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Portuguese new centrifuge facility

La nouvelle centrifugeuse portuguaise

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ABSTRACT: A new centrifuge facility has recently been established at the Portuguese National Laboratory for Civil Engineering (LNEC). The centrifuge is an Acutronic model 661 and it has a capacity of 40 g-tonnes. The platform radius is 1.8 m. The paper describes the development of the facility, including general features of the housing, centrifuge test equipment and associated electrical and mechanical systems.

RESUME: Une nouvelle centrifugeuse a été recemment mise en service au Laboratoire National de Génie Civil Portugais (LNEC). La centrifugeuse, une Acutronic modèle 661, a une capacité de 40g-tonnes, la distance de l'axe à plateforme nacelle étant de 1,8 m. Dans ce rapport on présente le dévèloppement de l'installation y compris les caractéristiques génerales du bâtiment conçu pour abriter la machine, les équipements et les systèmes èlèctriques et mécaniques associés.

1 INTRODUCTION

The paper describes the centrifuge facility that has been developed in the Geotechnique Department at the Portuguese National Laboratory for Civil Engineering (LNEC). A few new features have been included into the design of the centrifuge and the associated optical, electrical and mechanical systems. These features are presented in detail. Essential accessories for centrifuge geotechnical application are also described.

2 DESCRIPTION OF THE FACILITY

2.1 *General*

The centrifuge is housed at ground floor level of the Ferry Borges building at LNEC campus, in a circular reinforced concrete chamber. The chamber was constructed so as to ensure an appropriate operation of the apparatus and the safety of users. It has a direct access to a laboratory designed for the preparation of models, which contains also the control and power cabinets. Those cabinets ensure, respectively, the control and electric feeding of the system. The operation of the unit is carried out from a control room, especially designed for the purpose. This room is located at level 1 of the building. The operation and control systems (control desk and control panel) are housed in that room. Those systems ensure the user-apparatus interface, as well as the hardware required for data storage and transmission with the physical models under centrifugation. The control of the apparatus can be operated in manual or computer mode (IBM, PC compatible).

The centrifuge has a pyramidal steel casting structure, rigidly connected to the chamber's floor slab, which supports a rotating boom and a drive assembly. One of the ends of the rotating boom is equipped with a swinging basket into which the model-load is inserted. The other end has an adjustable counterweight for balancing the unit. The mean rotating radius is 1.55 m at the geometric centre of the basket and 1.80 m at the mounting platform. The useful basket volume is 500x700x500 mm^3. The maximum weight results from the acceleration attainable - 4kN for accelerations until 100g, decreasing linearly until 2kN for accelerations until 200g (corresponding to the maximum rotation speed of 345 rpm).

At the upper part of the pyramidal structure there are two rotary joints: a fluid rotary joint and a hydraulic oil rotary joint. The fluid joint makes it possible to have hydraulic (oil or water) or pneumatic (air) access to the test package. It is connected to the covering slab of the chamber by a metallic structure designed for the purpose and its cooling is ensured by water. The hydraulic oil joint is connected to a hydraulic unit, which is also housed at the covering floor of the circular chamber. That unit makes possible to operate the automatic in flight balancing system of the rotating boom.

The apparatus has an optical rotary joint and an electric rotary joint. Those joints were designed to establish a safe communication (the first one with an extremely low noise to signal ratio), between the data acquisition system and the data storage and control system, located at the control room.

The swinging basket is equipped with a video camera connected to a monitor installed at the control room. That equipment allows to the visual surveying of the behaviour of models during centrifugation.

2.2 *Description of the centrifuge*

Figure 1 presents an overview of the centrifuge. Basically, it consists of a pyramid-like steel pedestal (Figure 1-1), which is connected to the floor slab by means of 8 bolts (M30) fastened at 800 Nm. At the upper part of the pedestal there is a cube (Figure 1-2) supported on a axial thrust ball bearing and two straight roller bearings. The axis of the latter defines the running shaft of the apparatus. Two cylindrical units are connected to the cube, by means of a annular spring tensioning device with an axial locking, which ensures a highly firm fastening, with no clearances. The operating shaft of the cube is extended to the lower part of the pedestal where the operating system is installed. This system consists of a reducing gear box with horizontal and vertical shafts with a 1:5 transmission ratio (Figure 1-3) and a 45 kW three-phase electric motor with a horizontal shaft (Figure 1-4), fastened together by an elastic coupling. The output shaft of the gear box is hollow in order to make it possible to transmit signals between the rotating part of the apparatus and the fixed equipment. The transmission of signals is achieved with the help of several types of rotating joints. The description of those joints is presented in 2.3.5.

