Inverted Pendulum Equipment

User Manual

Man 073	3.1.0	04/07/2014	P.Day	Rob King-Mason	Chris Rasmussen
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Contents

Section 1 : Foreword

It is essential that the equipment covered by this manual is installed and operated by competent and suitably qualified personnel. They must read AND UNDERSTAND the procedures outlined in this manual before attempting installation or operation of the equipment on site.

Early consideration must be given to the space made available to `house' the equipment inside of the dam (or other structure) in order to avoid installation difficulties and rectification measures at the time of installation.

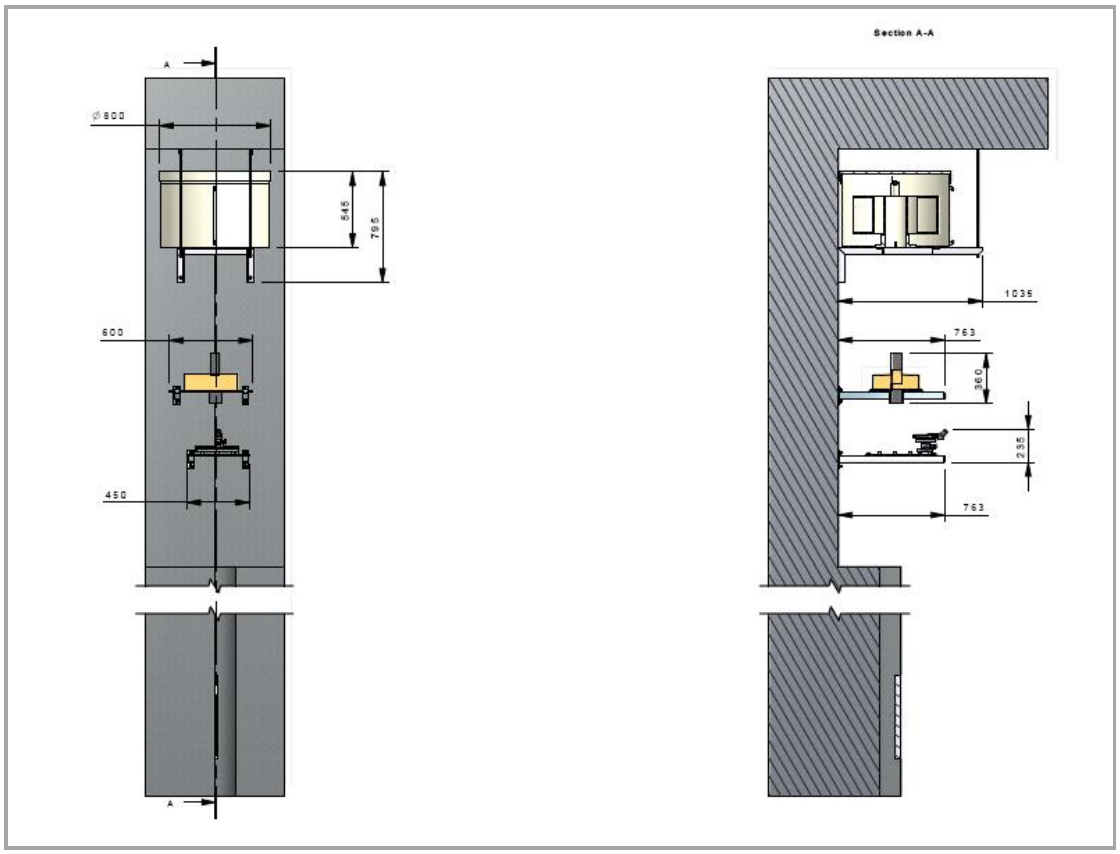
All the equipment is designed to operate consistently under normal site conditions but although all of the components are robust they will not survive mishandling or neglect. Components must be treated with respect and handled with CARE.

This manual can only serve as a general guide and the techniques mentioned will require modification to suit particular circumstances.

Section 2 : Introduction

The inverted pendulum is installed to provide an absolute reference from which accurate measurements of horizontal displacement of tall structures can be made, typically dam's.

