System for the Characterization of Soil Samples through Cyclical and Dynamic Tests

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THE CHALLANGE

Implementing an integrated hardware and software system for the physical and mechanical characterization of soil samples by cyclic triaxial tests. The system requires precision in handling the high loads and pressures involved during test, the storage and display of all collected data with a complete historical review of performed analyses.

THE SOLUTION

Up to four closed loop system (PID) based on real-time architecture, able to control the high loads and pressures involved during the analysis in short and reliable times. The real-time control has been developed on CompactRIO hardware, while the firmware (FPGA) and software (both real-time and PC) by LabVIEW.

ABSTRACT

On behalf of Controls Ltd, a global leader in the production of Testing Equipment for the construction industry, an automatic test system for the determination of the stress-strain relationship of soil through the application of loads has been developed. The device is controlled by a CompactRIO fully managed by a PC.

In particular, it provides:

. Management of actuators and pressure regulators with extreme precision, speed and high dynamics.
. Autonomous management of an entire test, showing as much information as possible and keeping track of all the history of the measure, without saturating the CPU or the memory of the PC and real-time system.
. High flexibility to perform tests according specific standards or using customized parameterizations.

ARTICLE

In geotechnical engineering, the triaxial test is the laboratory test most commonly used to determinate the stress-strain relationship of a soil, in order to obtain reliable soil parameter, replicating stress conditions experienced during excavations, constructions or natural events. The system (picture 1), developed for CONTROLS S.R.L., global leading company specialized in manufacturing testing devices on construction materials with headquarters in Milan - Italy, consists of: a high stiffness frame for the application of static loads by electric-driven gear motor (50-100 kN)

a servo-pneumatic actuator for the application of dynamic loads (maximum load 14 kN and maximum displacement 30 mm or alternatively 5 kN in load and 50 mm in displacement) triaxial cell for the axial (mechanical) and the radial (by water under pressure or air for the resilient modulus calculation) stress of the sample systems for the generation and the remote control of water pressures in the triaxial cell and within the samplemeasurement system of the volume change of water within the sampleCompactRIO to manage the system by PC.

An upgrade of the system above consists in using a "Double wall triaxial cell" and one more axis to control the "Air pressure" to perform tests on unsaturated samples. In fact unsaturated soil contains both air and water within the soil voids.

Typical screenshot of the software.

The test may include different phases:

- A preliminary phase in which the sample is prepared by saturating it through pressurized water so to remove any air micro-bubbles that would change its physical characteristics, reproducing also the original characteristics of soil in depth: in fact, in the subsurface, soil is subjected to high isotropic forces. This phase will last very long (hours, even days, depending on the material nature).
- The phase above can be executed also in a different way to test the strength of soil in unsaturated state (soils above the water table can remain unsaturated particularly in tropical and arid regions but even intemperate climatic zones). An unsaturated soil contains both air and water within the soil voids and this is achieved raising the air pressure to the sample and generating a flow of water from top to the bottom of the specimen. A ceramic stone, cemented into a special base pedestal, is used to allow the flow of water but to stop the air.
- A phase of sample characterization through the application of compressive and tractive forces (stress, volumetric and linear strains, pressure and suction). This phase involves the application of a vertical force or displacement with very slow and steady growth to characterize the breaking point of the specimen and the application of a cyclic loading, even at high frequency (from fractions of Hz to tens of Hz), to assess its strength and elastic properties.

The application, despite stress times not too low when compared to those of electronics, is nevertheless characterized by the need to drive in position a load unit of several kN through a proportional valve, that inherently leads to have a load control (1 Newton is roughly the force that a 100 g body generates on Earth: 5.000 N amount to more than 500 kg). This makes the system extremely complex, especially considering the contrast to this load can be extremely variable: the two extremes are the sand specimens - with virtually no opposition force - and samples of very compact ground - with very high compressive strength. In practice, by applying a force of few hundreds of Newton, the sample can be completely destroyed or, even applying thousands of Newton, the specimen can be only slightly compressed. The system must therefore be able to make very precise movements (hundredths of a millimeter), playing with forces that can vary from few to thousands of Newton.

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compactRio detail.