The two cylindrical units constitute the rotating boom of the apparatus (Figure 1-5). One of the ends of the rotating boom supports a swinging basket (Figure 1-6), in which the model is installed. The other end has a counterweight that can be hand-adjusted in order to balance the centrifuge boom prior to flight (Figure 1-7). The cylindrical units contain two hydraulic pistons that are included in the automatic balancing system. That system will be described in 2.3.2.

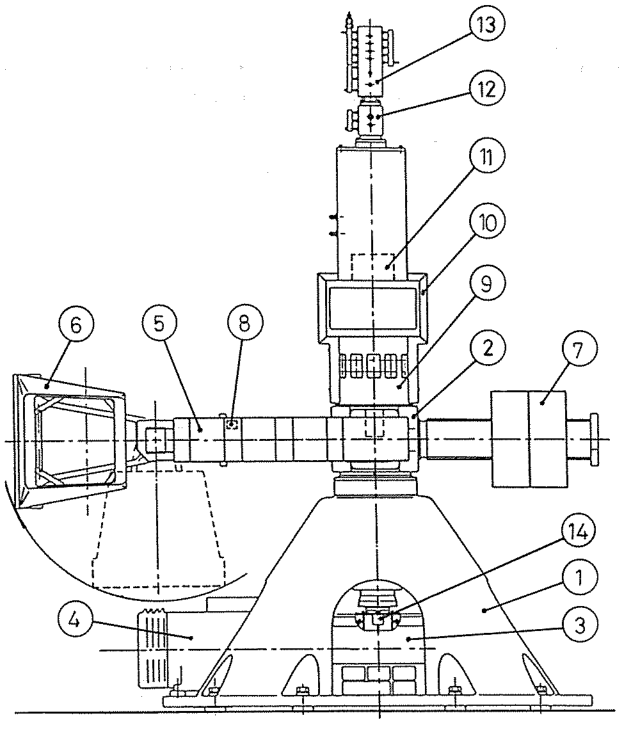
The measurement of accelerations is carried out by means of an accelerometer, which is installed at the rotating boom at a distance of 0.80 m from the centrifuge axis (Figure 1-8).

The upper part of the cube comprises a rack designed for inserting the data acquisition unit (Figure 1-10) with a 400x482x560 mm^3 volume. This rack was integrated in the unit according to LNEC specifications. Immediately below that structure there is the support of the electric contacts and the corresponding electric rotary joint (Figure 1-9), as well as the fibre optic rotary joint, consisting of four uni-directional channels. The electric joint is composed by 46 contacts, which support a current intensity of 1 Ampere at maximum voltage of 150 volts - DC; 12 contacts for a 5 Ampere current intensity at maximum voltage of 220 Volts - AC or 300 Volts - DC as well as 3 video channels for a 10 Volt voltage. At the upper part, there are two servo-valves (Figure 1-11) and the hydraulic oil rotary joint (Figure 1-12) which ensure the oil feeding to the automatic balancing system. Above that joint there is another rotary joint for fluids, which makes it possible to have access, by hydraulic or pneumatic means, to the models during tests (Figure 1-13).

2.3 *Main components*

2.3.1 *Rotary fluid joint*

This joint gives one access either by hydraulic or pneumatic means, to the models during tests and it is independent from the centrifuge. The joint consists of two hydraulic oil rotary contacts, of which the maximum operating pressure is 20 MPa and 4 rotating contacts for air or water, which can operate until maximum pressures of about 2 MPa. Between each rotating contact there are water cooling channels to avoid excessive heating of hydraulic sealing materials. The cooling system has also a valve that controls the water flow according to the temperature. The fixed part of the joint (when it is not in use) can freely rotate with the centrifuge. Thus, the lifetime of the rotating elements is extended.