The pendulum consists of a stainless steel wire grouted into bedrock at the base of a borehole with the upper end of the wire attached to an annular cylinder float, submerged in a water filled circular tank to provide tension to the wire. When the float is in its rest position, the tensioned wire is truly vertical and immediately above the fixed point in the bedrock at the bottom of the borehole. The wire, therefore, forms a datum from which any horizontal movements can be measured. Drawing No. 800-492 shows the general arrangement of the pendulum system.



Section 3 : General information

Full utilisation of the system requires that its installation is considered at the design stage of the dam (or other structure).

Anticipated maximum displacement of the structure determines the borehole diameter required to accommodate the resulting movement of the pendulum wire - the top of the casing, moving with the structure, moves relative to the bottom, in stable bedrock. Allowance must also be made for the probability that the borehole will not be drilled absolutely vertical e.g. over 20m depth a 0.5° deviation gives rise to a 0.175m offset of the top of the casing relative to the base - a difference in excess of the internal diameter of 6" casing. The anchor need not be installed in the centre of the borehole if it is safe to assume the movement of the structure will be predominantly in one direction e.g. downstream hence the casing may not need to be as large in diameter as twice the anticipated displacement.

The reading table may be installed either directly over the borehole or in galleries at higher levels with the wire passing up through the structure. In the latter case the shaft must be of sufficient diameter and appropriately positioned to accommodate all potential structural displacement plus an allowance for constructional deviations. Where practical a diameter of 550-650mm is appropriate. Furthermore the float tank has a nominal diameter of 850mm and it may be that both frame and tank will be installed in position not coincident with the shaft centre and it is therefore essential that the gallery walls are sufficiently distant to the shaft aperture.

3.01 Frame mounting walls

The walls upon which the float tank support frame and the reading table frame are mounted should ideally be no more than 470mm from the centre line of the shaft. They should be vertical and parallel to or at 90° to the main axis of measurement.

3.02 Checking borehole verticality

Verticality checks must have been conducted by the drilling contractor to prove a hole of required verticality at the time of drilling and casing installation.

The diameter and axis co-ordinates of the resulting free space should be provided based on the survey.

A similar survey at time of pendulum system installation should be conducted to confirm or otherwise the previous results.

3.03 Installation of float tank support frame

The float tank support frame should be positioned inside the pendulum chamber, on a suitable vertical concrete wall at a height of 900mm from the ceiling and centred about the anticipated initial wire position.

After establishing the correct position secure the frame to the wall using one of the 10mm expanding anchors, level the frame and then fit the remaining three anchors.

Temporarily fit the two lengths of vertical support studding to the holes in the frame arm’s with a nut both side of the arm and adjust until the end of the studding touches the ceiling when vertical.

Mark the positions on the ceiling and remove the studding, drill vertical holes then insert and secure the 10mm anchors in these marked positions.

Fit the long female 10mm connectors to the protruding thread on the anchors and refit the studding through the frame ensuring that the 35mm washer and the nut are fitted on the underside of the frame arms.

Adjust the nuts so that the frame arms are supported by the studding.

Re-check the frame with a spirit level in both axes and adjust accordingly using shims where necessary.

3.04 Float and tank assembly

Secure the adjustment beam to the float using the socket cap screws and washers. Carefully place the float into the float tank and lift into position on the support frame.

Retain the wire adjustment rod for later assembly to the wire.

