Pendulums, carefully installed and used, can take inclination measurements on dam structures that are practically free of marginal influences. Displacement caused by the mass of retained water compared with the empty basin lies in the magnitude of 10^{-6}, with a maximum deviation of $5 \cdot 10^{-8}$ of the radiant due to the attraction of the moon or sun. The quality of measurements depends mainly on the standard of the readout unit (coordimeter) and on how carefully the readings are taken.

There are two types of pendulum systems (Fig. 1):

- Plumb line or hanging pendulum
- Inverted pendulum

Hanging plumb lines consist of an invar wire that is fastened to a suspension device at the top end of the measuring section, an oil-damped pendulum weight at the bottom end of the wire that prestresses the invar wire to a predetermined amount, and a coordimeter that enables measurements to be taken of the distance between the wire and fixed reference points at various heights of the structure. The coordimeter is able to measure two horizontal displacement components of the wire (normally orthogonal and parallel to the structure). Provided the base point can be assumed to be fixed, measurement with one reference point directly above the pendulum weight is sufficient to derive the absolute horizontal displacement of the suspension point; with several reference points it is possible to derive the horizontal components of a bending line between the pendulum weight and the pendulum's suspension.

Inverted pendulums are anchored at their deepest point and end at the top with a float that can move freely in a float tank. In both versions the wire tension lies at between 20 and 200 kg. The advantage of the inverted pendulum is that the measuring section can be extended with a vertical borehole into the foundation of the dam to what can be considered a firm depth; often this assumption cannot be drawn with hanging plumb lines.

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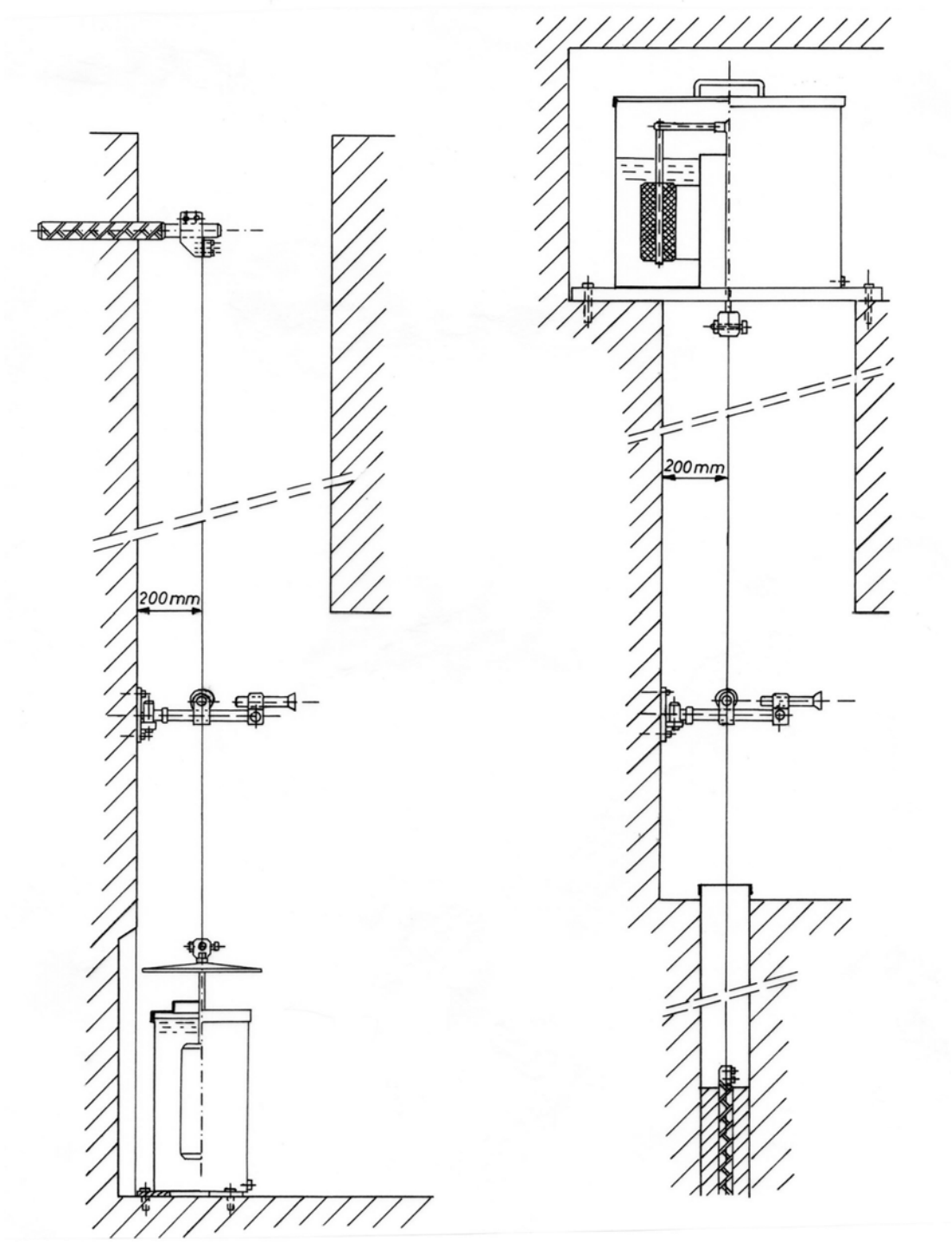

