DAM ENGINEERING – NEW CHALLENGES-CONSTRUCTION ISSUES

PEDRO S. SÊCO E PINTO

NATIONAL LABORATORY OF CIVIL ENGINEERING (LNEC)

UNIVERSITY NEW OF LISBON

UNIVERSITY OF COIMBRA

PORTUGAL

TOPICS

- QUALITY CONTROL
- FOUNDATIONS TREATMENT
- SURFACE COMPACTION
- MONITORING AND DAM SAFETY
- FINAL REMARKS AND TOPICS FOR DISCUSSION

Sir W. Bragg- British Scientist

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them"

QUALITY CONTROL
Core Materials

- Hilf Method
- Sand cone equipment
- Quality control criteria based on binomial distribution for the acceptance or rejection of compacted layers
- For measuring dynamic core materials properties LNEC has a cyclic simple shear equipment and also a cyclic torsional shear device

QUALITY CONTROL
Shell Materials

- Leveling of an area of compacted rockfill
- A steel ring is placed and rockfill within the ring is excavated
- Polyethylene sheet is laid inside the ring and the volume of the hole excavated is measured by filling it with water
- Rockfill density is derived from the weight of the rockfill excavated and the volume of the hole
- Grading of the rockfill removed is determined

QUALITY CONTROL
Shell Materials

- For the determination of rockfill strength and deformation LNEC has a triaxial equipment to test cylindar specimens of 0.70 m high and 0.30m diameter and a oedometer to test specimens of 0.50 m diameter
- Maximum participle size must be no more than one fifth the diameter of the test specimen as test results are heavily influenced by the shape of the grain size curve

QUALITY CONTROL
Filter and Drain Materials

- Gradation and permeability tests are performed both before and after placement at a frequency of about one test per 5000 m3
- Permeability tests in samples with 1.70 m long and 0.70 m width and 0.70 m high were performed in a special device

  K= 35x 10-4 (D15)2 (where K is m/s and D15 in mm)

QUALITY CONTROL
Rip-Rip Material

- For the rip rap material of upstream slope of Corumana dam an equipment was installed that allows the production of 4 different gradation
- The materials were obtained from a blasting of a ryolite quarry

FOUNDATION TREATMENT

EMBANKMENT DAM

USE OF SLURRIES FOR THE CONSTRUCTION OF PLASTIC AND FLEXIBLE DIAPHRAGM WALL

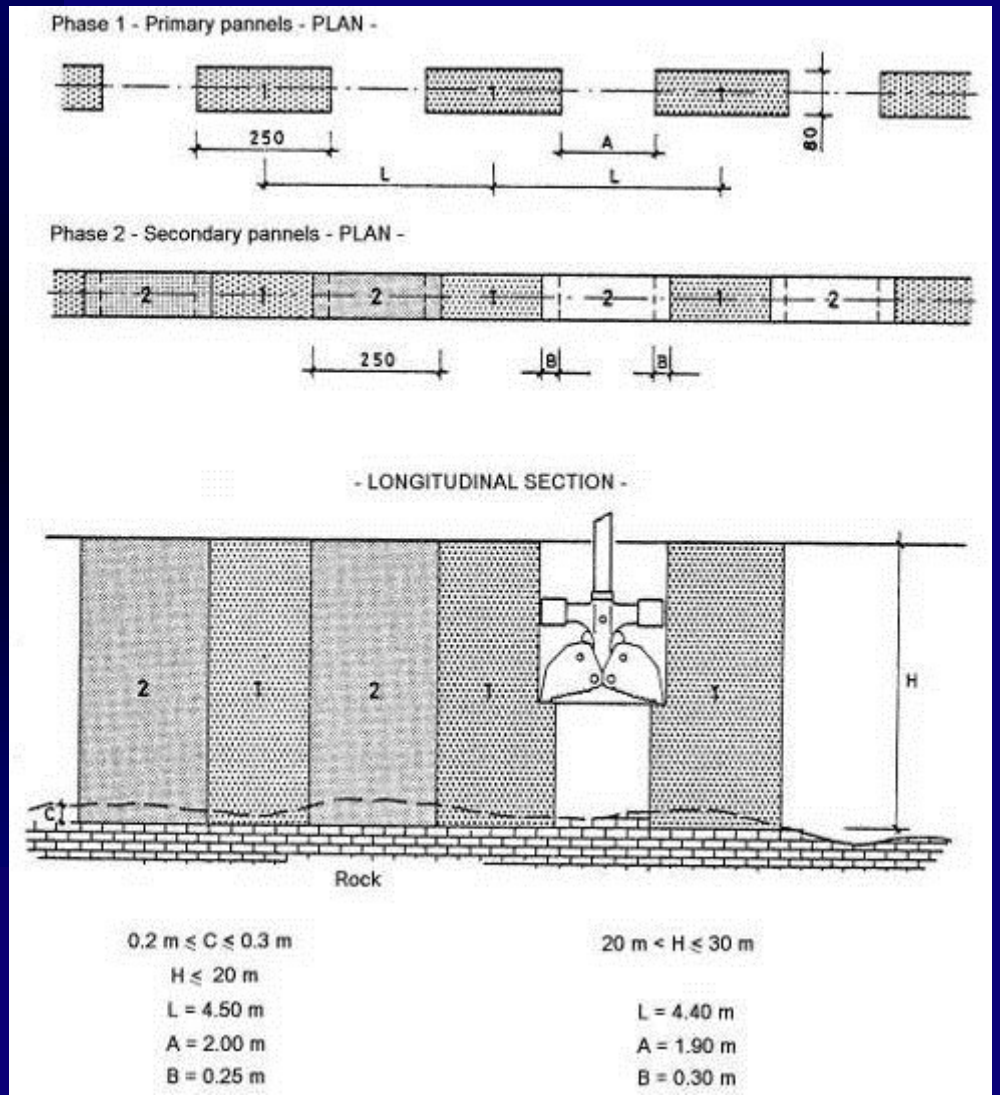
EMBANKMENT DAM

Embankment dam with 50 m high and 3000m long

FLEXIBLE DIAPHRAGM WALL

- Dam foundation composed by alluvial sandy materials with high permeability
  - Guide walls with 1.0 m depth and 0.30 m thick
  - Diaphragm wall with 30 m depth and 0.80 m thick and panels length of 3.0 m
  - Overlapping between primary and secondary panels 0.30 m
  - Penetration of the panels in bedrock minimum 1.0-2.0 m
  - Vertical deviation of the wall 1:133 =0.0075

DIAPHGRAM WALL PHASES



DIAPHGRAM WALL COMPOSITION

- Bentonite –Liquid limit = 400%
- Sand content less 15%
- Bentonite/Water = 8%
- Cement / Water ratio = 0.25
- Admixture NaOH/ Bentonite = 0.6%

EXCAVATION

Position of tool
Verticality and continuity between excavation units
Ground profile
Depth of excavation
Self-hardening slurry level
Boulders or obstructions in the ground

QUALITY CONTROL

Self –hardening slurry

Density =1.2-1.3
Ph value higher 8

Marsh values = 32-35 sec
Setting time
Bleeding

Compressive strength
(250-500 kPa 28 days

Permeability less 10-8 m/s
Axial deformation< 4%
Erosion tests for gradients around 75

