at a fixed interval (60 minutes in this case) and upload collected data to a data compiling software program. The uploaded and processed data in the office computer was stored in a database and managed by LabVIEW.

Autonomously, this program could:

- enter the data into a relational database for archiving;
- calculate field data using pre-programmed equations and turn it into useful information; and
- produce plots for distribution.

Once the data was recorded, processed, and plotted in the program, engineers could access the secured Web site with a browser to review or monitor the data or graphs.

This autonomous, real-time operation freed engineers from time-consuming tasks associated with the manually collecting, downloading, parsing, calculating, and plotting of new data from the field. Any daily dramatic change of the field data shown on the computer was reconfirmed by field inspectors and evaluated by design engineers. The password-protected site allowed users to view the latest data, search and plot historical data for comparisons, and set alarm thresholds for e-mail or text message alerts to engineers based on incoming data comparing to pre-setup performance criteria and/or limitation. This was extremely useful, particularly during excavation and dredging.

### Measurements and results

The purpose of the instrumentation monitoring was to confirm satisfactory wall performance during behind-wall backfilling and boat slip excavation at least three months after the completion of harbor construction. This would:

- facilitate effective monitoring of wall movement, ground settlement, and dissipation of pore pressure (*i.e.* pressure of groundwater held within pores in soil or rock); and
- confirm design assumptions—inclinometer, piezometer, settlement, and strain gauge data were all recorded and timely processed in the project database.

The data was very informative during construction to control construction sequence and the rate of wall backfilling and harbor excavation, as well as utility and paving installation. The field information was readily available for both the wall and civil engineering designers so 'red flag' criteria could be defined as construction progressed. The team had been witnessing an expected correlation between soil lateral movement, pore pressure buildup and relief, immediate and post-construction settlement, and height of wall backfill during construction.

The following sections summarize data obtained during the project at a typical location (specifically, Location 5).

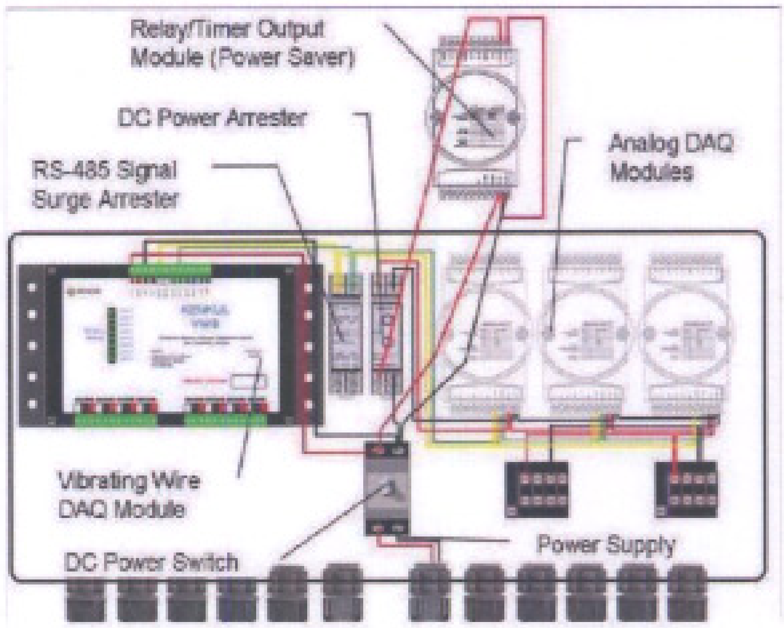
#### *Lateral displacement monitoring points*

A total of 49 in-place inclinometer sensors were installed for the project, seven at each monitoring enclosure. For the monitoring enclosures, the top four sensors were installed within the upper existing fill and alluvial deposits, and the fifth at or near the interface of alluvial and outwash deposits, while the sixth and seventh sensors were placed within the underlying competent outwash sand and shale bedrock, respectively.

Although the inclinometer data confirms that minimum soil lateral movement occurred below Elevation 430, the total cumulative wall top deflection surveyed was slightly greater than estimated total wall deflection (between 229 and 457 mm [9 and 18 in.]). Therefore, the performance of weekly optical surveys at wall top (wye pile) was prolonged to January 17, 2008, until both optical survey and inclinometer sensor results indicated minimum incremental movements.

Based on the instrumentation data, the initial 3 m (10 ft) of behind-wall backfill (from Elevation 460 to 470) did not trigger significant soil lateral movement measured by the inclinometer sensors below Elevation 460. However, once the new boat slip excavation began from Elevation 455 and extended to Elevation 436, up to 305 mm (12 in.) of total soil lateral movements below Elevation 460 and about 356 mm (14 in.) of wall top deflection at Elevation 480 were measured within a week (by October 11, 2007).

The backfilling resumed on October 12 (from Elevation 470 to 480), and, on completion of wall backfill, an additional 178 mm (7 in.) of soil lateral movement and wall top deflection was recorded



Typical monitoring enclosure details.
Image courtesy HC Nutting/Terracon

(by November 15, 2007). Both soil and wall lateral movements were generally stabilized within three to four weeks of backfilling completion, and 533 and 610 mm (21 and 24 in.) of total cumulative soil lateral movement and wall top deflection were recorded at Elevation 460 and 480, respectively.



A Lawrenceburg, Indiana, project included construction of a parking garage, surface parking, access roadways, and a pedestrian bridge, along with a new riverboat casino—one of the largest in the country.
Photos courtesy Messer Construction

### *Settlement monitoring points*

One set of precision fluid pressure transmitters was installed about 1.5 m (5 ft) below pre-existing grade within alluvial deposits at each station prior to wall backfill placement.