1 - Pedestal
2 - Cube
3 - Gear box reducer
4 - Drive motor
5 - Rotating boom
6 - Swinging basket
7 - Counterweight
8 - Accelerometer
9 - Electrical slip rings
10 - Data acquisition unit rack
11 - Servo-valves
12 - Hydraulic oil rotary joint
13 - Fluid rotary joint
14 - Optical encoder

Figure 1. Mechanical layout of the centrifuge (front view)

2.3.2 *Balancing system*

As was previously referred, the centrifuge arm assembly is equipped with an adjustable counterweight. The position of the counterweight in relation to the centrifuge axis is adjusted according to the mass to be inserted into the swinging basket. The displacement is achieved by means of a gear system operated by hand, using a set of sprocket wrenches. The distance between the counterweight and the centrifuge axis of rotation must be previously adjusted, with the machine stopped. This distance is established in such a way that the binary introduced by the counterweight is equal, but with a signal opposite to the one resulting from the embarked mass.

Apart from that hand-operated balancing system, the LNEC centrifuge has also an automatic in flight balancing device of the arm. That device makes possible to compensate, during the execution of tests, unbalanced conditions resulting from actions on the model that are likely to affect the position of its mass centre and/or the value of the embarked mass (e.g., introduction of water into the model).

The automatic balance is achieved with the help of the displacement of two mobile weights. Those weights are indeed two pistons housed inside the cylindrical bodies, as previously mentioned. The displacement of the pistons is ensured by the hydraulic oil unit. The oil (with a working pressure of about 6 MPa) is transmitted from the fixed part towards the mobile part of the apparatus, by means of the corresponding rotary joint. The circuit is controlled by two proportional directional control valves connected to 4 pressure sensors (in each of the chambers of the hydraulic cylinders) and to 4 strain gauges. The measurement of unbalance conditions is carried out by these strain gauges, which are fixed on four bars of the pedestal of the centrifuge. The system is operated from the control board and makes it possible to compensate unbalance conditions up to 20 kN.

2.3.3 *Closed T.V. circuit system*

The T.V. system in closed circuit makes it possible the monitoring of models during tests. It consists of a video camera (lens and control unit of the camera), with very small dimensions and a monitor. The lens is installed at the swinging basket. The control unit of the camera is housed at the rack on top of the pyramidal structure, which also contains the data acquisition unit. The monitor is housed at the control room.

The communication between the control unit of the camera and the monitor is accomplished by means of a coaxial cable and by one of the 3 video channels of the apparatus.

2.3.4 *Safety systems*

The apparatus has several systems that control and ensure its safety. When a malfunction is detected the corresponding alarm signal is operated at the control panel. Thus, the machine stops automatically while in rotation and it only restarts after the malfunction is repaired.

The safety devices installed at the apparatus are as follows:

- Unbalance system - the system can be divided into three subsystems. The first operates the alarm - Unbalance level 1 - when the maximum unbalance level admitted is reached (20 kN). It does not cause the immediate stop of the apparatus. The second operates the alarm - Unbalance level 2 - when the unbalance level exceeds 5 to 10% of the maximum value allowed (21 to 22 kN), causing the immediate stop of the apparatus. The third operates the alarm - Unbalance measurement - in case of anomalous behaviour of one of the strain gauges. It causes the immediate stop of the apparatus, when the latter is in rotation or prevents it to be started if it is not in operation.

- Excessive rotation speed - the system activates the alarm - Rate Trip - causing the immediate stop of the centrifuge when the boom rotation speed imposed by the operator is higher than the one allowed. The record of the rotation speed is accomplished by means of an optical encoder (Figure 1-14) located at the base of the centrifuge.

- Excessive acceleration - If the acceleration of the boom exceeds 205g (± 5g), the system activates the alarm - Excessive Acceleration - and causes the immediate stop of the apparatus. The measurement of the acceleration is performed by an accelerometer placed at the arm of the machine, as was referred to in 2.2.

- Power fault - A fault in the power cabinet activates the alarm - Power Amplifier - preventing the start of the centrifuge or causing its immediate stop.