In order to achieve this precision, the system was based on proportional-integral-derivative (PID) controllers extremely quick in acting, to avoid an incongruous test due to a too rapid movement of the thrust.
For the dynamic test, a proper algorithm named "Automatic Amplitude Control" was developed.
Enabling this option, the system compensates the changes that may occur during cycling, ensuring that the required peak and valley levels are consistently maintained without the user action.
In addition to the position, the system must accurately control the pressure inside and outside the sample. The specimen, in fact, might be saturated with water during the test and maintained at a constant pressure to simulate the stress conditions to which it is normally subjected. Also in this case, the PID must act very quickly to compensate for any changes undergone by the sample and the space surrounding it during compression test. Then the system manages independently and quickly up to four PIDs during the test: one for displacement/load control and three for pressures control.
The length and composition of the streaming of the setpoints is highly variable: during some stage it consists of ramps with very low gradients (movements of the actuator of a few tenths of a millimeter per hour that, in terms of voltage feedback, mean a few tenths of mV) and long-term (several hours or days), while in other cases it is much faster (sinusoidal movements of few millimeters with a frequency of 10 Hz).
To achieve the accuracy and speed required even for the tests at high frequencies, the cycle time of each PID implemented on the field-programmable gate array (FPGA) was set to 100 µs (10 kHz bandwidth). The sampling period of the four transducers which are the three PIDs feedback was set at 12,5 µs (the vertical actuator can operate both in load control and in position control requiring, therefore, different feedbacks) - which is then carried out on a moving average of eight samples. For the other six transducers the sampling period is set at 100 µs. The PID setpoints are generated and calibrated on PC to avoid limitations in their length, then they are sent to cRIO which controls autonomously the test, while the PC collects and displays data from transducers. By this way we obtained a very precise control in any condition and a low employment of the cRIO memory, whose buffer is, however, always sufficient to compensate any slowdown of the stream of the setpoints, transmitted via Ethernet by TCP/IP, that may be caused by a temporary saturation of the network or by a slowdown in the PC. Data transmitted to the PC (10 transducers whose size is encoded at 32 bit and transmitted at 2 kHz, plus an additional synchronization and timestamp channel) have a payload of useful data of 80 kbaud to whose also the overhead of the TCP/IP and management of the relevant packages should be added. The communication is effectively managed by the "Network Stream" VI of LabVIEW that provides a continuous data transfer with high throughput and low latency. Another important feature of

Dynatriax system by Wykeham Farrance, Soil Mechanics Division of CONTROLS.

the system is the test typically has a duration of several days: it is essential to ensure, even for a short time (ms), no unexpected behavior that would undermine the entire test. This aspect is crucial: test parameters are continuously monitored and processed, in order to control and drive the different units (pressure and force controllers) to maintain the required stress/strain conditions set up at the beginning. Software was implemented to save the various logs with accuracy and to show in real-time recorded data and relevant calculations, displaying them both as numerical indicators and time graphs (Picture 2). All software code was developed to optimize data processing algorithms, log management and graphic displays.
Since the system is not a custom device, but a product for market, different modes of operations were developed, in particular, implementing the 3 standard ASTM (American Society for Testing Materials):
- ASTM D5311 Load Controlled Cyclic Strength
- ASTM D3999 Load Controlled Modulus & Damping
- ASTM D3999 Displacement Controlled Modulus & Damping
  1 standard AASHTO (American Association of State Highway and Transportation Officials) for resilient modulus test:
- AASHTO T307 and two custom modes.

The management of different languages was also integrated: all the messages and labels can be set in five languages and a INI file allows a fully customization. The software implements, along with a simple calibration wizard, also the verification procedure to meet the requirement of International Organization for Standardization (ISO) in terms of repeatability and accuracy of measurements.
The use of LabVIEW allowed the development of the firmware for the FPGA and the software for the real-time system both on cRIO, and the application software for the PC.
The decision to use the CompactRIO, rather than developing a custom system, was carefully weighted: the use of cRIO for which it was decided for, has reduced both the time and risks of development, allowing to have immediately a hardware already extensively debugged and easily configurable at a lower cost than an ad-hoc hardware development should require.

LabVIEW, LabVIEW FPGA, LabVIEW RealTime, compactRIO 9073, LabVIEW Report Generator for Microsoft Office Toolkit.

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