Since the settlement device was installed at each station behind the sheet pile wall, the recorded settlement below the device (at Elevation 455 in this case) during construction consisted of immediate and post-construction settlement, as well as consequent settlement due to sheet pile wall deflection.

At Station 5, about 51 mm (2 in.) of settlement first occurred below Elevation 455 due to the wall backfilling process from Elevation 460 to 470, and then an additional 102 mm (4 in.) of settlement resulted from the new boat slip excavation to Elevation 436—a consequence of sheet pile wall deflection. Finally, an additional 127 mm (5 in.) of incremental settlement had been developed when backfilling resumed and reached Elevation 480.

A total cumulative settlement of 279 mm (11 in.) was recorded at Station 5 by November 26, 2007. The majority (*i.e.* 95 percent) of settlement was recorded within a week of behind-wall backfill completion. This only included settlement occurring below Elevation 455; fill-induced settlement above (or within new fill) was not recorded or included. Therefore, the magnitude of subgrade settlement may be greater than that reported.

Based on the available data, 65 percent of the total recorded settlement was attributed to the backfilling process (surcharge), while the remaining 35 percent of settlement was a result of sheet pile wall deflection below Elevation 455.

Due to the threat of significant fill placement and deep excavation during the bulkhead system construction (and other sequencing issues), wall and soil responses needed to be monitored.

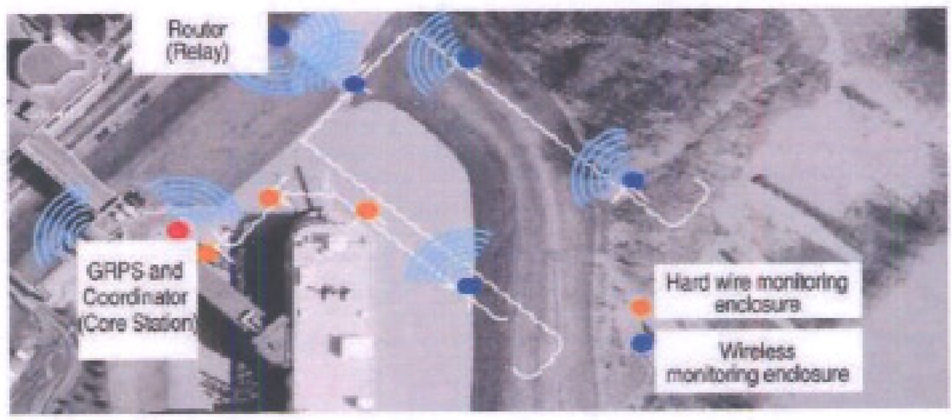
*Piezometer monitoring points*

A total of four piezometer sensors were installed at various depths below each monitoring station. Based on the measurements, only the uppermost sensor was distinctly influenced by the behind-wall backfilling process—excess pore pressure increased during and immediately after completion of each backfill layer, and then pressure dissipated to normal range within one to two days after each filling.

Pore pressure variation due to rapid drawdown was recorded when a de-watering pump station was activated inside the excavation of the new boat slip. Generally, a significant decrease of pore pressure was measured at the uppermost piezometer sensor within alluvium (above or near normal pool elevation of the Ohio River) as well as the bottommost sensor within porous outwash sand.

Once the de-watering pump was turned off on October 31, 2007, pore pressures at the uppermost and bottommost sensors elevated to normal levels on the same date.

Based on the available data, readings measured by the sensors within cohesive alluvium below water level did not quickly respond to water level variation.




Wireless network setup/aerial photo.
Image courtesy HC Nutting/Terracon and Messer Construction

Due to the cohesive nature of embedded soils, it took one to two weeks of lag time for pore pressure rise and dissipation.

Naturally, the pore pressure measurements throughout harbor construction also fluctuated with the Ohio River water level stage (normal pool at Elevation 455 and 100-year flood at Elevation 490).

### Summary and conclusions

A typical instrumentation monitoring system, especially its associated signal and power cable, is prone to excavation and backfilling-related damage,

The casino project demonstrates an effective instrumentation system can reduce maintenance and labor overhead by remote controlling and monitoring.
Photos courtesy Messer Construction

as well as to weathering and corrosion-related damages. The new instrumentation system must be designed to accommodate all types of potential damages. However, instrumentation design requirements intended to address one threat may complicate efforts to protect against another.

As an example, a manual readout system can reduce the risk of power and/or signal cable damage but may slow down the construction process when instrumentation data is not readily available or if the readout location is inaccessible. In many cases, it may not even be feasible to perform manual reading during earthwork construction. On the other hand, a wired automated instrumentation system can significantly reduce monitoring labor. However, it inevitably imposes much higher risk of construction- and weather-related damages to sophisticated instrumentation equipment, especially monitoring enclosures. Sometimes, these damages may even waste much more instrumentation labor time and cost for repair. Additionally, site power availability and power consumption may become an issue if a significant amount of sensors and DAQs are required and monitored simultaneously.

An effective instrumentation system can reduce maintenance and labor overhead by remotely controlling and monitoring the system around-the-clock. For both short- and long-range remote monitoring to be effective and economical, instrumentation data must be acquired and communicated autonomously.

This type of customized wireless monitoring program has already been adapted for use on various projects such as landslides, retaining walls, and building foundations; it will pave the way for remote monitoring for all types of projects. **CS**

## ADDITIONAL **INFORMATION**

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### Abstract

A Lawrenceburg, Indiana, project included facilities for a new riverboat casino—one of the largest in the country. Significant fill placement and deep excavation during the bulkhead system construction meant wall and soil responses needed to be monitored. A state-of-the-art instrumentation program became critical.

### MasterFormat No.

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31 45 00–Vibroflotation and Densification
31 62 16–Steel Piles
35 31 16–Seawalls
35 70 00–Dam Construction and Equipment

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A1020–Special Foundations
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