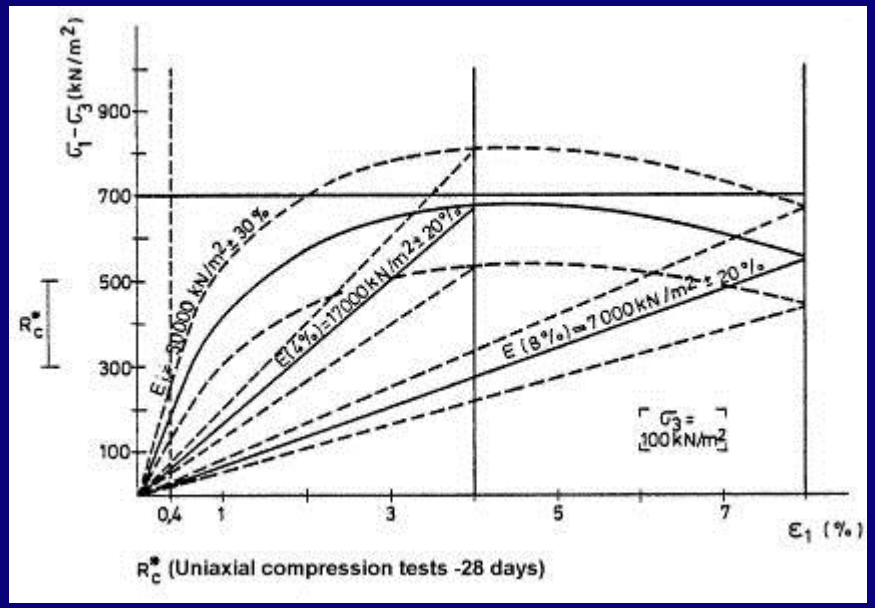
INSTRUMENTATION

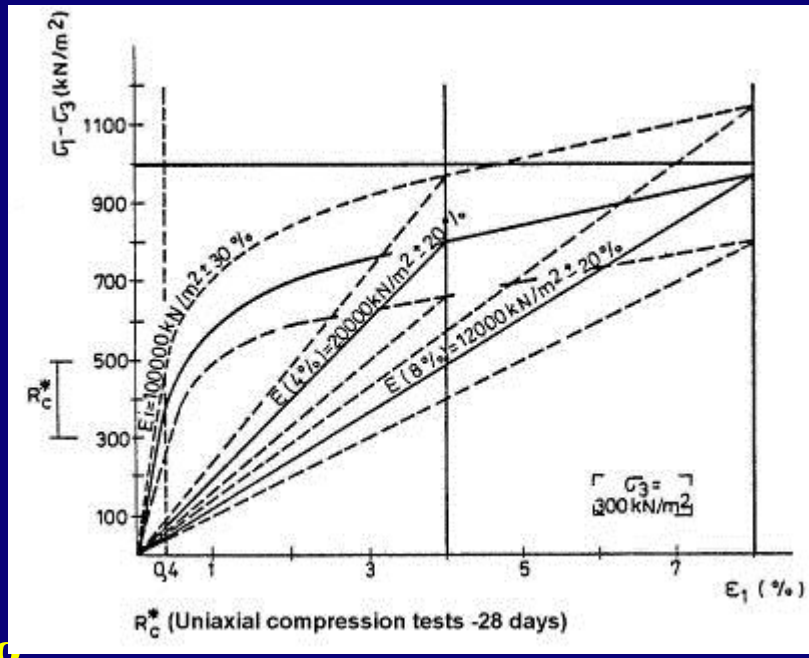
Piezometers placed in the upstream and downstream side of the diaphragm wall and with narrow mesh in the downstream side

Inclinometers placed in the upstream side of the diaphragm wall

Total pressure cells placed in the cap of the diaphragm wall

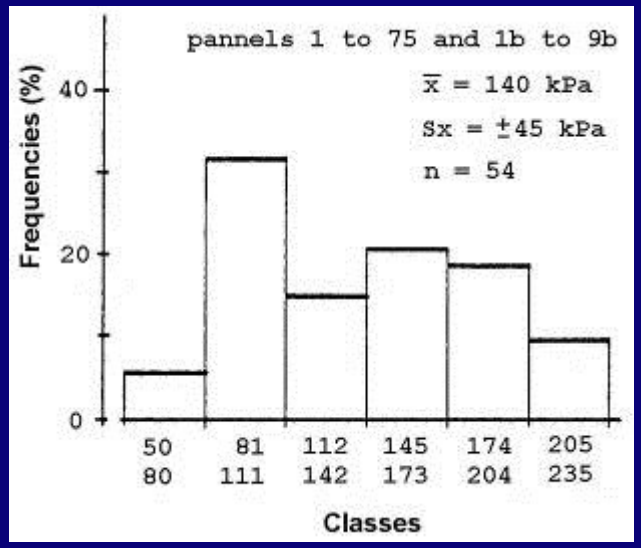
DIAPHGRAM WALL SPECIFICATIONS

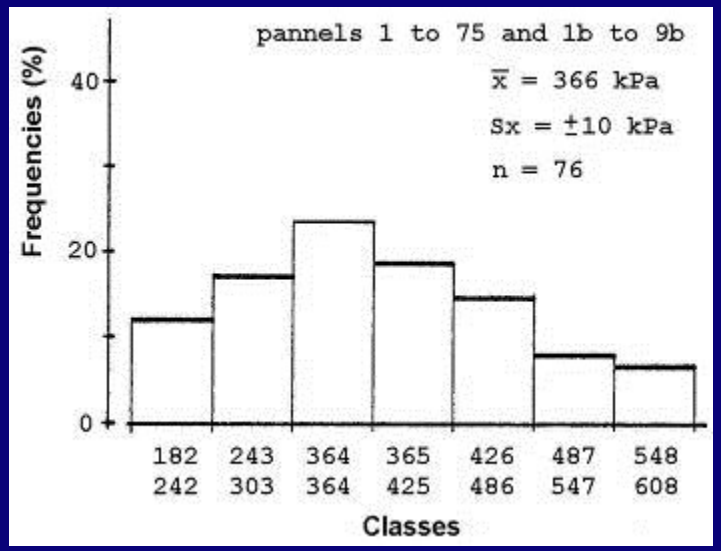




For triaxial tests the deviator stress >700 kPa and > 1000 kPa for confining pressures of 100 and 300 kPa

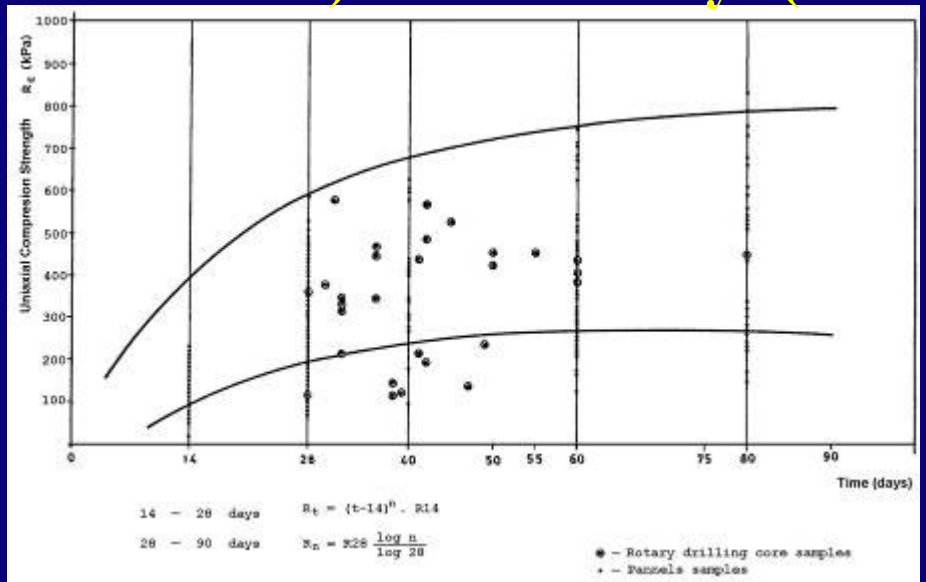
QUALITY CONTROL





Uniaxial compression tests 14 days (values in kPa)

Uniaxial compression tests 28 days (values in kPa)



SUMMARY

- To assess the mixtures characteristics a careful control of the components was performed

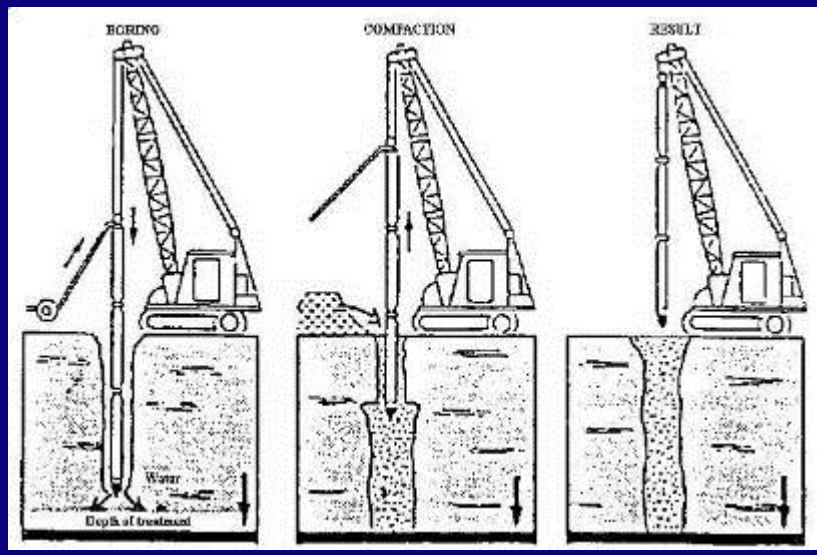
- For the execution of pannels, due the high temperatures, admixtures to increase the setting time were used