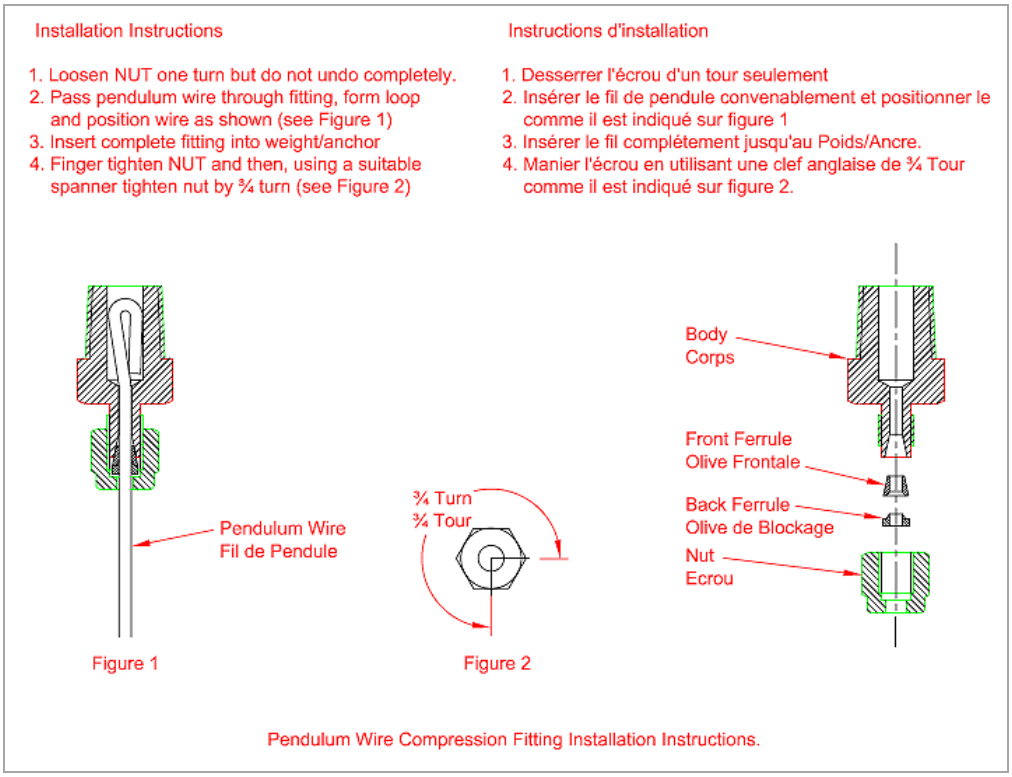
3.05 Preparation of Anchor Weight

Remove the complete wire connector fitting from the anchor and remove the nut and the two parts of the compression olive from the fitting taking care not to drop or lose the olive parts and noting their correct order of fitment within the connector body.

Pass the nut and olive parts over the pendulum wire ensuring the correct orientation of the parts.

Form the wire into a loop as shown below using pliers, check the wire for cracks after bending. If cracked cut off and form again, when successful pull back into the fitting.

Tighten the nut as per the instructions shown below.



A suitable pull-test should be carried out to ensure that the wire is clamped correctly.

Screw the fitting back into the anchor without twisting and kinking the wire then fully tighten.

3.06 Installation of Anchor Weight

There are two basic methods for installing the anchor. The first is to use the pendulum principle to `hang' it from the top of the casing with the wire clamped in the initial XY position required within the free space and then grout it up.

The second is to locate the anchor on the bottom of the borehole in the position required to put the wire in an acceptable initial position at the top of the casing and then grout up. In practice the latter method is more time consuming and becomes near impossible in a deep hole where lighting, rope twisting etc are all problematic - however it may be relevant to a truly vertical borehole where the anchor is to be centrally positioned.

If installation is proceeding alongside construction, then the pendulum wire must be suitably protected while the construction continues up to the pendulum reference gallery.

The recommended method for positioning the anchor at the bottom of the hole is to use a rope (approx. 6mm diameter) which must have a length greater than twice the borehole depth.

A cross hole is drilled through the rebar for lowering the anchor down the borehole on the rope. Pass the rope through this and tie the two free ends of the rope together. Lower the anchor down the borehole, carefully uncoiling the pendulum wire at the same time.

Continue lowering the anchor assembly to the bottom of the borehole and then lift it clear of the bottom.

Secure the rope at the top of the borehole so that the anchor is suspended above the bottom of the bore hole.

Take up the slack in the pendulum wire and cut it level with the top of the tank support frame arms.

Thread the wire to the float adjustment rod using the compression fitting as per the previous instructions.

Fix the float adjustment rod though the base of the float tank and up to the float adjustment beam ensuring that a nut and washer are positioned either side of the beam on the threaded adjustment rod.

Adjust the tension in the rod so that the pendulum wire is now suspending the anchor instead of the rope and the rope is not under tension, ensure that the end of the rod does not protrude above the lip of the float tank.

Move the position of the float and tank until the float is central in the tank and the pendulum wire is in the desired position in the borehole.

The rope is then removed from the borehole by untying the ends and slipping the free end through the cross hole.