Fig. 1 Pendulum systems for inclination measurements
a) Hanging plumb line; b) Inverted pendulum

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There are two methods to measure the relative position of the wire to the structure:

1. Contactless **optical measurement** in two orthogonal directions with a so-called coordimeter. With a measuring lens the wire is sighted in both orthogonal directions parallel to the cross and longitudinal axis of the structure and the relative displacement to the zero point is manually recorded by a slide gauge with nonius. The measuring accuracy lies around 0.05 mm. Only for measurements the coordimeter is suspended at a setting board fixed at the structure and adjusted, after the measurement it is taken away. We recommend to periodically check at a control setting board with an integrated piece of wire if the coordimeter is perfectly working. It would be the best to install the control setting board definitively in a lockable niche of a control gallery in the height of the eyes.

2. Contactless **laser distance measurement** in two orthogonal directions with a laser coordimeter. This laser works according to the triangulation principle. The laser is reflected by the measuring object and projected to a pick-up element recognising the position. A distance change of the measuring object causes a position change of the light beam at the pick-up. So the distance of the measuring object gives the position of the reflected light at the pick-up element. As measuring object a cylindrical body is fixed at the pendulum wire, its distance change in x- and y-direction is continuously or intermittently measured by two laser distance measuring instruments. Both measuring values can either be read out at a unit with digital display or recorded by an automatic data acquisition system.

In both versions you have to take care that during the measurements the wire does not oscillate by air current.

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Sales Information

2.7.1 **Hanging pendulum**, consisting of:

2.7.1.1 Suspension device (stainless)

2.7.1.2 Weight 200 N (20 kg) with wire clamp

2.7.1.3 Damping vessel, h = 500 mm, d = 300 mm
measuring range +/- 75 mm

2.7.1.4 Invar wire d = 1.0 mm

2.7.1.5 Drop screen d = 300 mm

2.7.1.6 Coordimeter, measuring accuracy +/- 0.05 mm,
measuring range +/- 75 mm in cross axis or
+/- 25 mm in longitudinale axis

2.7.1.7 Setting board for coordimeter

alternative to coordimeter:

2.7.1.8 Laser coordimeter for remote recording,
read out accuracy +/- 0.05 mm,
measuring range 10 - 50 mm,
output signal 0 - 10 V,
service temperature 0 - 50° C

2.7.1.9 Digital display unit for laser coordimeter

2.7.2 **Inverted pendulum**, consisting of:

2.7.2.1 Anchorage in the borehole

2.7.2.2 Float tank with float and wire clamp,
h = 600 mm, d = 560 mm,
buoyancy 300 N (30 kg),
measuring range +/- 35 mm

2.7.2.3 Invar wire, d = 1.65 mm

for all other accessories see above

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