- The quality control of the slurries has shown that the design specifications were fulfilled

- The instrumentation has shown the efficiency of the diaphragm wall

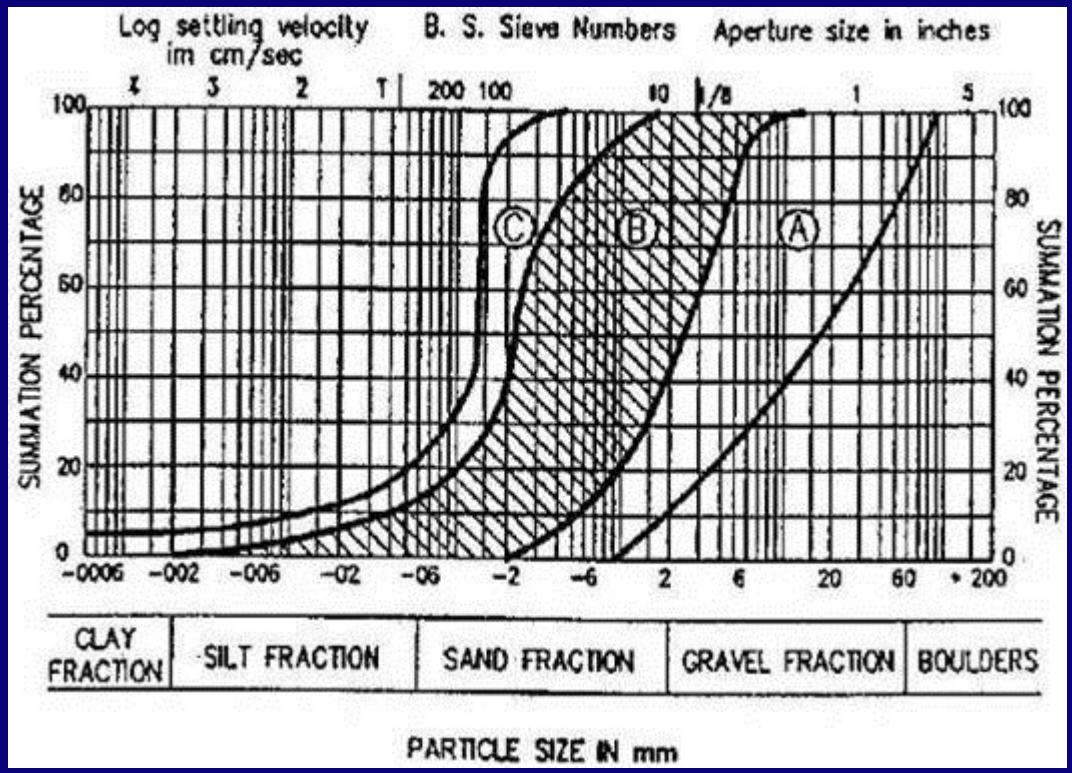
VIBROFLOTATION

- A VIBRATOR CREATES VERTICAL AND HORIZONTAL VIBRATIONS
- THE DEPTH OF COMPACTION DEPENDS OF : (I) MAXIMUM ALLOWABLE TOTAL SETTLEMENT; (II) MAXIMUM ALLOWABLE DIFFERENTIAL SETTLEMENT; (III) REQUESTED BEARING CAPACITY; (IV) FINAL SHEAR STRENGTH VALUE; AND (V) INCREASED RESISTANCE TO LIQUEFACTION
- THE TREATMENT EFFICIENCY IS EVALUATED BY : (I) SPT TESTS; (II) CPT TESTS; (III) PRESSUROMETER TESTS ; (IV) LOAD TESTS



VIBROFLOTATION

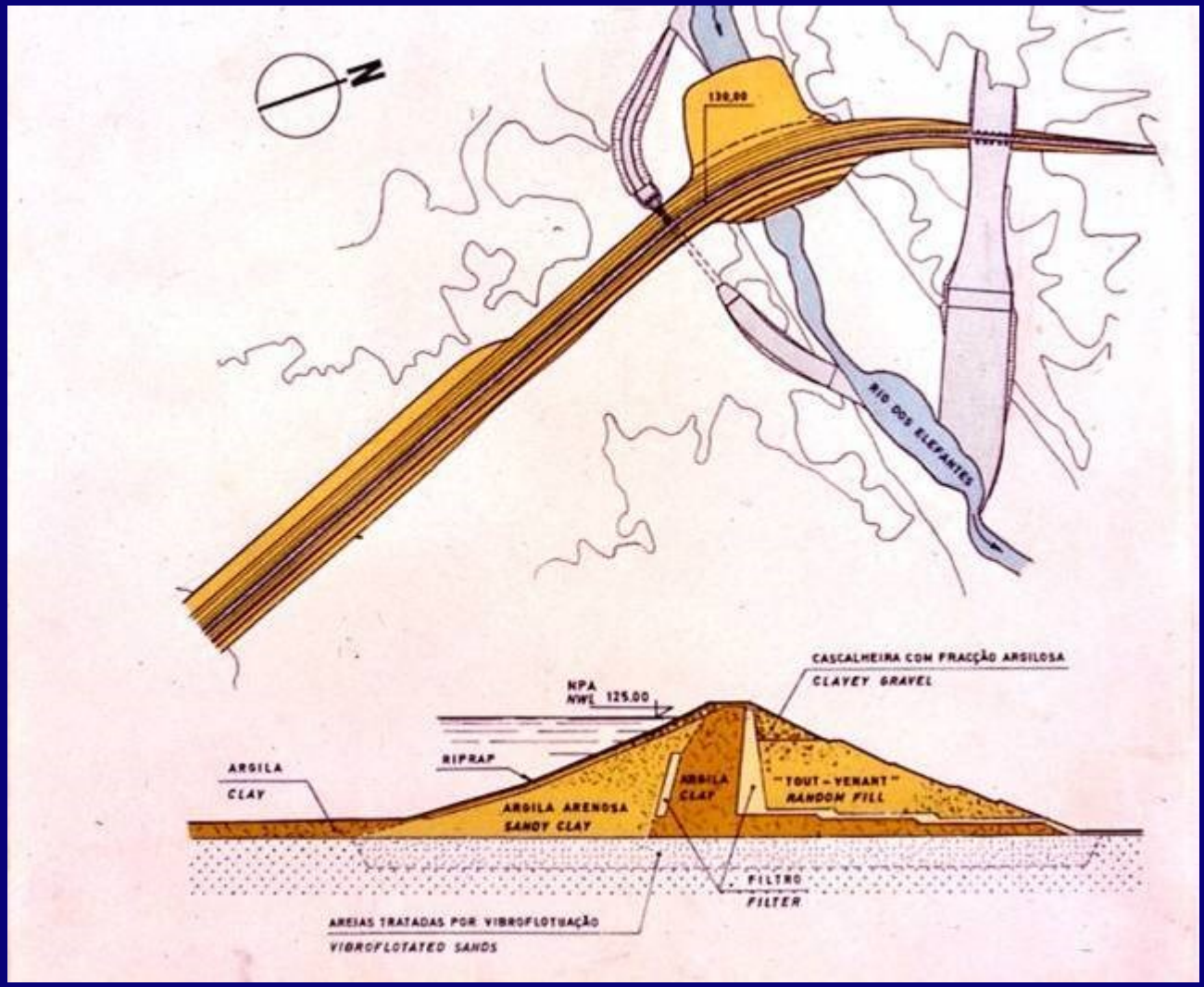
- Grain size distributions within zone B are excellent soils for densification by vibroflotation
- For soils with grain size distribution falling within zone C require some modifications of compaction procedures due the presence of silt and excessive fines material (over 15% passing on sieve 200)