- Closed door system - if the gate of access to the chamber of the centrifuge is open, the system prevents the start of the apparatus. When the gate is closed that indication is given at the control panel - Door Closed.

- Latched door system - prevents the start of the apparatus, if the operator, through the control panel - Door Latched - has not latched the gate of access to the antechamber of the centrifuge.

- Acoustic-luminous system - the aim of the system is not to ensure the very protection of the apparatus, since its operation is independent from it, but instead the protection of people in the vicinity. The system consists of a siren and an intermittent light and it is controlled from the control panel of the control room. After the operator has given the start signal of the centrifuge, the siren emits a sound, indicating that within a few seconds the apparatus will start flight (that interval is established by means of a timer located at the control cabinet). Subsequently, the siren stops and the intermittent light starts together with the movement of the arm. The centrifuge has a 2 KVA power for feeding this system.

2.3.5 *Data acquisition control and storage*

This system is divided into two units: i) acquisition unit and; ii) data control and storage unit. The first is housed at the centrifuge (§ 2.2). It consists of a data acquisition unit made by Hewlett-Packard, Model 3852-A, with one Mbyte RAM (for storing data and programmes) and a 24 channel modulus for reading DC signals. The reading of signals is accomplished with a 6 and a half digit resolution voltmeter, in scales ranging from 300 mV to 300 Volts DC. In the future, the system is to be equipped with a complementary module to carry out the conditioning of signals and analogue and/or digital outputs for controlling electromechanical actuators.

The second unit, installed in the control room, consists of a computer made by Hewlett-Packard, model 382, with a polychromatic monitor. The aim of the computer is to control the data acquisition, processing and storage unit, collected by the latter.

The communication between the two units is carried out by means of a transparent, optical system, composed by two fibre optic cables and two converters (National Instruments, model GPIB-110), which perform the conversion GPIB-optical and vice-versa (one of them installed at the centrifuge and the other at the control room).

3 ACCESSORIES

3.1 *Equipment for the construction and monitoring of models*

The facility has a prototype design and construction laboratory, beside the centrifuge, where all equipment needed for the construction of models is placed.

Two containers, a circular tub and a rectangular box, are used for model preparation. Soil specimens can be consolidated using a consolidometer manufactured by CIEL.

In flight characterisation of soil samples by on-board cone apparatus is also possible.

In flight monitoring of models is accomplished by using displacement potentiometers, LVDT's and load cells, while the on-board CCD camera allows real time survey of models behaviour.

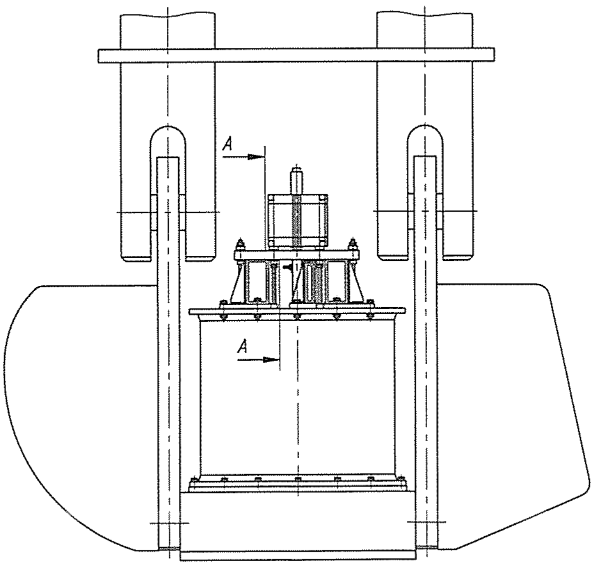
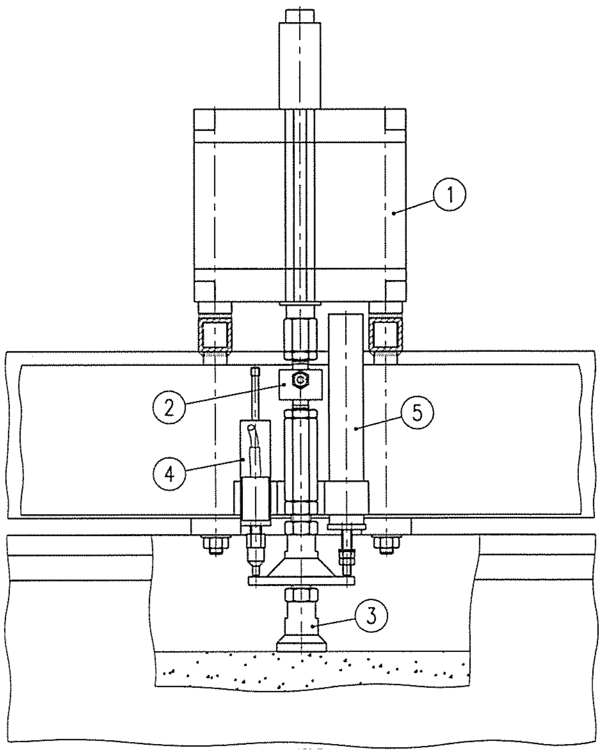


