Landmark Projects: Dynamic Foundation Testing

If you live in Northeast Ohio, you are familiar with the Interstate 480 bridge over Valley View, the "Valley View Bridge." It spans the deep and wide valley of the Cuyahoga River and the Ohio and Erie Canal that runs parallel. You cross the bridge coming from the Cleveland airport to the eastern suburbs; you commute on it from the western suburbs to downtown. It's when you walk or bike along the beautiful Canal Towpath Trail and look up that you appreciate the sheer magnitude of the structure. There you are close to the practical beginnings of dynamic foundation testing.

1971. Those tall massive bridge columns rest on some of the very first piles – tapered pipe piles – that were instrumented with strain transducers and accelerometers during driving. It was 1971, and the Ohio Department of Transportation (ODOT) was starting to rely on the results of the research project it was funding at the Case Institute of Technology a few miles east of the bridge.

1972. A year later, dynamic foundation testing had its debutante ball. The young technology was presented to the geotechnical community – about 400 people – at the American Society of Civil Engineers Soil Mechanics and Foundations Division Specialty Conference on the Purdue University campus in Lafayette, Ind. A DELMAG D-12 diesel hammer drove an instrumented steel H-pile (10HBP57) approximately 47 ft (about 14 m) into the ground. The project demonstrated two methods of predicting pile capacity from dynamic measurements. The first method, based on the one dimensional wave propagation, already had its current name CAPWAP®, and required a "large digital computer" to process the data measured by two pairs of accelerometers and strain transducers, and record the data on a four channel magnetic tape. The second method used a "special purpose computer in the field" that provided signal condition, analog computation and a digital readout of the calculated static pile capacity immediately following each hammer blow. It was the predecessor of the Pile Driving Analyzer® of today and performed calculations by what is now known as the "Case Method." Both dynamic methods showed very good agreement with a static load test conducted on site.

Demonstration of dynamic pile testing, Purdue University, 1972

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Valley View Bridge

1973. Dynamic foundation testing traveled abroad for the first time soon after its USA debut. Four test piles were instrumented in an Esso refinery in Antwerp, Belgium, in 1973. This was also one of the first occasions in which dynamic measurements were made on concrete piles, a material with a set of challenges much different than that of steel ones (dynamic foundation testing calculations are a function of, among other quantities, the elastic modulus E of the foundation material; E is a known quantity for steel, but varies for concrete). Not that dynamic testing of steel piles did not present its own learning opportunities: In 1975-1976, steel H-piles were driven to hard rock in Sandusky, Ohio. These were test piles intended to investigate a then common pile driving criterion for piles driven to rock – "20 blows per inch (2.54 cm) for the last few inches of penetration." When the engineers extracted the steel piles after driving, they found that virtually all had been damaged by overdriving due to the required blow count. This landmark test eventually changed the driving criterion specified by many agencies and consultants. Most now base driving criteria on a bearing graph developed by wave equation analysis, with field verification of capacity by dynamic testing.

H-piles extracted after overdriving, Sandusky, Ohio, 1975

1974-1977. The first high profile job in which the dynamic testing was the method of choice to determine capacity was the Lazaro Cardenas – Las Truchas Steel Plant in Mexico, in June of 1974. Twenty six dynamic load tests were conducted in 4 days, and results compared, very favorably, with those of a static load test. That project also marked another first – the use of this method to test a non-driven pile (a slurry cast pier). "The cross-sectional area of the pier was over three times as large as anything previously tested by the dynamic analysis" says the project report. It was an important first step in bringing high strain dynamic testing from the realm of driven piles to the reach of the entire deep foundations industry. (Augered cast-in-place piles were dynamically tested for the first time in 1977 at the Charleston Arbor Housing Project in Charleston, W.V.).

1981. Following a collapse of an older bridge due to ship impact, construction of the Sunshine Skyway Bridge in St. Petersburg, Fla., started in 1981. The Sunshine Skyway is a very beautiful bridge, a world class landmark, and is currently on a priority mail stamp. Frank Rausche, of Pile Dynamics, recalls that the approaches "needed a lot of piles because they were designed [to withstand] a major ship impact. Fortunately, we were just ready with the RMX method on the GC." The GC was a relatively early model of Pile Driving Analyzer. At the time it was considered a mighty machine, and essential to test the 24 in (61 cm) diameter concrete piles of this project. This "paved the way for successfully testing larger piles," according to Rausche.

The Florida tests caught the attention of engineers in Australia, who were facing the prospect of 60 extremely expensive static tests up to 2,000 tons (20 MN) for the West Gateway Freeway in Melbourne. After a good correlation was established between static and dynamic testing methods for a few piles, the remainder static tests were replaced with dynamic tests. The project is supported by cast-in-place shafts socketed into weak rock with a diameter more than twice that of the Sunshine Skyway piles. Up to then – this was in the early 1980s – a dynamic test had not been attempted on piles of this type or size. The tests were successfully conducted by impacting the shafts with a 20 ton (200 kN) ram dropped 8.2 ft (2.5 m) in free fall.

Other Testing "Firsts"

By the mid to late 80s dynamic testing was so prevalent around the world that tracing "firsts" becomes quite challenging. Among the notable projects in which dynamic testing played a key role include:

When the I-10 Bridge over Escambia Bay in Pensacola, Fla., was taken down by Hurricane Ivan in 2004, a temporary bridge was quickly constructed, followed later by a permanent replacement. Engineers performed a static test initially in that fast track project, the challenging setup led to suspect results. Had dynamic foundation testing not been conducted, the test flaw would not have been detected; the project would have faced costly consequences and would most likely have been considerably delayed.

Drop weight used to test cast-in-place shafts at the West Gate Freeway project in Melbourne, Australia

Still in Florida, a pier supported by drilled shafts collapsed during the construction of the Lee Roy Selmon Crosstown Expressway in St. Petersburg. The project managers brought the largest hydraulic hammer ever used to conduct a dynamic test on the pier to the site in order to verify the capacity of the remaining piers. The magnitude of the test made front-page news in the St. Petersburg Times; that newspaper dubbed the hammer "MOAPH" – the mother of all pile

Sunshine Skyway Bridge

Construction of the Escambia Bay Bridge

hammers. The project was successfully completed and went on to win multiple engineering and construction awards.

In 2004, the Burj Khalifa, still today the tallest building in the world, was built in Dubai, UAE. The now routine method of high strain dynamic foundation testing was the method of choice to control the quality of the foundations of one of the most visible landmark projects of the 21st century.

Material for this article was obtained from conversations with Frank Rausche, Ph.D., P.E., and Garland Likins, P.E., from unpublished project reports and from case studies available at www.pile.com/references.

Dynamic tests on pier at Lee Roy Selmon Crosstown Expressway