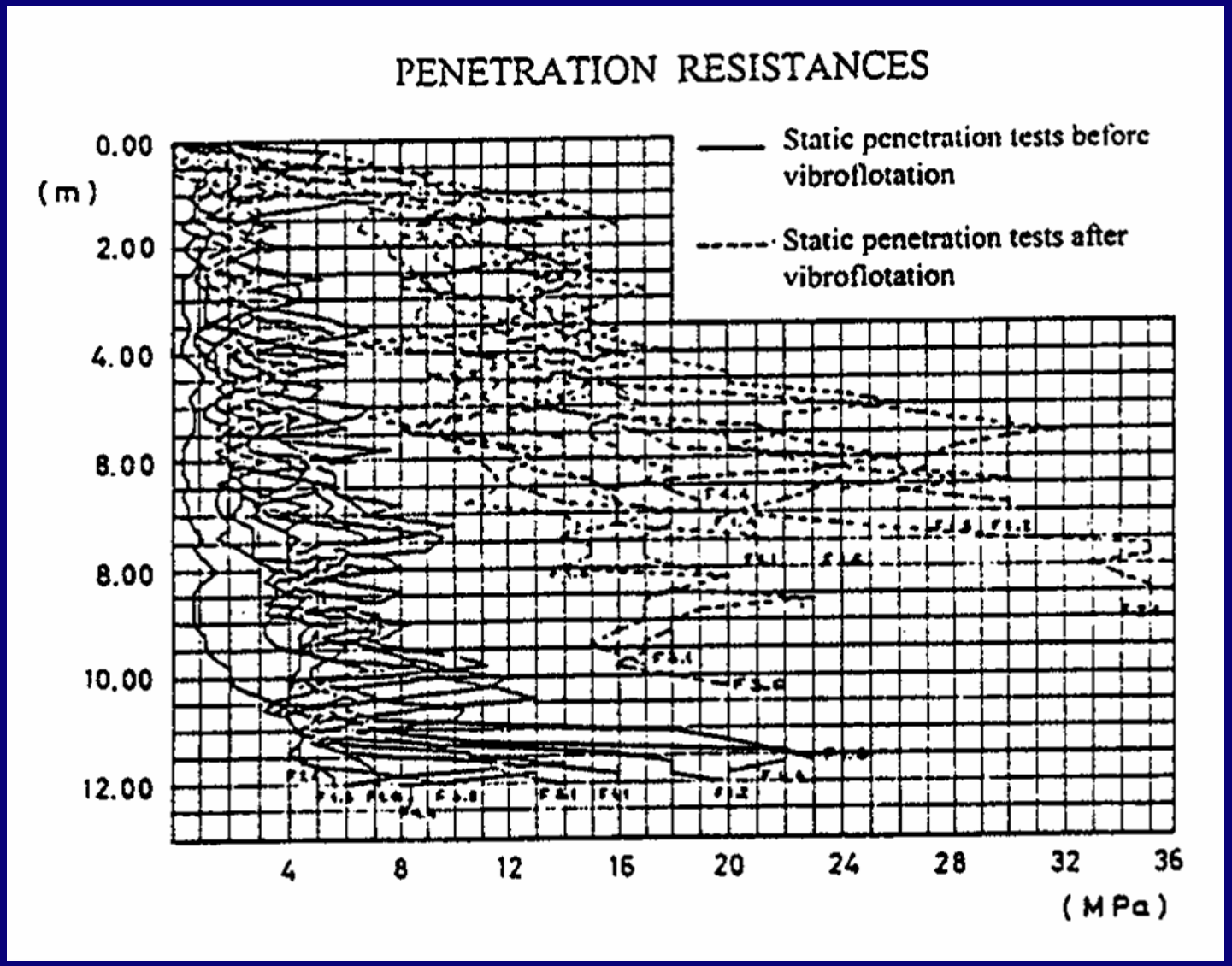
VIBROFLOTATION TREATMENT OF MASSINGIR DAM FOUNDATION

- DUE TO LOW DEGREE OF COMPACTION OF THE ALLUVIA AND THE SEISMIC CHARACTERISTICS OF THE AREA, TREATMENT BY VIBROFLOTATION WAS ADOPTED TO AVOID LIQUEFACTION OF SANDS
- THE TOTAL LENGTH OF THE EARTH DAM IS 4596 METERS, WITH A MAXIMUM HEIGHT OF 48 METERS AND WITH A WIDTH OF 12 METERS AT THE CREST
- THE VALLEY IS PARTIAL FILLED BY SANDS OF DIFFERENT GRADING, VARYING FROM FINE TO COARSE, COARSE SANDS PREVAILING, SOMETIMES WITH BOULDERS AND BEDROCK FORMATION WAS FOUND AT 26 M DEPTH

MASSINGIR DAM PLAN AND PROFILE

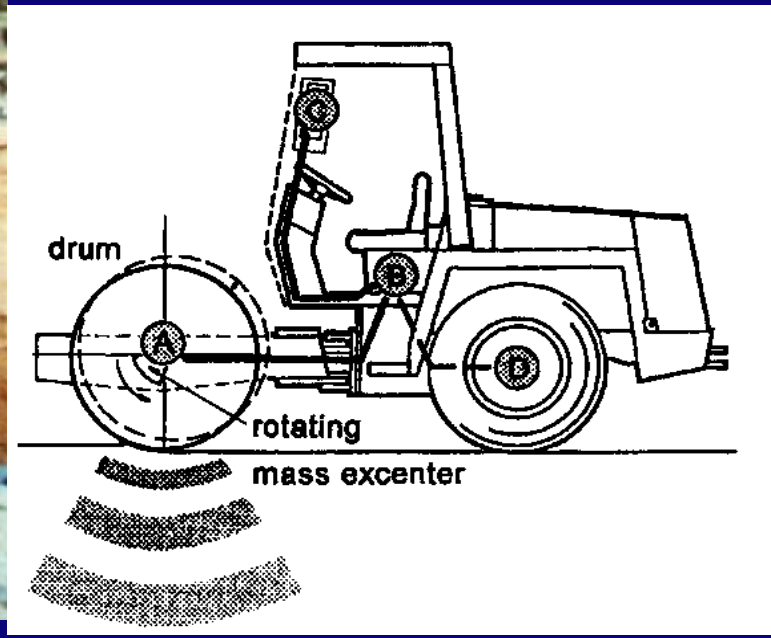


VIBROFLOTATION TREATMENT OF MASSINGIR DAM FOUNDATION



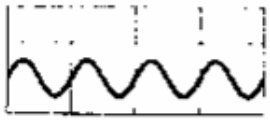
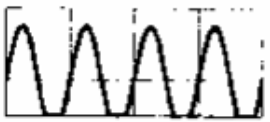
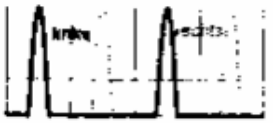
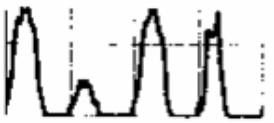
SURFACE COMPACTION

EARTH MASSES ARE PLACED IN LAYERS
EQUIPMENTS: SMOOTH ROLLERS, TAMPERS, GRADERS AND VIBRATORY PLATES
EFFECTIVE DEPTH OF COMPACTION IS LIMITED