Figure 2. Loading system inside the swinging basket (front view)



1 - Pneumatic actuator
2 - Load cell
3 - Loading plate
4 - Linear potentiometer
5 - LVDT

Figure 3. Loading system set-up (Figure 2 - section A-A)

3.2 *Actuator for cone and foundation testing*

A pneumatic loading system (Figures 2 and 3) provides for the possibility to apply a variable force to a foundation model or a structure. The equipment was designed for testing foundations bearing or piles under vertical loading. It was designed in such a way that loading and unloading forces are allowed. It has two degrees of freedom and operates in a user-friendly manner (easy to adjust).

This device is to be operated from the control room (next to the control panel of the centrifuge and the acquisition data computer).

The system is basically constituted by a pneumatic actuator controlled by a precision pressure regulator. The actuator is a double-acting cylinder with through piston rod. The piston diameter is 100 mm and the stroke length is 50 mm. It weights about 4.0 kg and provides a loading capability of 4.5 kN at 0.6 MPa to a maximum working pressure of 1 MPa.

To measure the applied force a load cell is installed at the end of the actuator piston rod. All the components are supported by a structure designed for tests up to 100g. Displacement measuring of the loading plate is accomplished by an LVDT and a linear potentiometer placed in positions diametrically opposites relatively to the loading axis. These two devices are supported by an independent steel structure mounted parallel to the first one.

The referred to configuration is to be used during tests with the 420 mm diameter tub. A similar configuration can be used for the rectangular plane strain box.

The compressed air is supplied by an ATLAS COPCO unit installed at a room near the laboratory, which feeds an air circuit to the control room. This circuit is then connected to the centrifuge by the fluid rotary joint.

4 PLANNED ACTIVITIES AND CONCLUSIONS

The new centrifuge facility recently established at the Geotecnhique Department of the Portuguese National Laboratory for Civil Engineering was described.

The facility has added to the existing potential at LNEC for solving some geotechnical problems, but requires initial effort on mastering the technique and training staff. The nature of the initial tests is, for learning reasons, simple and concentrates on areas that have generated results published elsewhere for the sake of certification of procedures.

A slight exception to the simplicity was made on environmental topics, recognisably hard, because a valuable opportunity of cooperation with other European centres advised LNEC to participate as described below.

In summary, the topics at study are:

- Behaviour of laterally loaded piles and pile groups on dry sand;
- Scale effects on modelling soil-pile interaction problems, including the evaluation of the importance of rugosity versus size parameters;
- Transport of contaminants on soils - similitude problems on the modelling by tests on geotechnical centrifuges;
- Study of clay liners, their cracking and its influence on soil contamination.

LNEC as been cooperating with LCPC (Bouguenais) in a project, financed by a joint program of Portugal and France, on the aspects of scale effects on centrifuge modelling.

On environmental problems, LNEC is associated to ten other European institutions, owners of centrifuges in the United Kingdom, France, Netherlands, Denmark, Italy and Germany, through a recently started networking project (NECER) financed within the Training and Mobility of Researchers Program of the European Union. The duration of NECER is 4 years, its themes are on environmental engineering and it is expected to contribute to an end of decade with experience applicable to the modelling of transport of pollutants in soils, a serious and technically challenging problem at present.

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