Mix sufficient grout to envelope the anchor at the bottom of the borehole, adding plasticisers, aggregate etc. as required - or if installing the anchor at a higher level sufficient to just cover it at that level. Ensure that the grout is sufficiently fluid to allow the anchor to flow through the grout to its required position. Place the grout with a tremie pipe and then retrieve the pipe.

Leave grout to harden but making absolutely certain that the wire cannot move or be displaced during this time.

Once fixed by the cured grout, remove the temporary wire support clamp and fixings at the top of the borehole casing.

3.07 Adjustment of the pendulum float

Adjust the two nuts on the adjustment rod so that the wire is slack and the adjustment rod is not protruding above the float adjustment beam and adjustment nut.

Pour sufficient water into the tank to lift the float approximately 50mm off the bottom of the tank.

Adjust the nuts on the adjustment rod to apply tension to the pendulum wire.

It is important to position the tank to allow the float to centralise within the tank and allow for maximum future movement of the pendulum wire in any direction.

When the float is centralised add additional water to raise the water level up to the top of the float.

If necessary adjust the wire tensioning nuts to ensure that the float is submerged horizontally and stably, but completely clear of the bottom of the tank.

Pour a 5mm layer of mineral oil on the surface of the water to prevent evaporation of the float tank water.

Fit the lid to the float tank.

Carefully move the wire around its movement area checking for completely free uninhibited movement.

3.08 Installation of optical reading table

The support frame and reading table are supplied in kit-form for assembly on site.

The reading table frame should be positioned inside the pendulum chamber, on a suitable concrete wall with a height to provide convenient viewing position when looking through the microscope (if used). The wall brackets should be mounted 400mm apart with the pendulum wire positioned at mid distance between them.

Ensure the brackets are mounted in a horizontal position and parallel to each other, a spirit level and shims should be used to achieve this.

The end of the brackets should protrude between 200mm and 400mm beyond the position of the pendulum wire.

Fit one set of sprung clamp nut, clamp, washer and bolt to each bracket and slide to the rear of the bracket

Place the reading table onto the brackets position the table into its approximate position.

Adjust the reading table position to suit the required initial wire position and ensure the reading axes are aligned with the axes of the structure being monitored.

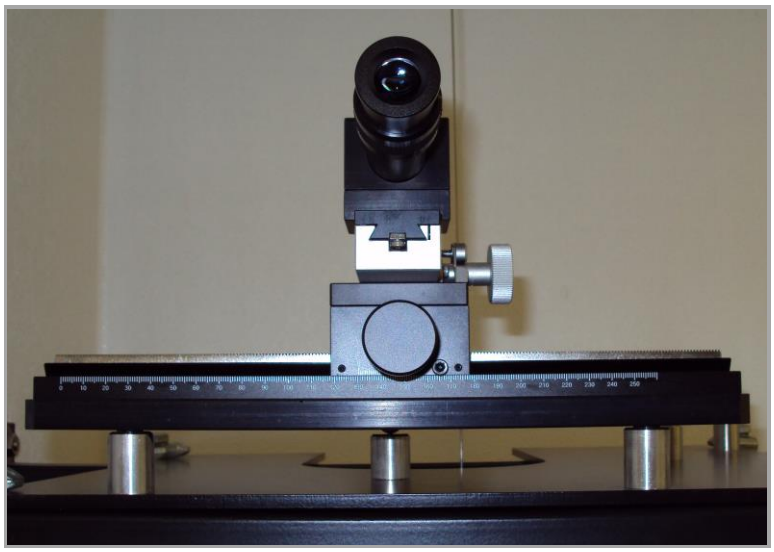
When aligned position the four sets of clamps over the clamping bars and tighten to secure the reading table to the wall brackets.

Cut and fit the plastic cover strips to the exposed sections of the wall brackets and fit the plastic end caps.

Section 4 : Taking Readings

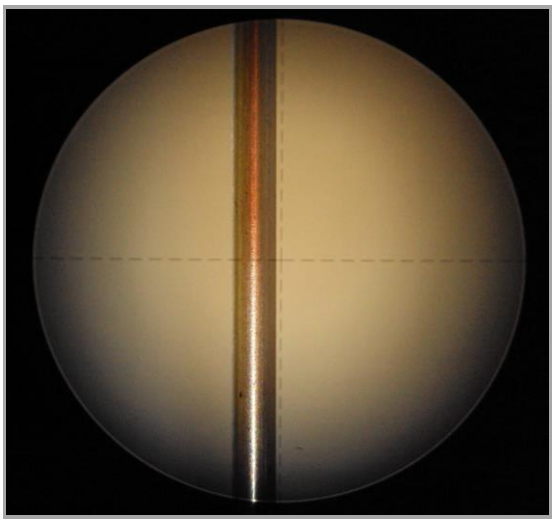
4.01 Operating the portable measurement microscope

The Portable Measurement Microscope comprises a telescope with fine "graticules" for viewing the pendulum wire, mounted on a Vernier scaled slide with adjustments for focus and measurement. When not in use the Microscope must be kept in the carrying case provided for protection. The reference frame has two fixed mountings which allow accurate location of the portable measurement microscope. These mountings are fixed at 90^{o} to each other to enable co-ordinate readings of the pendulum wire position to be taken when the microscope is fitted at each location.



The co-ordinate position of the pendulum wire relative to the fixed reference frame is determined by adjusting the position of the microscope to view the edge of the wire against a graticule on the telescope lens. The control knob on the front of the microscope is used for traversing the microscope along the track. The control knob on the right hand side is used to focus the microscope on the wire by moving the microscope lens toward or away from the wire

It is important to read the same edge of the wire each time a measurement is taken; this is usually the left hand edge. Alternatively, each wire edge maybe recorded and the average of the two readings obtained.



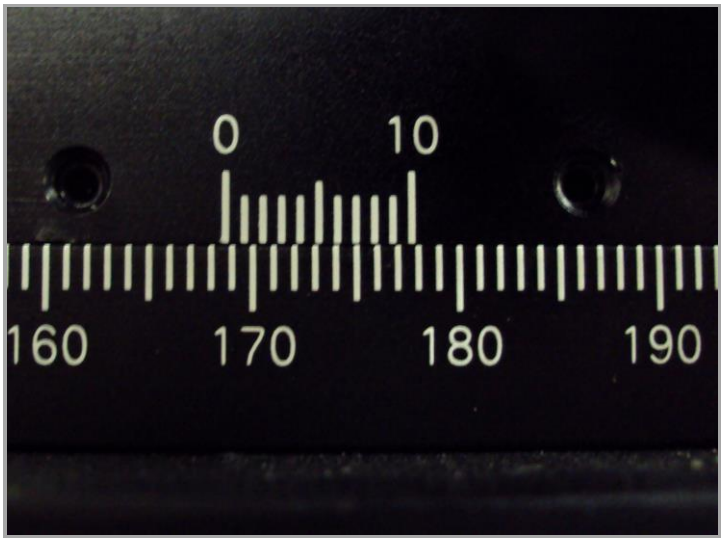
With the graticule aligned with the edge of the wire the microscope position is read-off the Vernier scale and recorded.

To read the Vernier scale take the closest line on the lower scale that is to the left of the zero line on the upper scale, in the example below it is the 168mm line and is called the lower scale reading.

Now read the line on the upper scale that best aligns with a line on the lower scale, on the example below it is the 7^{th} line.

Each of the lines in the upper scale equates to 0.1mm so the 7^{th} line is 0.7mm.

Add this to the lower scale reading to obtain the total reading, in the example below this is 168.7mm.



This procedure is repeated again at 90^{o} in the other reading location for the second axis.

The two axes readings obtained are noted on a suitable record sheet as required.

It is essential to carefully establish the first set of readings; these represent the "base datum" from which all future movements are referred.

4.02 Routine maintenance and servicing

The inverted pendulum is a very simple system requiring little servicing.
The following maintenance points will ensure trouble free operation:-

Before taking readings always check the water level in the float tank. Ensure that the float is fully submerged and completely clear of the bottom of the tank.

If the water in the tank is at the correct level but the float is not sufficiently submerged it may be necessary to slightly re-tension the pendulum wire.

Always protect the portable microscope by keeping it in it carrying case when not in use.

Avoid damage to telescope lens, only use lens cleaning tissue (as recommended for cameras).

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