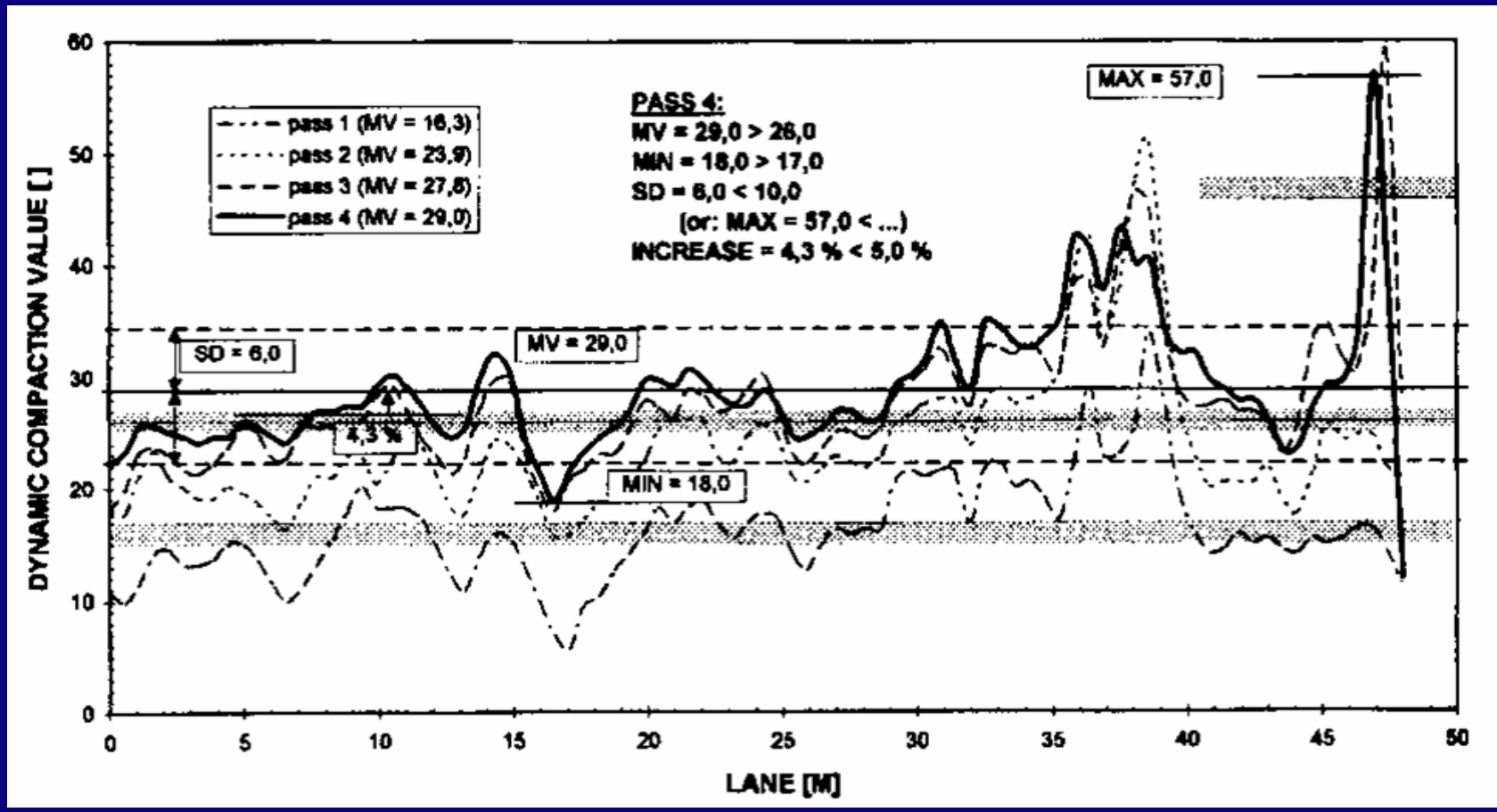
SURFACE COMPACTION

Definition of the operation modes of vibratory rollers and their qualitative relationship with soil stiffness (after Brandl, 2006)

drum motion	interaction drum-soil	operating condition	soil contact force	application of CCC	soil stiffness	roller speed	drum amplitude
periodic	continuous contact	CONT. CONTACT		yes	low	fast	small
	periodic loss of contact	PARTIAL UPLIFT		yes			
		DOUBLE JUMP		yes			
		ROCKING MOTION		no			
chaotic	non-periodic loss of contact	CHAOTIC MOTION		no	high	slow	large

SURFACE COMPACTION

Progress of CCC-data and CCC-criterial: MV = mean value, MIN = minimum value, MAX = maximum value, SD = standard deviation, INCREASE = increase between two roller passes(after Brandl et al, 2005)

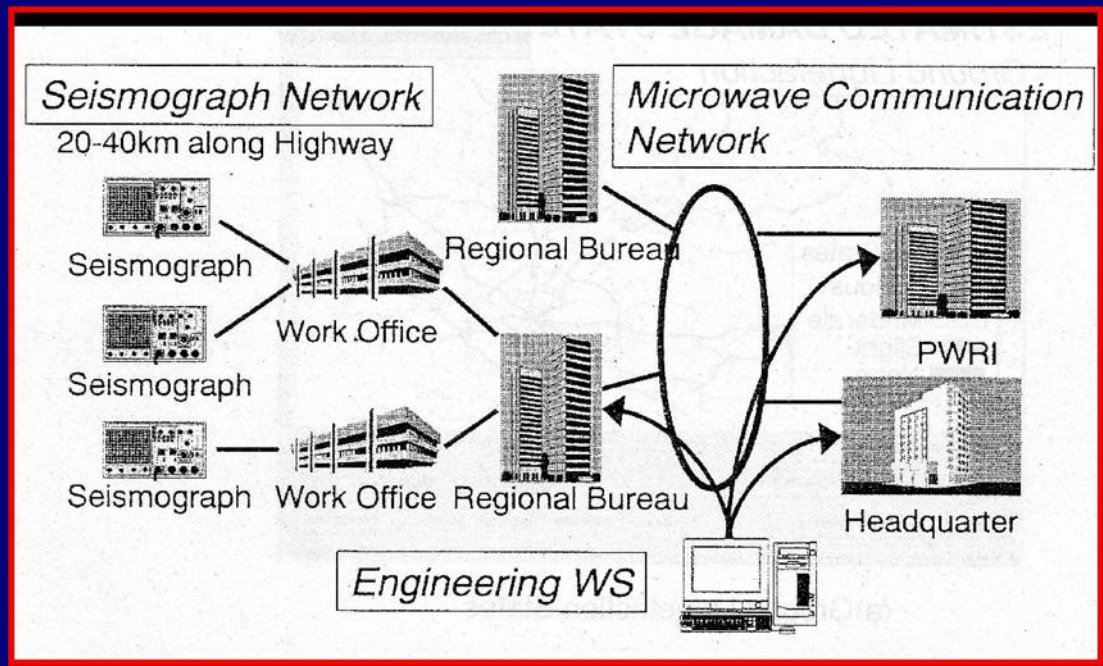


MONITORING AND DAM SAFETY

- **POTENTIAL RISK DEPENDS ON STORAGE CAPACITY, HEIGHT OF THE DAM, DOWNSTREAM DAMAGE AND EVACUATION REQUIREMENTS**
- **SEISMIC DOWNHOLE ARRAY DATA PROVIDE SOURCE OF INFORMATION**

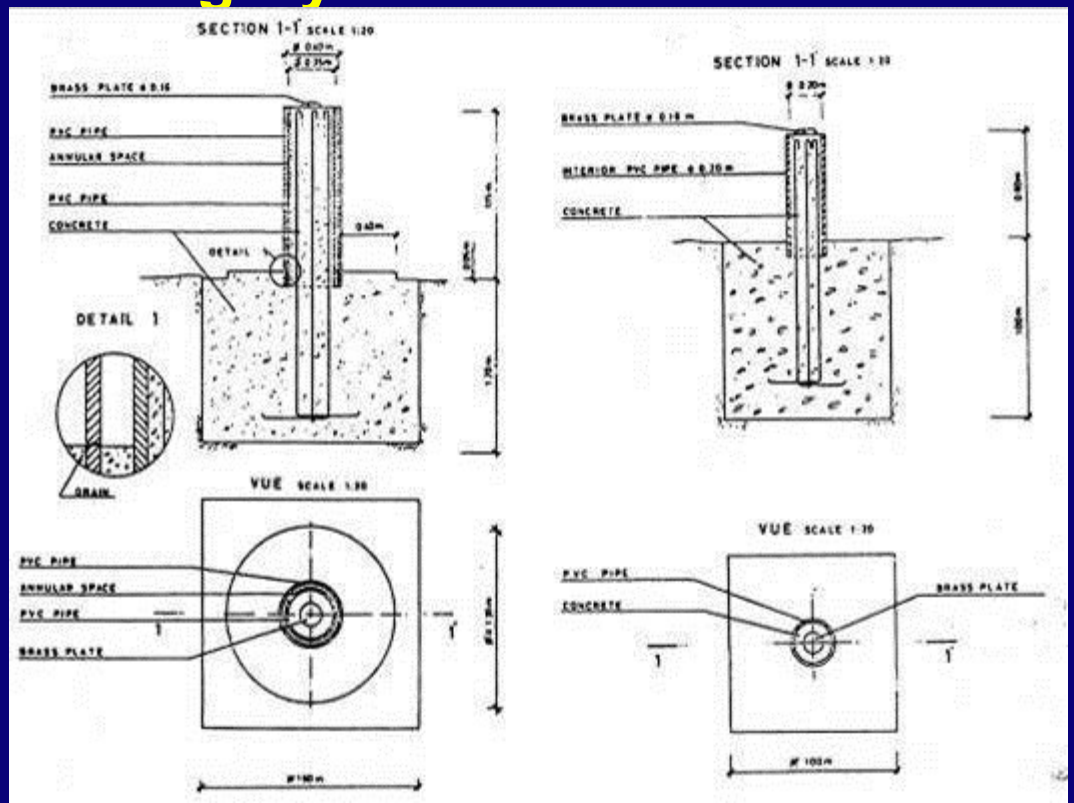
OBSERVATION PLANS

- **RISK FACTORS ARE RELATED WITH ENVIRONMENTAL, RELIABILITY AND HUMAN AND ECONOMIC HAZARD**
- **NETWORK OF SEISMIC RECORDING STATIONS SHALL BE INSTALLED PRIOR TO RESERVOIR FILLING**



