The Port of Tivat, in Montenegro, may become a luxury resort area after its renovation. LVMH's Bernard Arnault, gold magnate Peter Munk, and financier Nathaniel Rothschild have invested in a major effort to transform it into a marina for luxury yachts. The original port dates from the 19th century when it was an Austro-Hungarian Naval Base, and one can still see old submarines on shore.

When the work began, there was little information about the piles that supported the old port. Although steel pipes with a diameter of 60 cm (1.9 ft) and a wall thickness around 10 mm (3.9 in) filled with concrete were visible, their lengths were unknown. Ideally, these old piles could be reused for the new project. But first, some detective work had to be done.

In May 2009, the site developer BRIV, from Montenegro, retained SLP d.o.o from Ljubljana, Slovenia to determine the pile lengths on Jetty 4, Jetty 3 and on the Town Quay. Testing unknown foundations is challenging, and may be performed, depending on field conditions, by the induction, parallel seismic or pulse echo methods. SLP decided to use the Pile Integrity Tester (PIT), manufactured by Pile Dynamics, Inc., for the test. Depth determination by the pulse echo method involves striking the top of the existing pile with a hand held hammer. This impact creates a stress wave that travels down the pile at a certain speed (called the wave speed, c), reaches the pile toe and reflects back to its top. If a pile has a length L, the wave takes a time equal to $L/c$ to reach the toe, and another $L/c$ to come back to the top. As the wave travels down and back up, the PIT collects data and displays it. The engineer conducting the test must assume a wave speed for the procedure, and conditions must be ideal for the wave reflection to be clearly seen.

Since the piles of the old pier consisted of concrete encased steel pipes embedded under some old concrete structures, SLP assumed that the steel protected the concrete. The company therefore assigned a wave speed of $c=4000$ m/s, which is characteristic of good concrete quality, to estimate the unknown pile lengths. If the actual wave speed were lower, then the correct pile lengths would be somewhat longer than the estimated ones, so this was a conservative assumption.

For some of the tested piles, the wave reflection from the pile toe was not clearly visible, thus complicating the depth determination procedure. However, on each dock, a large number of piles were successfully tested and it was possible to make an assumption about the average pile length. SLP found that pile lengths varied considerably, from 10 m (32.9 ft) to more than 25 m (82 ft), but generally seemed to have been driven to the top of the weathered flysch bedrock — a bedrock material composed of sandstone and marl layers; marl is a very sensitive compacted clay.

While information about the geometry of the existing foundations was important, estimating their bearing capacity was even more so. One year after the depth determination test, SLP performed dynamic load tests on four old Jetty 4 piles and three piles that supported synchro lifts, (synchro lifts are used to lift submarines or other vessels out of water for repair and service) to obtain the information for deciding to reuse the foundations.

Dynamic load tests involve impacting the foundation with a suitable large mass — a pile driving hammer or other drop weight — and using strain and acceleration data collected by sensors installed on the upper portion of the foundation to estimate bearing capacity and the distribution of shaft resistance and end bearing, as well as to assess pile...
integrity. The geometry of the foundation is modeled as part of the data analysis process. A Pile Driving Analyzer® (PDA) and the CAPWAP® software program were used to perform the dynamic load tests at the Tivat Port.

To prepare for the PDA tests, the workers removed the old concrete superstructure, and extended the selected test piles 1.5 m (4.9 ft) above sea level with a new steel tube filled with concrete. They used a 5 ton Junttan hydraulic hammer for the test.

Removing the superstructure exposed the top of the piles, and allowed the testers to redo the length determination tests in better conditions. However, the pulse echo method still did not yield a good estimate of pile length. The dynamic load test revealed that the lower part of the piles consisted of approximately 4 m (13 ft) long steel tubes that were not filled with concrete. The pulse echo-based length evaluation had not detected the steel extension, and showed only the concrete filled portion. The piles were actually 4 m (13 ft) longer.

The tests helped explain the technology used to install the foundations of the old port. First, the workers drove open-end steel pipe piles, then they removed all the soft soil from the upper part of the tube down to the compact soil (in general weathered flysch). Finally, they placed a reinforcement cage on the upper portion of the pile, and filled the tube with concrete.

The tests revealed that the capacity of the old piles was sufficient for all of them to be reused, along with some additional new piles.

PDA old piles (Photos and job details courtesy of SLP d.o.o., http://slp.si. SLP is a full service geotechnical firm in Slovenia, and represents Pile Dynamics in that country)