SURFACE MOVEMENT MEASURING DEVICES

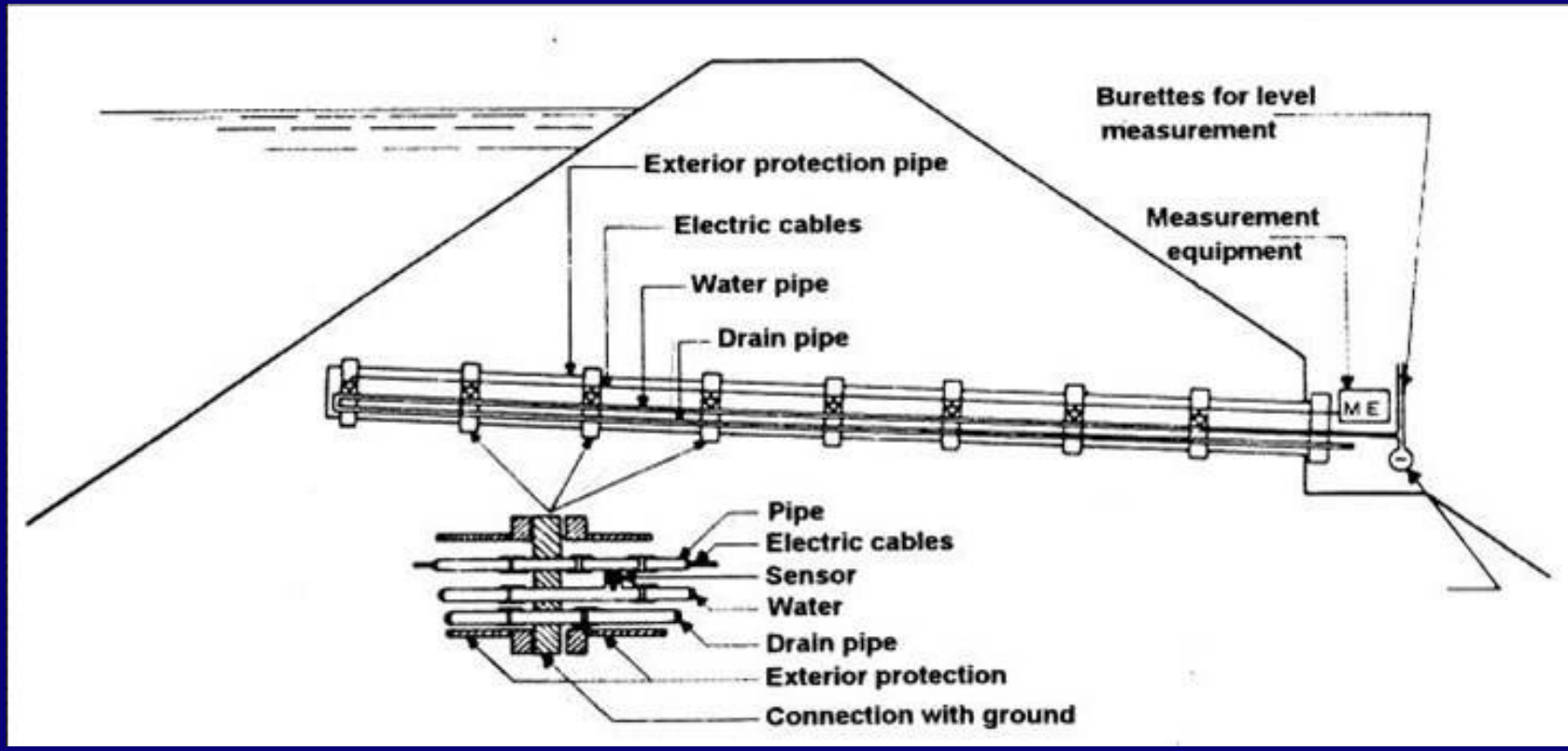
- Application of techniques of trilateration measurement technology has achieved the degree of precision required to assure, with confidence, the safety and integrity of the dams



VERTICAL INTERNAL MEASURING DEVICES

IVM device

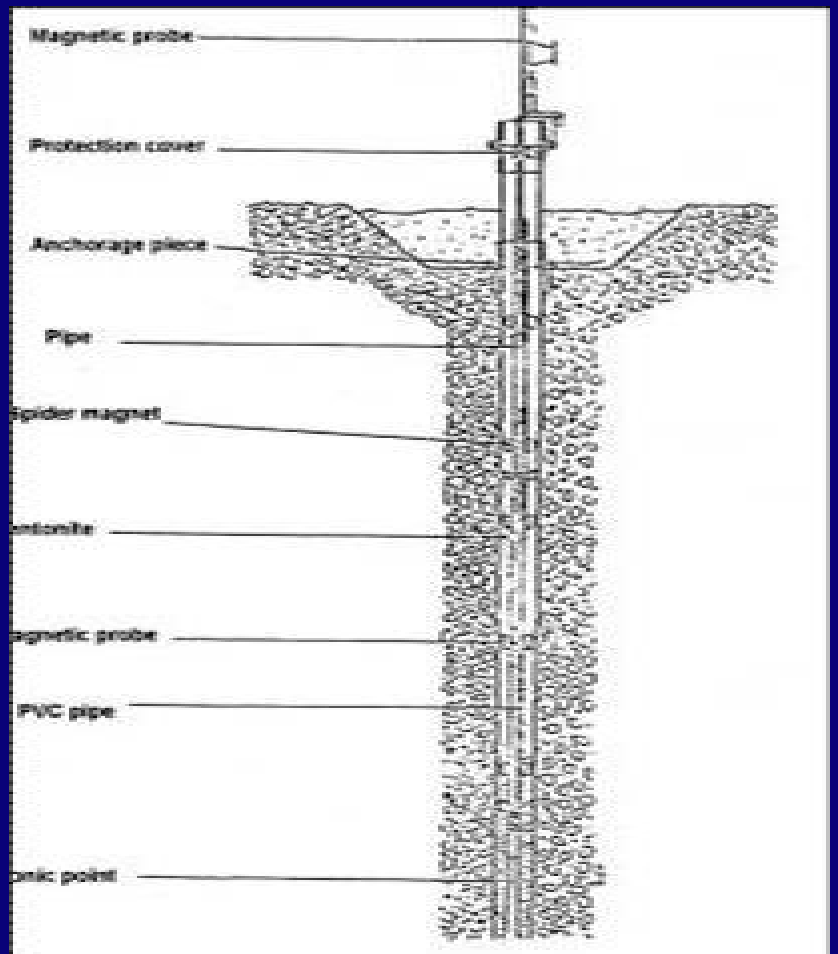
Liquid level gages



VERTICAL INTERNAL MEASURING DEVICES

Magnetic probe

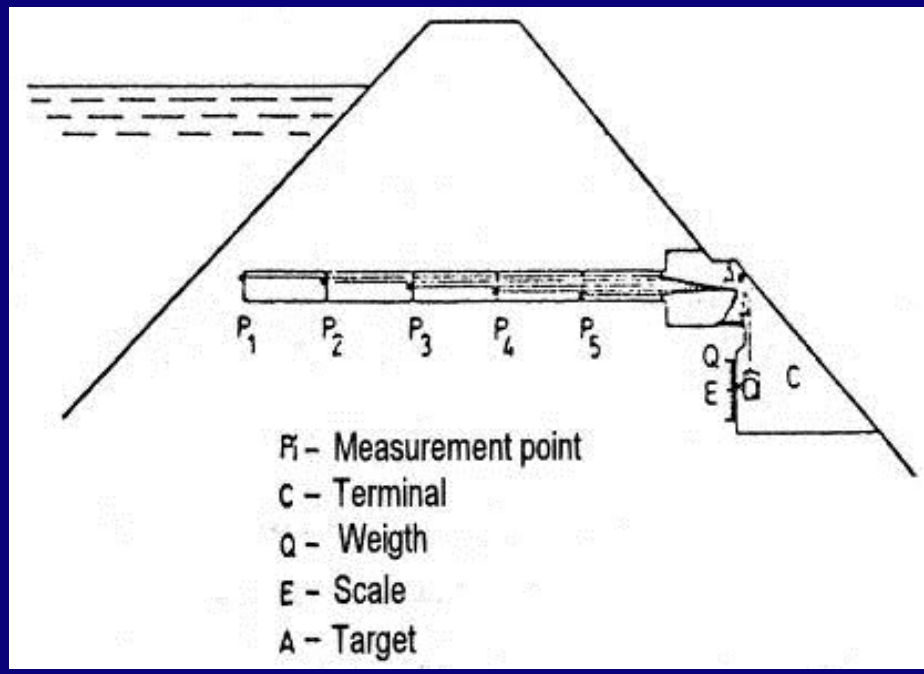
Pneumatic settlement sensor



HORIZONTAL INTERNAL MEASURING DEVICES

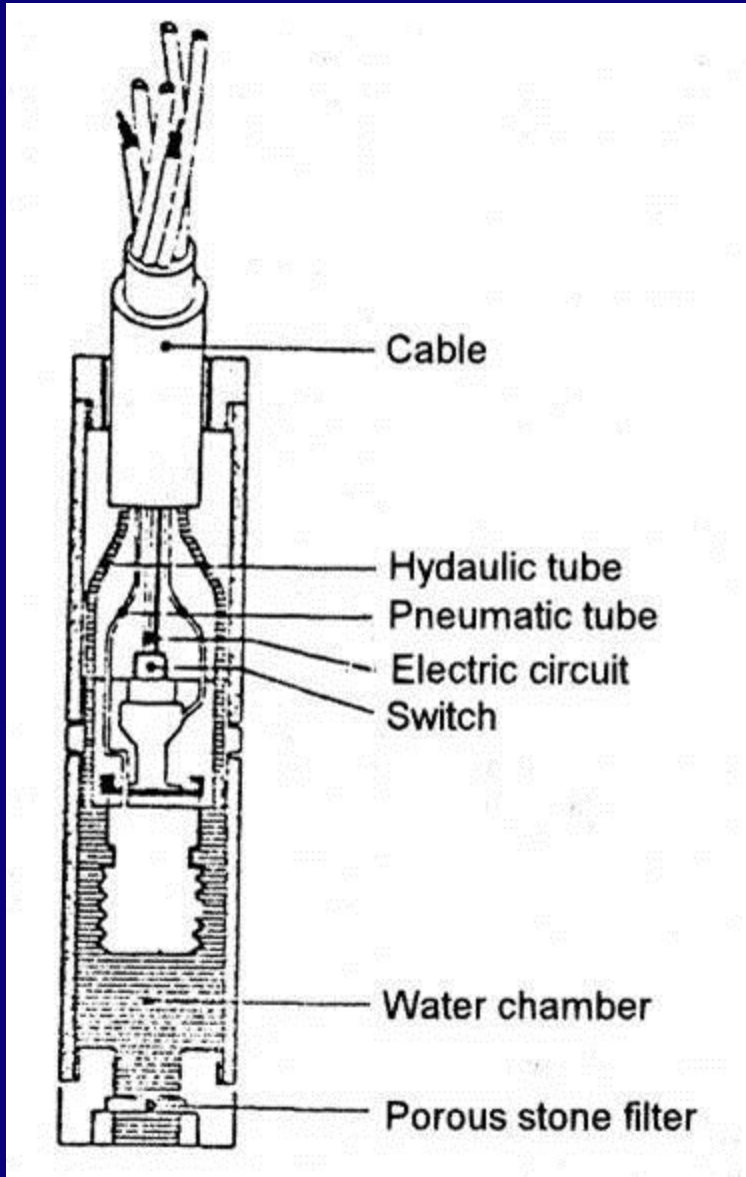
Inclinometers

Extensometers



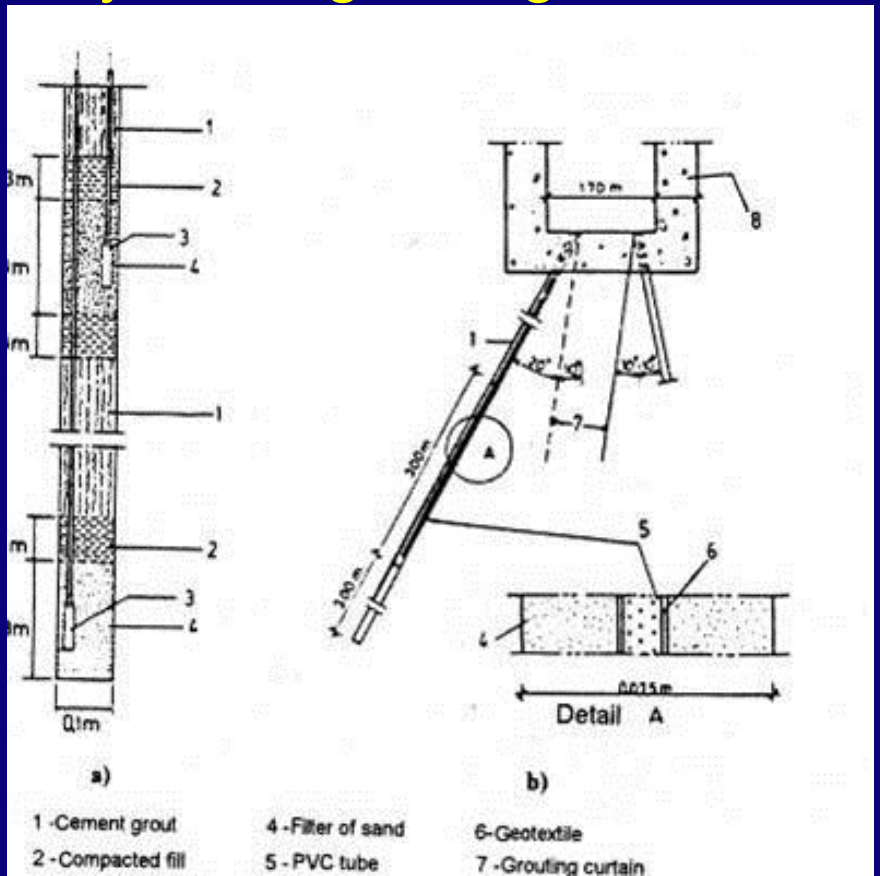
PORE WATER PRESSURES

- Vibrating - wire piezometer
- Hydraulic twin-tube piezometers
- Hydraulic Piezometers
- Pneumatic piezometers



FOUNDATION

The instalation of piezometers with radial distribution is particulary implemented for foundations. The boreholes are slightly inclined for upstream and downstream of the grouting curtains, in order to evaluate the pore pressures and the efficiency of the grouting curtain



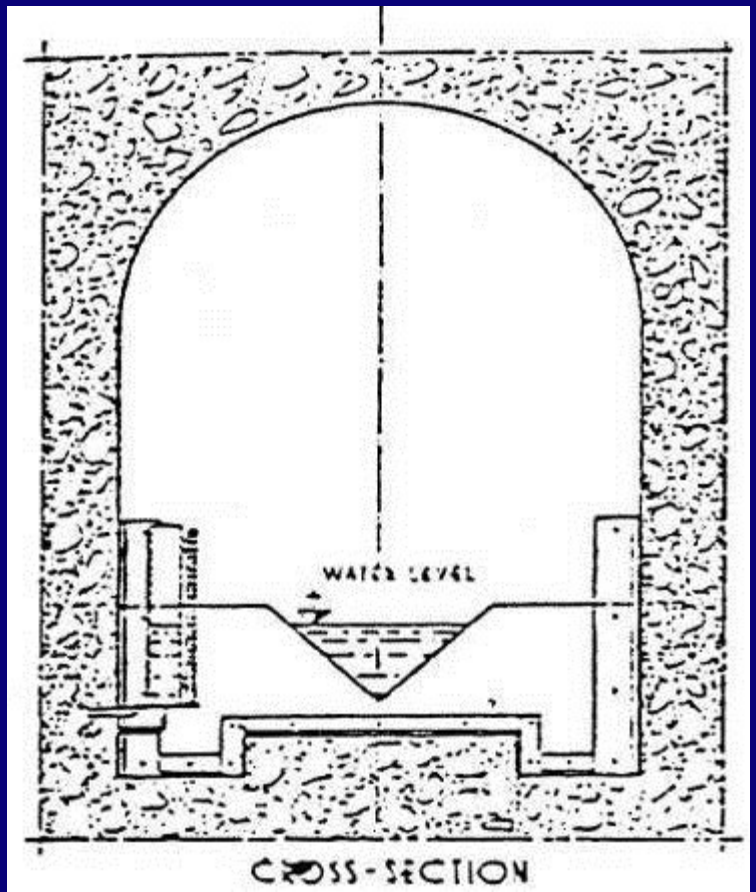
TOTAL PRESSURE CELL

Pneumatic Total Pressure Cell

Vibrating - Wire Total Pressure Cell

SEEPAGE MEASURING DEVICES

Leakage data is undoubtedly the best indicator of the overall performance of a dam. The reason for this is that leakage is an integrated quantity and, thus reflects the performance of the entire dam not just the conditions at discrete instrument points



SEISMIC INSTRUMENTATION

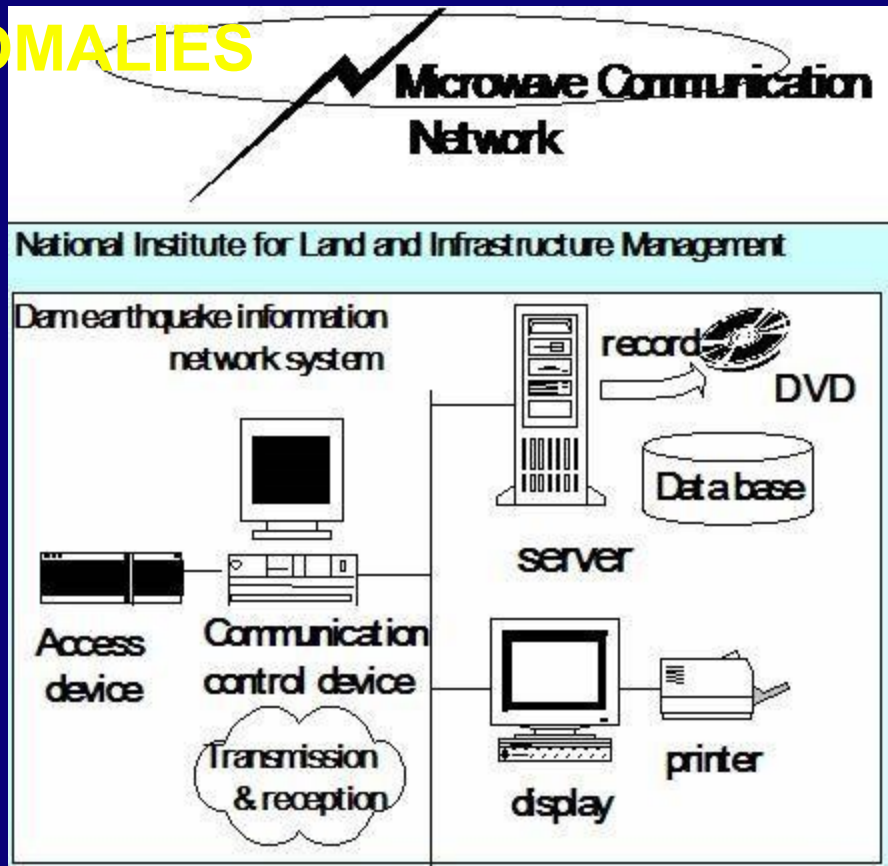
- SEISMIC INSTRUMENTATION TO ASSESS SEISMICITY AROUND THE RESERVOIR AND THE RESPONSE OF THE DAM
- STRONG –MOTION ACCELEROGRAPHS, PEAK RECORDING ACCELEROGRAPHS AND SEISMOSCOPES

DATA ACQUISITION

- AUTOMATIC SYSTEM ALLOWS A RAPID DATA PROCESSING AND REDUCTION OF PERSONAL
- AUTOMATIC SYSTEM IMPLIES AN INCREASE OF COMPLEXITY AND CAN BE DESTROYED BY AN EARTHQUAKE

DATA MANAGEMENT

- COLECTION OF DATA FOR SOME INTERVALS
- CHECK OF DATA TO ASSESS THE RELIABILITY
- DATA STORAGE
- MANAGEMENT OF ANOMALIES
- POSSIBILITY OF COMMUNICATION WITH REMOTE UNITS



DATA VALIDATION

- COMPARISON OF THE READINGS WITH ESTABLISED LIMITS
- USE OF STATISTICAL, DETERMINISTIC OR HYBRID MODELS
- USE OF BACK ANALYSIS METHODS FOR THE INTERPRETATION OF THE BEHAVIOR OF DAMS

SAFETY CONTROL

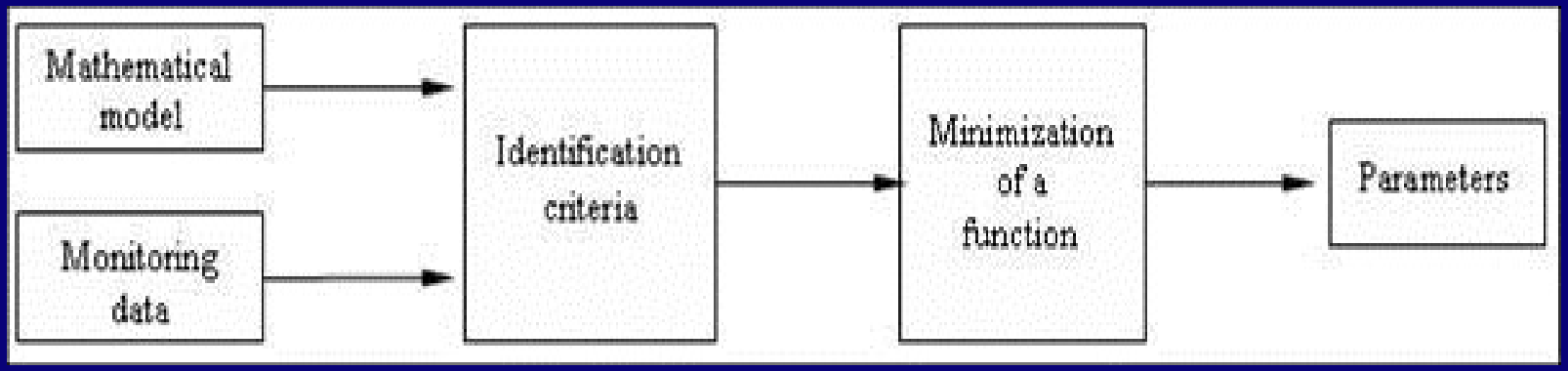
- **REGULAR MEASUREMENTS USING INSTRUMENTATION**
- **DATA VALIDATION**
- **DATA STORAGE**
- **SAFETY EVALUATION**
- **CORRECTIVE ACTIONS**

SAFETY CONTROL

- LNEC has developed a new system GESTBARRAGENS to deal with automatic data acquisition, very flexible, that allows users to perform treatment of the information integrating tests and analysis, behavior models, visual inspections, documents data by any computer connect with Internet visualization
- Application of expert system technology to dam safety control activities may contribute to improve its speed, provide higher levels of economy, robustness and efficiency

SAFETY CONTROL

The use of back analysis methods for the interpretation of the behavior of dams is increasing. The more general back analysis methods are based on the minimization of a function on the parameters to be identified, which is established with the monitoring data and correspondent values calculated with a mathematical model



VISUAL INSPECTIONS

- INSPECTIONS BEFORE THE FIRST FILLING
- INSPECTIONS AFTER THE FIRST FILLING
- INSPECTIONS AFTER EXCEPTIONAL OCCURRENCES
- DURING INSPECTIONS THE FOLLOWING ASPECTS DESERVE ATTENTION: DAM BODY, SPILLWAY, OUTLET WORKS, RESERVOIR AND ACCESS ROAD

ORGANIZATION of MONITORING ACTIVITIES in PORTUGAL

- The dams safety regulations are applied to dams that present great or significant human or economic hazards construction, and to all dams more than 15 meters high and to dams that are less than 15 meters high when their reservoir has a capacity of over 100 000 m^3
- (1) Authority who is responsible for the execution of the safety activities; (2) LNEC (National Laboratory of Civil Engineer); (3) Owner ; (4) SNPC (National Civil Defense Service); (5) and on Dam Safety Committee

FINAL REMARKS AND TOPICS FOR DISCUSSION

- DIAPHGRAM WALLS

–Procedures to control the diaphgram wall behaviour and efficiency

- VIBROCOMPACTION

–(i) Use of vibrocompaction in hydraulic fills to increase the strength related liquefaction

– (ii) The presence of boulders, utilities and adjacent structures

- SURFACE COMPACTION

–Implementation and benefits of roller-integrated continuous compaction control (CCC)

FINAL REMARKS AND TOPICS FOR DISCUSSION

- What are the advantages and limitations of automatic system with teletransmission during exceptional events such as earthquakes and large floods?
- Benefits of conducting regular and exceptional visual inspections
- Continuing education is highly recommended to follow the very fast developments of earthquake geotechnical engineering and particularly of dam engineering

Francis Bacon - Advancement of Learning

“If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties”