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Autor: Kavyrchine, M.
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Inspection and Monitoring

Inspection et enregistrement des mesures

Überwachung und Bestandesaufnahme

M. KAVYRCHINE
C.E.B.T.P.
Saint-Rémy-Les-Chevreuse, France

SUMMARY
This report gives a general presentation of the aims and methods of investigation in use of damage of structures. It is written to provide a basis for discussion and provoke contributions on the matter of inspection and monitoring.

RESUME
Ce rapport présente les buts et méthodes d'investigation utilisés pour des structures endommagées. Il représente une base de discussion et a pour but de susciter des contributions au sujet de l'inspection et de l'enregistrement des mesures.

ZUSAMMENFASSUNG
Dieser Bericht behandelt die Ziele und Methoden zur Feststellung der Ursachen und Ausbesserungen baulicher Mängel. Er schafft eine Diskussionsgrundlage für Beiträge über Überwachung und Bestandesaufnahme.

1. GENERALITIES

A good knowledge of the real state and the behaviour of a building structure may be necessary for different purposes :
- to adapt the building to a new destination, a modification of its structure is needed : for instance, strengthening for higher service loads, rehabilitation of old dwellings.
- to check the capacity of an existing structure to sustain actual service conditions and present required safety.
- to analyse the danger causing some damage : for instance to detect the cause of distress to suppress it, and to verify the safety still offered by the structure.
- to define the needed repairs and design them.

To be able to establish a diagnosis on the safety of a building it is necessary to get a good information on the structural system of it and on the possible scenarios of damage, to help to define and realise direct investigation.

The origin of damage can be known from hearsay, from direct inspection and visual examination : fire, explosion, apparent corrosion, flood, wear under traffic etc... As much information as possible has then to be obtained and checked on what happened : duration and temperature of fire, importance of accidental excessive loading, influence of environment on corrosion for instance. In other cases when the causes are not obvious a careful study of the surrounding conditions and of the state of the structure are needed to give the causes and nature of distress.

Various experimental methods exist, to study the state of a structure.

One of the most important is visual examination by an expert, which gives often a good orientation for more detailled studies. A look at the appearance of concrete, see figures 1 and 4 will give for instance already useful information. More complex and precise study is performed in situ with the help of specialized equipment and with laboratory tests.

Physical properties : nature of material, its strength, permeability of concrete, resistance to frost, yield point of steel, presence of moisture, presence of small cracks, etc... can be tested on samples or directly by non destructive methods.

Dimensions, levels, settlements, deflection, rotations, width of joints, real dimensions of structural elements, have to be known.

Chemical analysis of materials, and of the environment (air, water), may be necessary.

Global measurements of the behaviour of a structure give useful information.

The use of a model to represent the behaviour is finally needed after having obtained a representation of the state of the structure.

The experimental methods to be used have to be choosen adequately, to gain time and reduce cost of investigation and to get relevant data.

The choice of the methods and of the areas to be specially studied is depending on the materials, the structural system, the causes and nature of damages, the intentions of the owner. If the intention is to increase service loads after repair, even non damaged parts have to be checked. If the main aim of the inspection is to find legal responsabilities, the measurements have to be specially defined and may be necessary even if the building is damaged beyond repair. Generally, it is necessary to inspect not only obviously damaged elements but also other parts to have a global idea of the state of the whole structure.

The knowledge of causes of disorders is useful to be able to suppress this causes, suppression which in some cases is urgent, and cannot wait for a lengthy examination. A further examination has to take into account the possible origin of the damages.

So we propose a classification of causes and damages, with a correlation between both of them, then to examine the methods of investigation, taking into account their reliability.

We are considering structural damages on buildings made of reinforced or prestressed concrete, masonry, steel, wood.

2. CLASSIFICATION OF CAUSES OF DAMAGE - CORRELATION BETWEEN CAUSES AND DAMAGES

2.1. Immediate cause of damage

Excessive loading, or insufficient strength of the structure under normal loading, may provoke excessive deflections of all types of structures, cracking of concrete and masonry, in some cases excessive deformation of connections in steel, wooden structures, and small cracks in all materials. The location and direction of cracks are related to the type of sollicitations supported, and the deficiencies of the structure.

Take for instance reinforced concrete structure. Cracks can be created by internal differential stresses during erection (superficial shrinkage, effect of non controled heat curing for instance) or by long term effects.

When cracks can be correlated to the influence of stresses, under loading, they correspond to specific diagrams.

Take for instance a reinforced concrete beam. Flexion under loading will cause normally a typical set of thin cracks, more or less uniformly distributed. Such distribution of cracks will, reversely denote a flexion of the beam. The presence of one big crack is not normal and correspond to a brittle failure corresponding to an internal deficiency of the beam. A longitudinal crack along a reinforcement bar can be produced by a bond failure, (but also by long term corrosion). Oblique cracks in reinforced concrete beam correspond to shearing stress. Punching of a slab correspond to a circular zone of cracking.

So the form and situation of cracks, their width and variation of width, can give significative information on the repartition of stresses and local danger if any, in reinforced and prestressed concrete structures.

The form and situation of cracks give also interesting data with other type of materials.

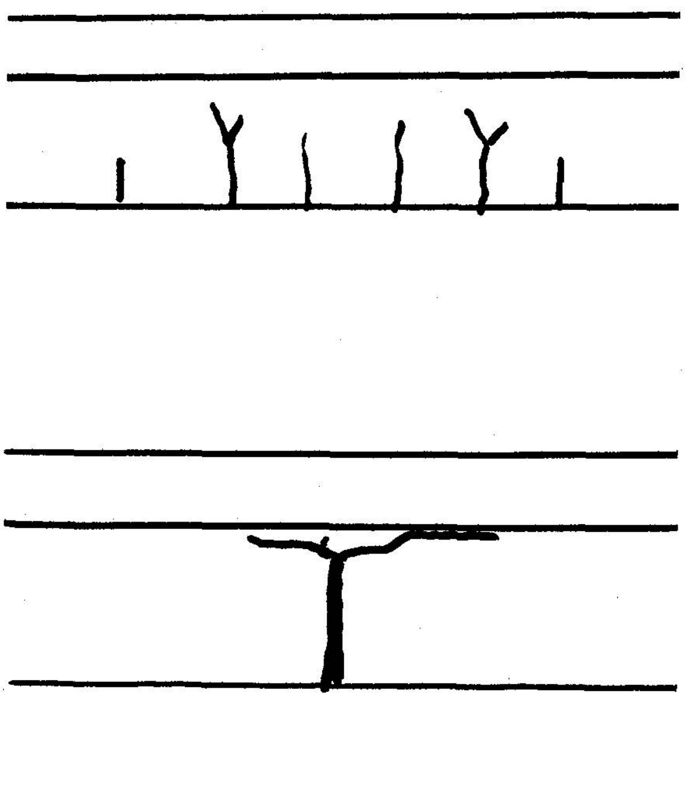

Fig. 1 Example of cracks in concrete beams

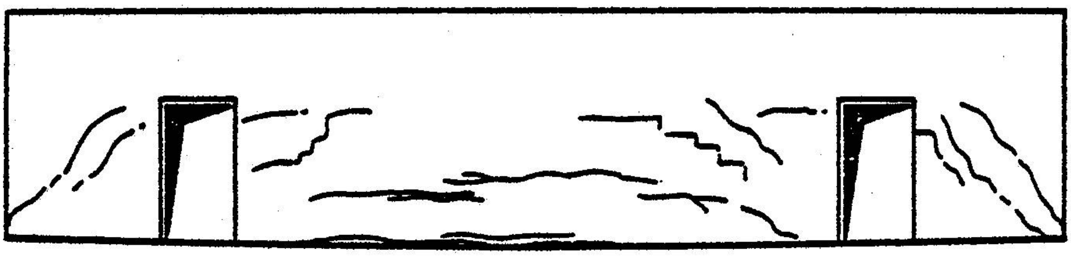

Fig. 2 Significative cracks in a masonry partition supported by a flexed beam

Cracks in non structural elements inform also on the movement of a building. For instance significative cracks appear in a masonry partition supported by a flexed beam having an important deflection (fig. 2).

Excessive stresses and strains can be created not only by mechanical loading but also by imposed deformations, by differential settlement of foundations, differential thermal deformation in floors producing flexion in columns. Thermal gradient in a structural element, will produce rotations and displacements, and if the deformations of the element are hindered, provoke stresses even with small apparent strains. For instance, a slab laying on the ground and more warm at its upper face thât at its lower face will present tensile stresses, on this lower face.

The observation of the form and direction of cracks in non bearing partitions is specially useful in the case of imposed deformations ; it is possible then to have an indication on the geometry of this deformations : which part of the building is descending in the ground more than the others, for instance.

In extreme cases failure can appear, under compression, tension, bending, shear punching, buckling, instability, combination of various effects. Failure may be sudden and brittle or progressive and with widening cracks or big deformation.

The form of the failure has to be observed and described. Some failures of steel structures were caused by the instability of the web of supporting steel elements. Vertical tension in the web of prestressed concrete beams was produced by suspended loads on the lower flange : horizontal cracks and failure of the beams was the consequence. Excessive loading of flat reinforced concrete slabs ended by punching of the slab around the columns and fall on the floor.

Accumulation of water, on flat roofs due to bad evacuation of water brings supplementary loads. Unexpected presence of water on a great height behing retaining walls may have catastrophical consequences under the effect of the supplementary pressure thus created.

2.2 Damages appearing progressively with time

Mechanical action described above, can be accidental and present on a short time. It can also produce fatigue or wear effect by repetition o long duration and damages appear progressively with time. Fatigue failure is often without warning.

Creep and shrinkage of materials, causing deformations and in some cases redistribution of loads, may provoke mechanical damage such as cracking and failure.

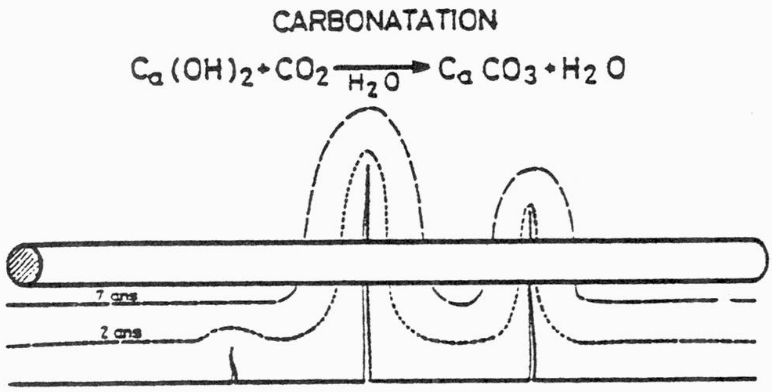

Fig. 3 Carbonatation of concrete

Prestressed concrete bridges, built by the cantilever method, and made hyperstatic after erection, presented a redistribution of flexural moments and bearing forces, which led to unexpected cracking due to the fact that in some sections the values of flexural moment where finally higher then expected.

Thermal effects can be of short duration (during a daily cycle) or have long term cycles (seasonal variation, beginning and end of heating period of building, etc...).

Fig. 4 Corrosion of concrete with expansion

Corrosion of steel is a very important cause of decay, especially under agressive environment (splash zone on sea shore is specially agressive). Structural steel elements will be reduced in dimension or pierced. The protection of reinforcement by concrete cover is reduced progressively by carbonatation (see fig 3). Cracks of big width will increase the speed of steel corrosion, but the width of cracks seems not significant after several years. Rust of reinforcement bars will cause the concrete to spall and create longitudinal cracks and consecutive failure of bond. Local corrosion of prestressed cables under tension provokes sudden failure of the stressed steel. Presence of chlorures in concrete will facilitate reinforcement corrosion. Different metals within a concrete element create electric currents which will also increase corrosion speed. Generally speaking concrete of poor quality (high permeability facilitating internal progression of moisture and oxygen) provides a poor protection.

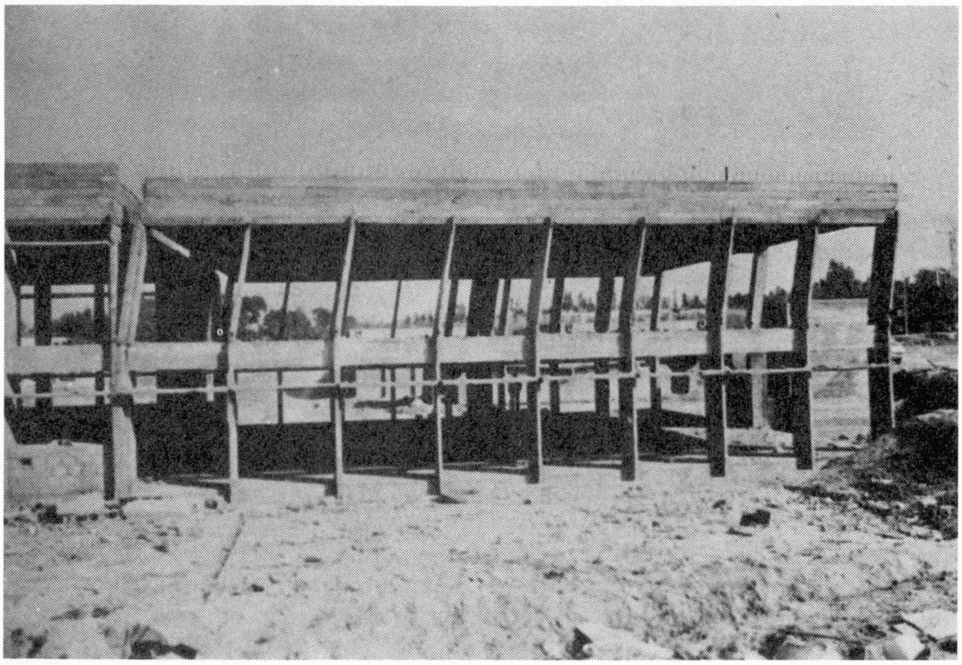

Fig. 5 Building damaged by an earthquake

Other products will create chemical destruction of concrete itself : instable grains of sand, incompatibility of cement and aggregates, development of salts from sulfates. The last phenomena creates expansion and destruction of concrete (see fig. 4).

Corrosion of masonry (stones, blocks, mortar) is also possible under chemical action (for instance the agressive environment of towns).

Presence and action of water have an important effect on durability, if necessary precautions have not been taken local corrosion effects come from humidity and water.

Moisture feeds corrosion. Oxygen and water together are necessary to the production of steel rust ; penetrating into concrete they are at the origin of the development of steel corrosion, and if agressive salts are present, of destruction of concrete.

Flowing water may deteriorate the surface of concrete, mortar or stone, excavate earth under foundations, for instance of piles or abutments of bridges.

Different physical effects can be present, together or not with chemical decay : cycles of frost, near under traffic, under water flow, ice pressure etc...

Combination of physical and chemical actions are often present : splash zone with repetitive frost will create a dangerous environment for masonry or concrete.

Biological action is possible on different types of structures : fouling on marine structures, sea worms penetrating concrete, worms and decay action on wood.

2.3 Exceptional effects

The nature of exceptional actions is generally well identified : explosions, fire, earthquake. The form of disorders corresponding to them is generally known. But it is often difficult to have a precise information on the level of corresponding loading. For instance, earthquake action will provoke significative alternate actions (oblique cracks in two perpendicular directions), general failure (see fig. 5).

3. PRINCIPLES OF ASSESSMENT OF THE STATE OF A BUILDING AND CHOICE OF EXPERIMENTAL METHODS

3.1 Inspection and monitoring

A building has normally to be inspected and maintained. Visual observations have to be regularly made and have to be recorded, as well as registration of users comments and of accidental effects. Some measurements have to be made from time to time, of levels and deflections for instance.

A good measure for inspection is the monitoring of the building, by placing transducers within its structure and making measurements with them at regularly spaced intervals of time. Monitoring can be made in the field of measurements of geometrical displacements, of local deformations, of bearing loads.

3.2 Exceptional inspection

If damage has been noticed, or if an exceptional event took place, an exceptional inspection is needed and an assessment of the real state of the structure may be necessary.

If the problem is of chemical or physical agression, the direct study of the material is necessary. If the general stability is involved, the method currently used consists then in assessing the real strength of constitutive materials as well as the real geometrical dimensions of structural elements and in making a new calculation of the safety and strength of the building (redesign) using the values thus obtained. The tests can be made with local destruction (on cores or samples taken from the building) or be non destructive.

The measurement of geometry and of material properties have to be made in a systematic manner, to obtain useful data on the general state of the building. The most stressed parts have to be specially inspected, but non only them : other parts have to be examined, to be sure that some unknown defects have not created unsafe sections outside the more stressed ones.

If some parts of the structure have been obviously damaged it is evidently needed to make a special study of them.

Another method consists of global tests : loading tests, vibration tests, which give direct information on the behaviour of the structure. Loading tests can be made up to a level higher than service condition, to check the existence of a margin of safety, but possible structural damage due to overloading have to be avoided during such tests. A good knowledge of the structural system is necessary to have a valid interpretation of such tests, and this can necessitate some local measurements (as of the geometry of the real structure).

Both methods, of taking account of well distributed local measurements and of overall testing, can be usefully combined.

In all cases, a good knowledge of the initial conditions of the building is very useful (drawings of as built structures, nature and origin of materials, quality control checks).

Testing methods use different type of measurements : geometrical, mechanical, chemical, physical measurements are made on samples (which enable to make several tests at a time on the properties of the material) or with non destructive procedures. These last methods use generally measurements of physical properties and their correlation with others, directly useful for designer.

The accuracy of the measurements made and the validity of the conclusions derived from experimental studies rely on numerous parameters :
- Use of well established physical properties and correlation between them ;
- Good knowledge of loadings and actions existing during test ;

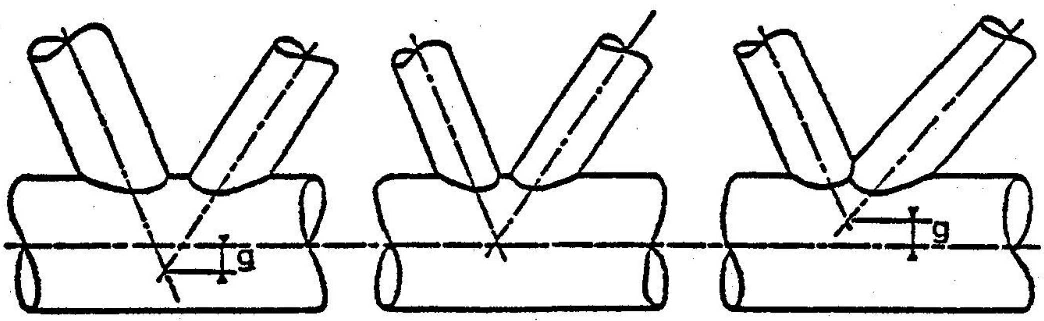

Fig. 6 Excentricity in tubular steel connections

- During tests several actions may be present at a time and difficult to distinguish ;
- Registration of all needed types of measurements (knowledge of temperature may be necessary) ;
- Accuracy of measured values ;
- Good choice of the places where tests are made (where to take samples, where to check dimensions or make non destructive tests) and possibility to make a good choice (non accessibility of critical zones) ;
- Good knowledge of the behaviour of materials and structures : it is necessary to have a theoretical representation of the phenomena studied experimentally to be able to understand it ; generally stresses are needed and strains are measured ; if needed the theoretical model will be modified or replaced by an other ;
- Good information and experience of experts ;
- Financial aspects and time have not to be discarded. It is better to have for the same price well distributed (even not perfect) measurements than a very precise study of a very limited zone of the structure.

4. GEOMETRICAL GLOBAL MEASUREMENTS

The real dimensions of structural elements (steel girders, reinforced or prestressed concrete beams, bearings, masonry walls, wooden elements, etc...) can be measured by normally used means. It can be in some cases difficult to have access to structural elements : scaffolding, movable bridge, removal of surrounding elements may be needed. Check of columns have to include the exact location of sections at different levels. Thickness of slabs or walls, of beam webs, can be made with the help of sound wave propagation within them, if it is wished not to pierce holes.

Special attention has to be paid to the deformations of specially stressed parts: excentricity of truss, connections (see fig. 6) displacement, and deformation of bearings (fig. 7) : joints have to be checked : are they open, and clear ?

Measures of levels, of deflections, useful to check foundation settlement and structural displacements can be made with topographical instruments, optical or with laser beams.

Registration of deflections is possible with fleximeter with an invar vertical cable, or with a laser beam (see fig. 8); the last method allows to measure horizontal as well as vertical displacements. Clinometer measures rotations (figure 9). Pendulum is used for the same purpose. Dynamical displacements may be measured with the help of accelerometers.

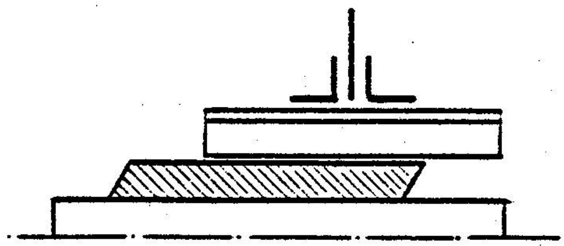

Fig. 7 Excessive displacement on a neoprene bearing

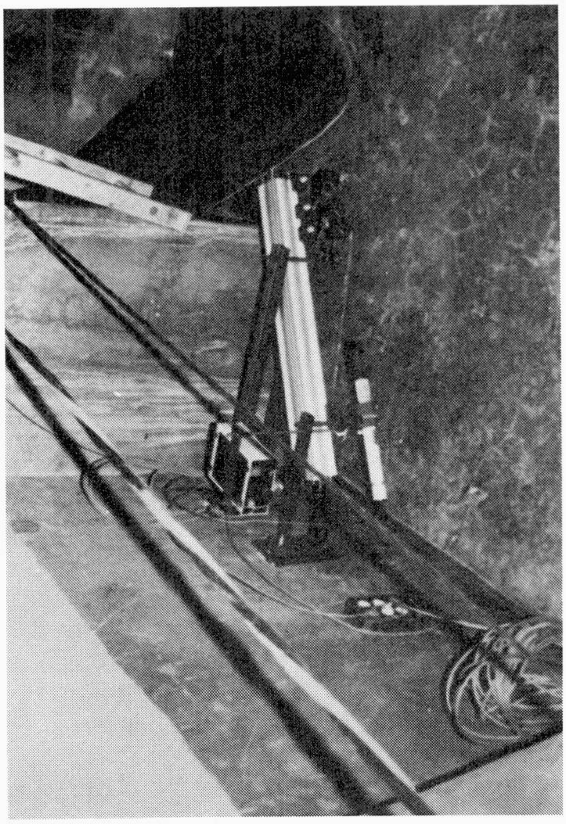

Fig. 8 Laser for measurement of displacements

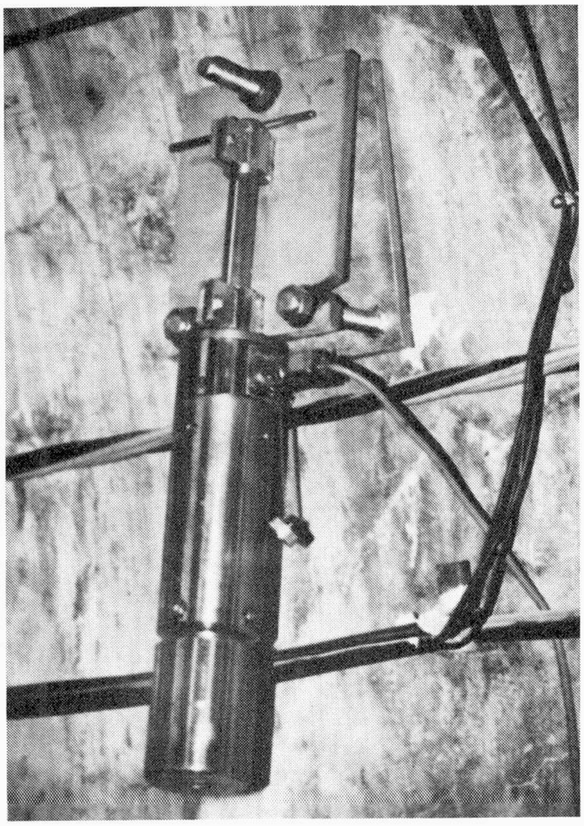

Fig. 9 Clinometer

5. MEASUREMENTS ON FOUNDATIONS, SOIL AND UNDERGROUND STRUCTURES

Settlements of buildings, deformations of retaining walls, have to be measured and compared to the initial state. The reference marks have to be stable. The movements of the soil have to be recorded, in areas where landslides or big settlements (in mining zones for instance) are to be feared.

Variation of underground water level is often to be observed.

Possible excavation under piers and abutements must be checked (divers, under water camera).

To assess the real state of the soil foundation conditions, new study of the underground, may be necessary, with the help of borings to a sufficient depth, penetrometer or pressiometer tests, tests on samples.

The real level of foundations can be measured with the help of local excavations. The depth of deep foundations, can be checked with the help of measurement of sound propagation speed between the pile (on which hammer impacts are applied) and a microphon progressively lowered in a boring. Fig. 10 gives the principle of tests, and figure 11, an example of determination of the depth of sheet piles. A variation in the speed of sound transfer indicates this depth.

The bearing strength is then calculated in function of the geometry of the foundations and the soil properties assessed by tests. It happened often than an unexpected settlement was caused by the poor quality of soil under the lower level of the borings made at construction : for instance when groups of piles are founded on a limited and thin layer of ground under which the soil is very compressible.

Underground structures are checked for their integrity and their contact with the soil. For instance, in tunnels concrete and masonry linings, are observed to detect cracks ; their geometry is checked by measuring the variation of width and height (convergence measurements). Photography, laser equipment, have been used to made quickly geometrical measures. Radar beams can help to

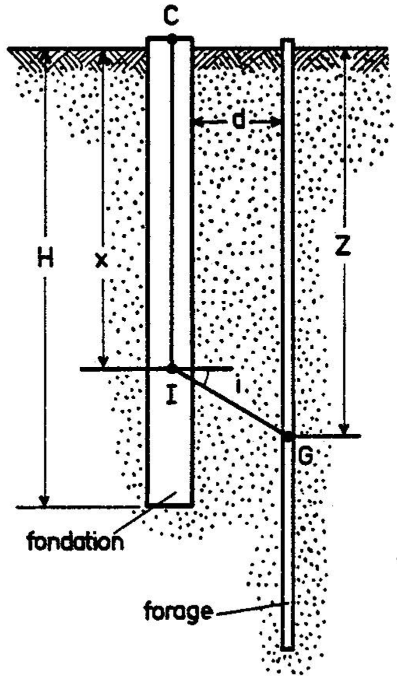

Fig. 10 Principle of determination of a pile depth by sound propagation.

measure the thickness of linings and the voids between them and the surrounding soil.

6. LOCAL DEFORMATION AND TEMPERATURE MEASUREMENTS

The strains of structural elements can be measured with different extensometers :

- Steel balls serving as bases for deformeters and fixed on the surface of the material ;
- Electrical strain gages or vibrating wires fixed on the surface or imbedded within the structural material. Fig. 12 shows vibrating wires, fig. 13 strain gages glued on rail.

For a long term monitoring, vibration wires are generally used, as strain gages have not constant behaviour with time.

All these devices measure deformations under different types of actions. Temperature effects are often very important and have to be taken into account : they provoke directly thermal deformation and induce stresses in case of restraint of deformations. For this purpose, different dispositions can be used :

- Measure the temperature of the material on the base of measure. Vibrating wires give an approximate value of temperature.
- Place non stressed gages near the location of the stressed areas, to registrate simultaneously the variation of local dimension under temperature effect only and the total deformation. For instance, in a reinforced concrete beam strain gages are placed longitudinally to registrate total deformations, and a gage is placed transversally to measure the dimensional variations under temperature effect only ; it is possible to glue gages on the surface of a steel structure, and to place nearley another on a free sheet of steel. Generally temperature compensated electric gages are used. If ε_1 is the total relative deformation, $\Delta\theta$ the variation of temperature, α the coefficient of thermal expansion of the material, ε_2 the relative deformation measured by a strain

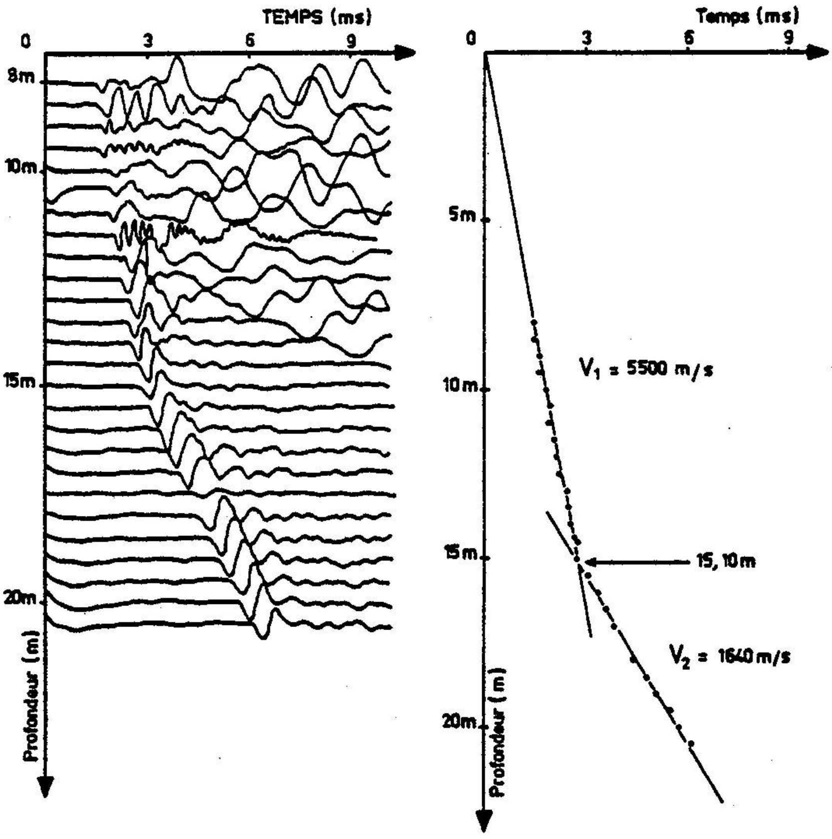

Fig. 11 Example of determination of sheet piling depth

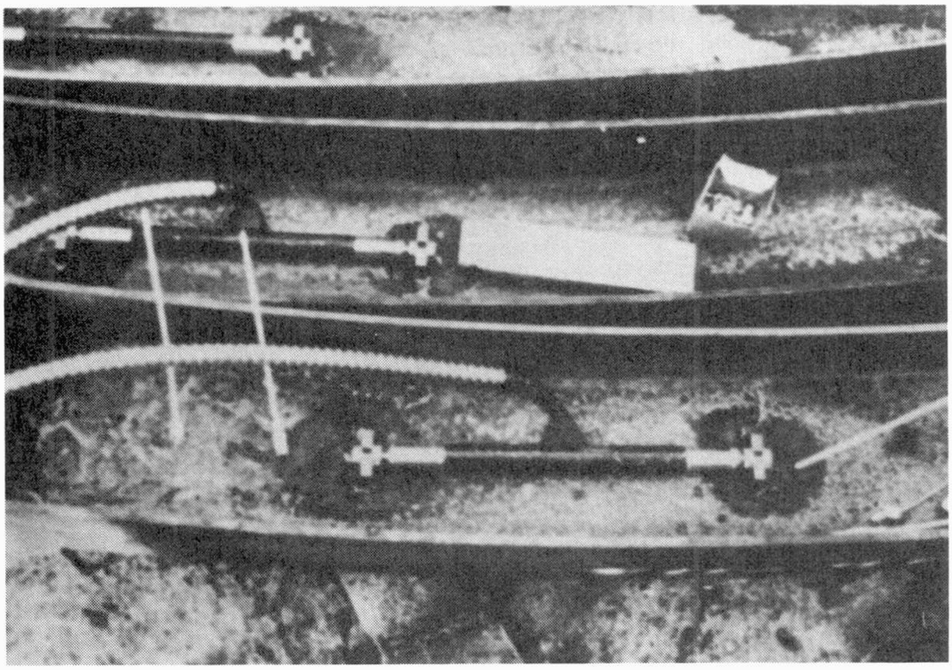

Fig. 12 Vibrating wires

gage, which is compensated for this value of α, we must have $\varepsilon_1 = \varepsilon_2 + \alpha \Delta \theta$

The measurements thus made give variation of strain, when variation of stresses have to be known. To find stresses from strain, we must know the stress strain behaviour of the structural material (modulus of elasticity when this behaviour is linear).

If we consider for instance strain gages imbedded in concrete, we need, to obtain values of stresses, the measurements of strains (without temperature local effect), the stresse strain behaviour curve of the concrete, the creep of shrinkage of it for long duration measurements.

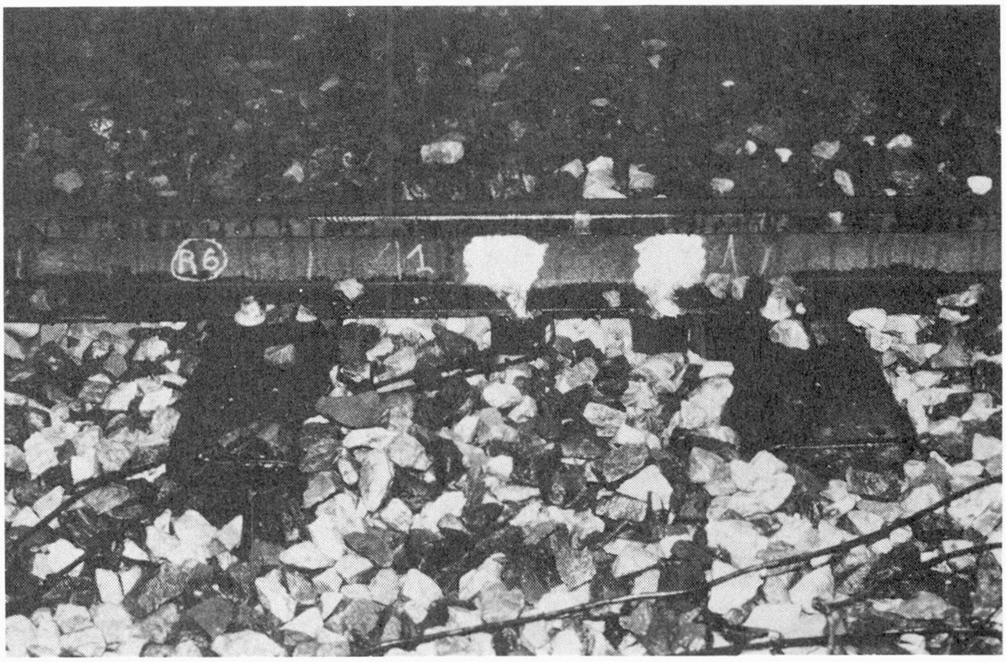

Fig. 13 Strain gages on a rail (used to measure wheel load)

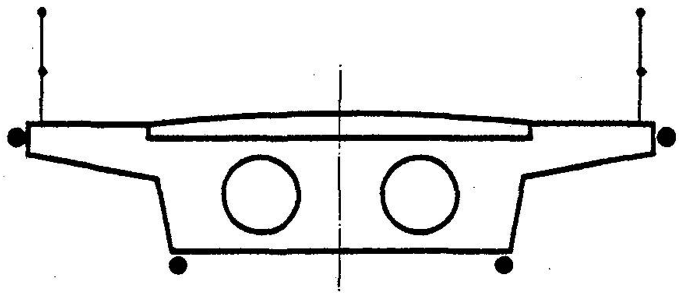

Fig. 14 Location of strain gages on a concrete section

The measurement of strains in different points of a transverse section will give the values of variation of flexural moments and normal force acting on the section.
Figure 14 shows the location of strain gages on a concrete section.

An important problem is the determination of the absolute values of the stresses. The measurements of the strains during a test will correspond to variation of the stresses, but will not give an indication on the values of stresses before the test. The safety of the structure depends on the total absolute values of the stresses, and the correspondance between stresses and strains can also depends on this absolute values. It some cases, it is possible to measure this value by cutting a separation around a stress measuring base, reliving the stress of the material on this base: this method is currently used on rock, it is also applied to concrete.

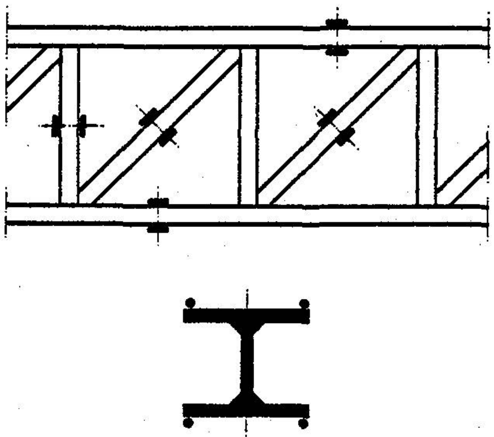

Fig. 15 Location of strain gages on steel truss

7. MEASUREMENTS OF FORCES

Monitoring of a structure with extensometers will give information on the variation of forces present in it, and by deduction the variations of forces acting on it. For instance several extensometers placed at different angles will allow to calculate the variation of shearing action.

Forces can be measured directly :
- Bearing forces under an hyperstatic bridge may be measured with the help of calibrated hydraulic jacks. The initial bearing force correspond to a displacement equal to zero (see fig. 16). Combination of dynamometer and jacks are also used. In concrete, it is possible to place devices giving the variation of mechanical stress and thus of applied force (contraintemeter).

Different type of pressure cells are used to measure pressure or earth, of grain in silos, of water and wind.

Loads on rails are measured by calibrating the signal given by well located extensometers. See figures 13 and 26.

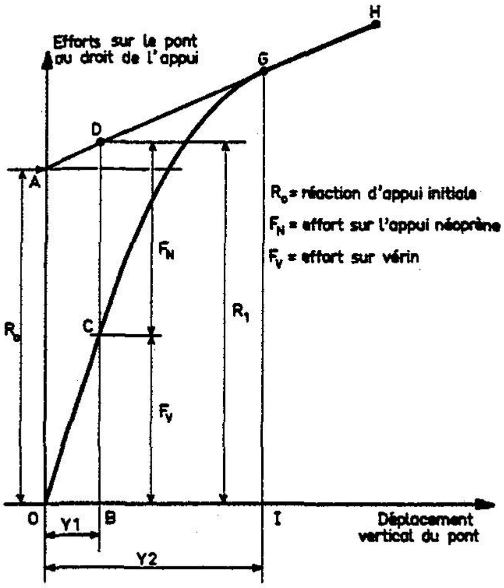

Fig. 16 Principle of determination of bearing force under a continuous bridge beam

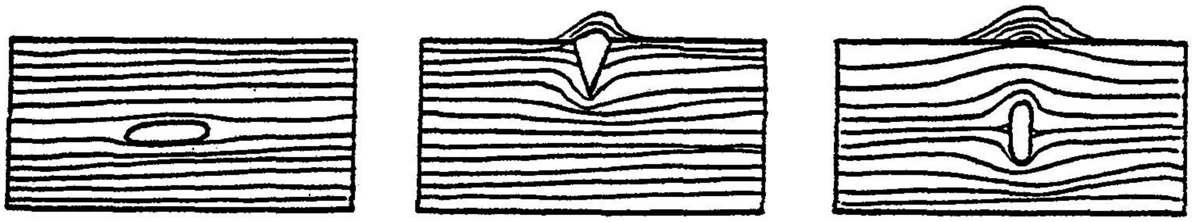

Fig. 17 Variation of magnetic field due to defects in steel

8. MEASUREMENT OF PROPERTIES OF MATERIALS

8.1 Measurements on steel

Steel samples are tested in laboratory to get information on the strength yield point and nature of steel.

Microstructural studies are made on samples or on replica of the surface of the material.

Many methods of control of the state of steel and of welded connections have been developped and can be used in situ : sound speed, transversal radiography, gammagraphy, magnetoscopy, etc...

Sound speed measurement technique have been specially and successfully developped for detecting cracks within steel elements and welded joints, but in some cases the geometrical disposition of steel pieces is such that this technique cannot give a sufficient information on the presence of cracks.

The measurements of variations of magnetic field enables to find small defects, with a better accuracy if defects are apparent on the surface (see fig. 17).

Observation and detection of cracks are very important, as crack in steel is always a defect. Visual inspection is of obvious necessity ; it is hindered by the paint (or the superficial oxydation of weathering steel) and sometimes by the fact that some parts are normally not visible (small caisson girders). A good knowledge of possible dangerous zones are necessary for a good inspector, to be able to find quickly possible cracks.

Effect of corrosion is obviously to be specially observed.

Fatigue effects will create or develop cracks, in some cases in a relatively short time, and specially in zones when holes or structural defects are present. Acoustic emission of sound waves is caused by the formation of cracks. Methods have been developped to catch the formation of cracks and know their location by registration of acoustic emission.

The quality and situation of welded joints have to be specially observed. Small cracks begining in a welded joint of secondary structural importance can propagate in important steel sections.

Connection by rivets, bolts, high strength bolts needs special attention. Failure of connecting pieces, presence of cracks, unadequate holes, bad disposal of connecting elements have to be noticed.

Cables and fixation of cables (is suspended bridges for instance) are submitted to special methods of inspection (Foucault current measurements).

Monitoring with extensometer gives values which are generally easy to understand as the behaviour of steel is linear until a distinct yield point, but local buckling is sometimes possible.

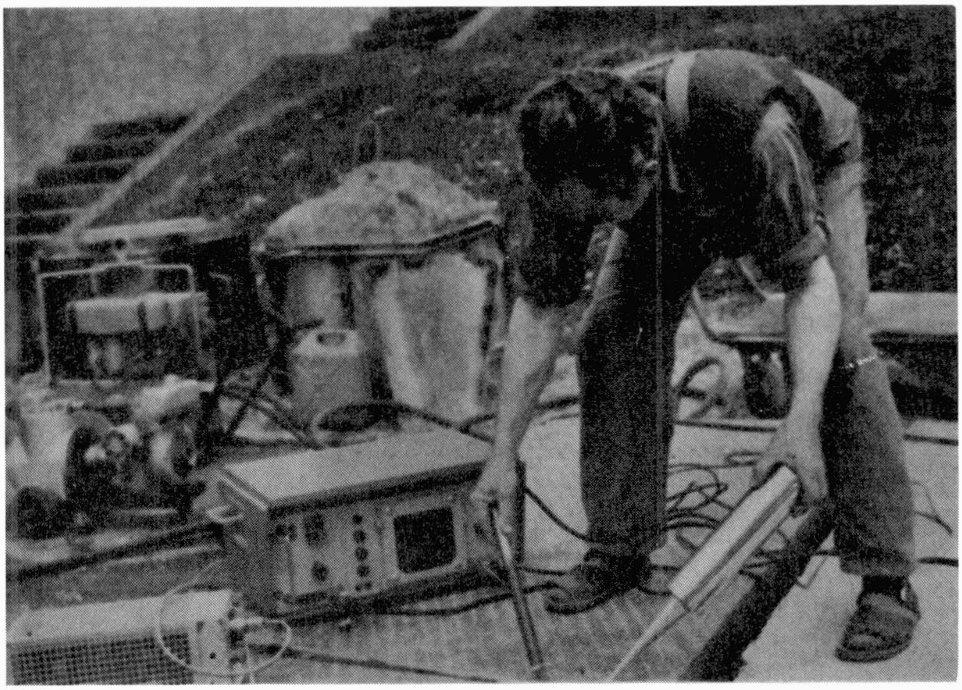

Fig. 18 Measurement of sound speed in concrete

8.2 Testing on concrete structures

8.2.1 Analysis of constitution of concrete

An analysis of the components of concrete can be made on samples taken from the structure : the gravel is manually taken out, its dimensions and proportions measured : the cement content can be defined by a chemical analysis, which will be more accurate if the composition of the cement used is known. Chemical analysis will inform on the presence of harmful components. Optical microscope, X rays spectrometry give complementary information on the microstructure and on chemical contents.

Several properties may be assessed on cores : strength, own weight, porosity, composition, chemical contents.

Carbonatation of concrete can be observed on the lateral face of a hole digged within the material.

Non destructive methods of testing of strength are mainly the use of sclerometer and of sound speed. This last value is related to the dynamic modulus of elasticity and to the strength.

Fig. 18 shows a measurement of sound speed propagation. Propagation of sound may be studied transversally to an element (from both sides of a column or a beam for instance) and then inform on the internal quality of the concrete. It may be measured from one side only (of a slab or a wall for instance) with one fixed point of sound emission and regularly spaced points of reception ; information is obtained then on the quality of concrete under the surface, and on the presence of well formed cracks, arriving on this surface.

Fig. 19 shows the correlation between strength and elastic modulus of concrete, and this last value is directly related to sound propagation speed. Figure 20 presente correlation curves between strength and sound speed in concrete and in stone.

Location of low strength concrete will be easely detected by this method.

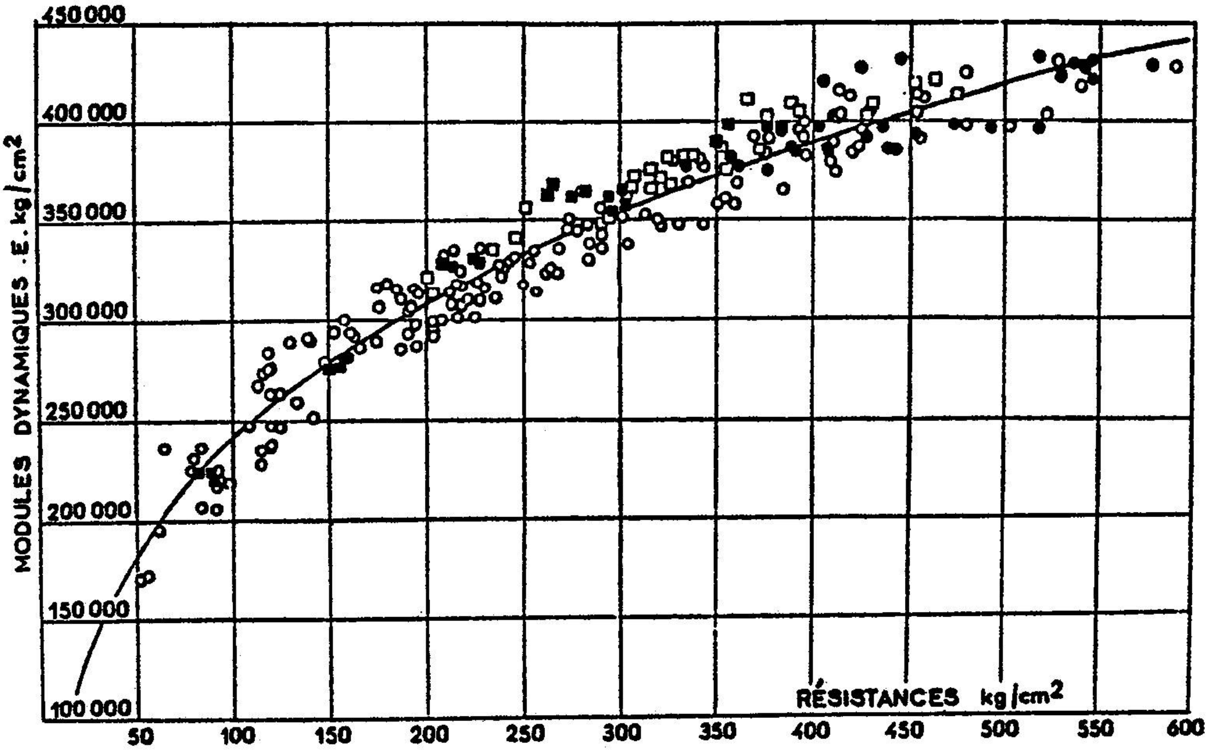

Fig. 19 Correlation between dynamic elastic modulus and concrete strength

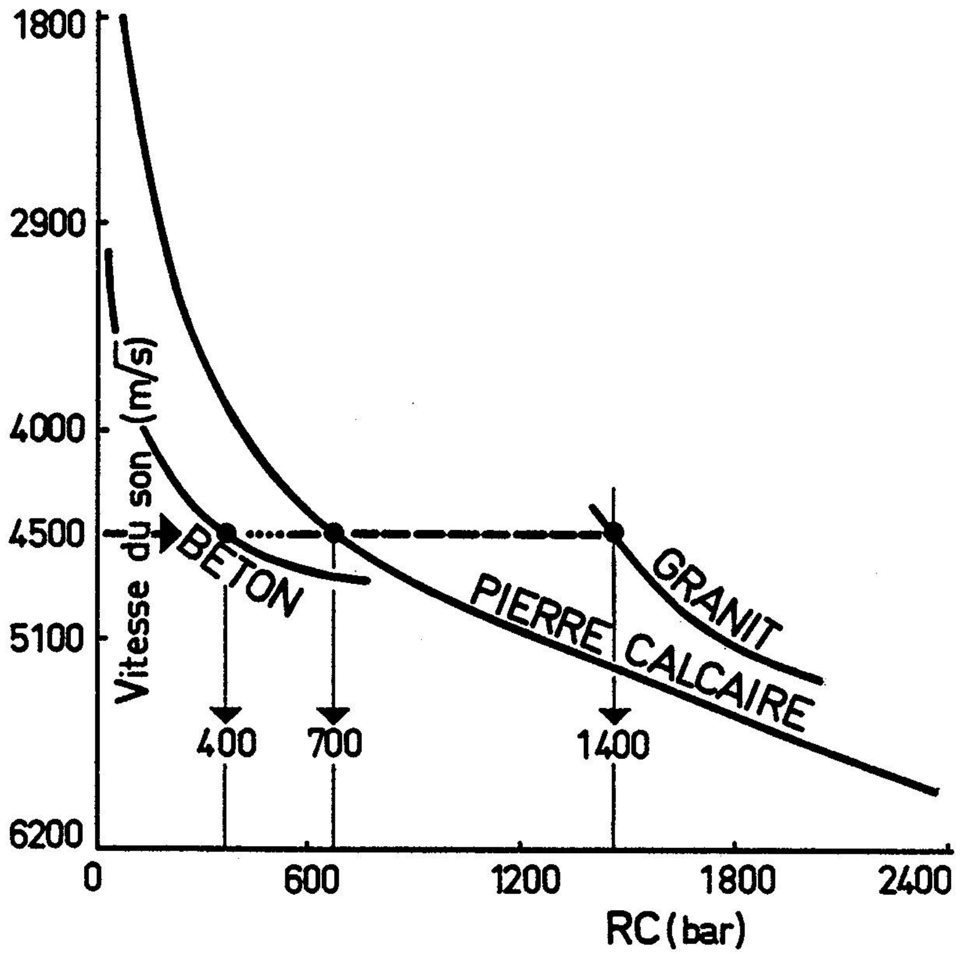

Fig. 20 Correlation between sound speed and strength of
concrete or stone

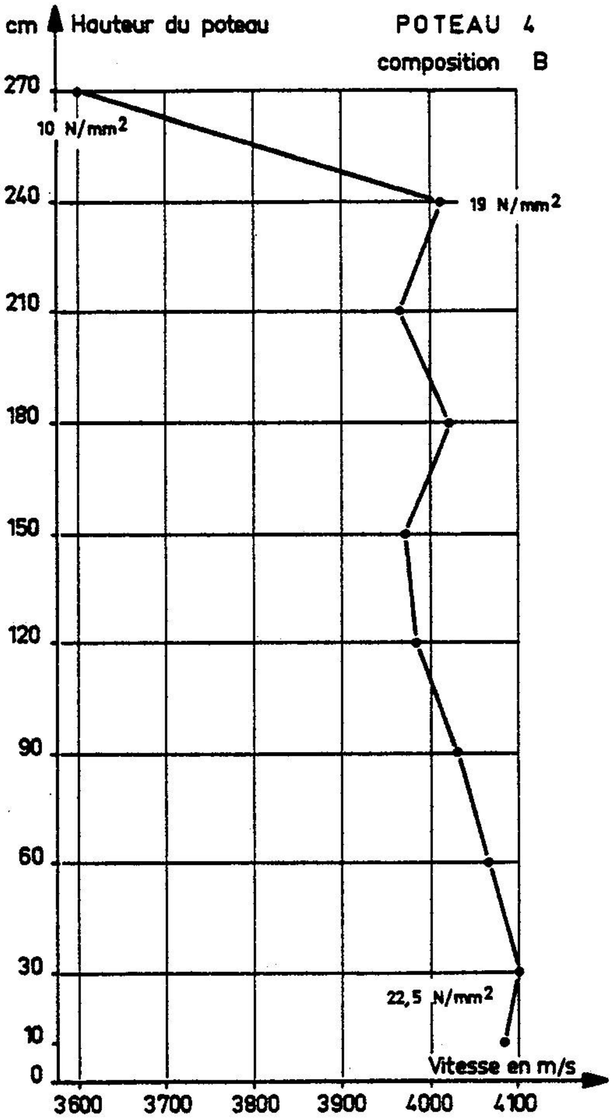

Fig. 21 Transverse sound speed values in column

It is more difficult to distinguish between concrete strengths of high level, the correlation curve is flat in area of high strength. Measures of superficial hardness give no information on the real internal strength of concrete, but are helpful to assess homogeneity of concrete, are usefully used in coordination with sound velocity studies, and are easy and quick to made.

Such type of measurement have shown that the strength of a concrete element is lower at its upper part. The result of transverse sound speed measurements on a column is given on figure 21. This reduction corresponds to the practical conditions of concreting and is systematic.

Pull out tests on steel pieces placed in concrete at the moment of casting and producting from the surface of the material enables to check strength. The force necessary to pull the piece out of the concrete is related to the strength of the material; if the test is made for a force value equal to that corresponding to the desired strength, it is possible to check if this value is really obtained.

Non destructive methods have to be calibrated on samples made with the concrete used within the buildings (on cores, or on samples taken during construction). Presence of reinforcement within the concrete can be detected with the help of measurement of magnetic field variation, (pachometer). But is not possible to find at a time the depth and the diameter of the steel.

Gammagraphy gives more precise information, but is difficult and expensive to use.

Detection of corrosion of surface of steel imbedded in concrete is made by measurement of electrical potential. The principle of this test is shown on figure 22. The potential at the surface of the steel bar in contact with the concrete is measured with reference to an electrode (for instance soluble calomel electrode).

Corrosion at the surface of steel bars correspond to higher value of difference of potential which can be plotted on the surface of the concrete element (see figure 23). Tests with applied current may be possible to detect not only the location of corrosion but also its speed and intensity.

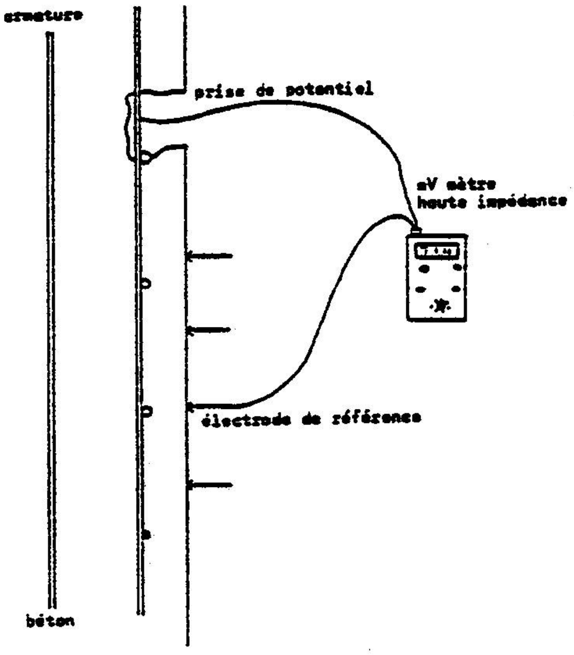

Fig. 22 Principle of measurement of elastic potential between steel bar and concrete

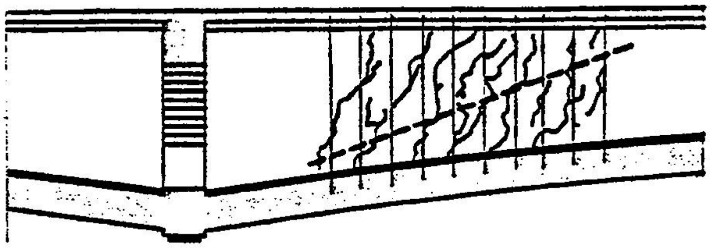

Fig. 24 Cracks in prestressed concrete box girder. Theoretical crack is less inclined on the horizontal

8.2.2 Tests on prestressed concrete

Gammagraphy is very interesting to check the quality of grouting of cables and their position, and even to detect local tendon failures.

A very important parameter in prestressed concrete is the value of the real prestressed force within the tendons. Loading tests, are a possible method to estimate the remaining prestressing force. If a small crack is present on the surface of a beam, on the side where a flexural moment will create extensions, the local deformation is measured accross this crack and also on other points of the transverse section going through it. A loading test is performed, and it is easy to detect the load for which the crack begins to open. The calculation of the internal equilibrium for this load can give the value of prestress ; effect of temperature have to be carefully taken into account on this test, which has to be combined with measures of bearing forces.

It may be possible also to cut a hole around a prestressing tendon and study its stress by a vibration test.

8.2.3 Cracks in concrete

The observation of the distribution and form of cracks can help to find the cause of damages and the level of damage endured. Cracks exist normally in reinforced concrete, but have to remain of limited extend and width they have to be more strongly limited in prestressed concrete. In some cases, they correspond to a structural danger, like shear cracks of unexpected angle in prestredded concrete (see fig. 24)

Formation and location of cracks in concrete can be observed by acoustic emission observation

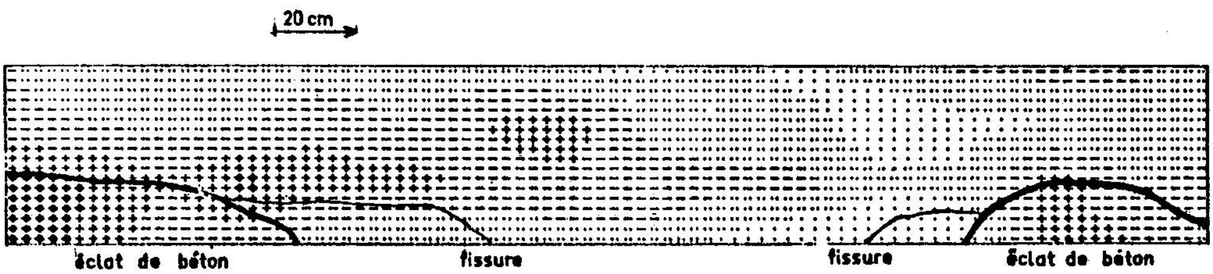

Fig. 23 Example of electric potential measurement on a beam

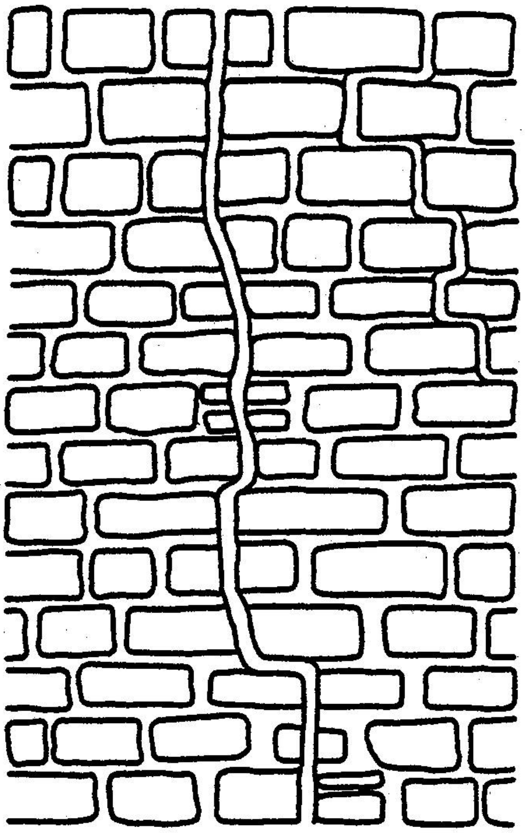

Fig. 25 Cracks in stone masonry wall

8.3 Measurements on masonry

Stones, bricks, concrete blocks, mortar, plaster can be observed by different methods, on samples or in situ. Measures of strength of carbonatation of mortar, measures of humidity content, of sound speed are used.

Measures of adhesion on masonry can be necessary (plaster, sprayed concrete).

Chemical analysis, cristallography (microstructural studies) give useful data on the internal structure and the presence of possible agressive salts.

Observation of cracks, measurement of their width and width variation is obviously needed. See figure 25 : cracks can go through the stones or be present only within joints.

Water leaking in cracks or joint within masonry needs special attention.

As well as for concrete, different properties (other than strength) are useful to study, as frost resistance for instance.

8.4 Measurements on wood

A good knwoledge of different kind of wood species are necessary to identify the nature of wood and its possible strength. Local defects, cracks, form of fibers, possible worm attack, decay, have to be observed. Deformation of connections (of steel pins between two connected wooden elements for instance) give significant information. Corrosion of steel pieces of connection may appear.

Measure of strength, of humidity content, are made on samples, but non destructive methods like sound speed give also interesting informations.

9. OVERAL TESTS

For loading tests, already described devices, are applied for measurements of deflections, rotations, local deformations, variation of weight, temperature.

A permanent monitoring allows to registrate the loading effect in service conditions.

The study of the global behaviour of a structure necessitates the knowledge of a representation model of this behaviour, and of the loadings applied to the structure. Figure 26 shows an example of tests under traffic of a railway bridge. There is only one isostatic span, which means that the static system is well known. The load of each wheel of the train is measured by the signal given by a couple of strain gages glued in the form of a V on the rail, and calibrated by the application of a known local force. Two sets of a strain gages are placed in P1 and P2 to be able to measure the speed of the train (knowing the time between the passage on both points). The deflection F at mid span is measured with the help of a laser beam. The correlation between the loads applied and the deflection is known by this system of measurement.

The influence of variation of temperature and of temperature gradients is often very important for the behaviour of a structure. On a continuous bridge for

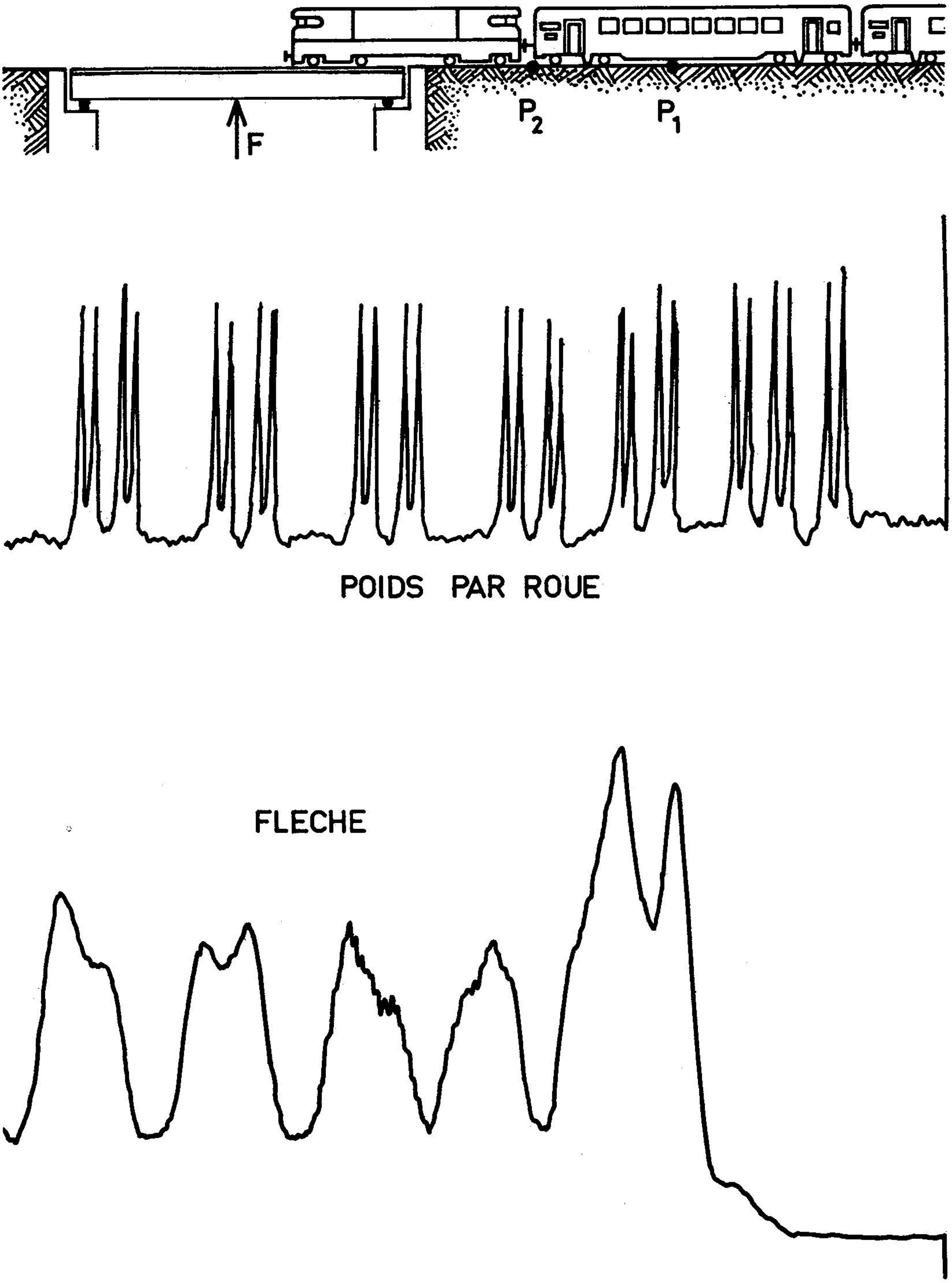

Fig. 26 Registration of wheel loads and of mid span deflection on a railroad bridge

instance, gradients of temperature will change bearing forces and flexural moment. Stresses may be applied without apparent strain variation. Take for instance a slab laying on the ground, with different temperature at the lower and at the upper face. Any variation of curvature is hindered by the effect of the own weight of the slab ; with a constant mean temperature, and variable temperature gradients, tensile stresses will appear on the colder face without any strain variation. A non compensated extensometer will show a relative deformation equal to $\varepsilon_1 = 0$ and a compensated strain gage a relative deformation equal to ε_2, with $0 = \varepsilon_2 + \alpha \Delta \theta$, the variation of stress will be equal to $E\varepsilon_2 = E\alpha\Delta\theta$

It is very important to have a complete information on all the variations of parameters having an influence on the structural behaviour : measure of temperature, as well as of strain, knowledge of thermal coefficient α , knowledge of statical model of behaviour.

Overal tests are made not only on the mechanical behaviour, but also an other needed properties : watertighness, permeability to air for instance.

It may be of special interest to study experimentally the dynamic behaviour of a structure. Exact calculation is often difficult in this field, a direct study can give important information on the real structural study before and after repair, and afford to assess the effect of strengthening on the stiffness of the structure ; this is of peculiar interest in seismic areas.

Different methods are used : measures of accelerations under transient excitation (under the effect of an instant force or release of applied force), random excitation under natural causes, harmonic excitation by the use of special equipment with unbalanced rotative mass of very stable frequency (see fig. 27).

The results of such measure under an important harmonic excitation give the possibility to define the behaviour of the structure by the means of nodal parameters that is, for each mode, the frequency, the damping, the deflection and information on the flexibility. This necessitates the knowledge of the basis of nodal decomposition. (see figure 28).

The application are numerous : determination of the effects or wind and earthquakes, studies of effectiveness of strengthening, studies of the influence of soil and foundation deformations.

Resonance excitation is also proposed to study the development of cracking and variation of prestressing forces in prestressed concrete beams and bridges.

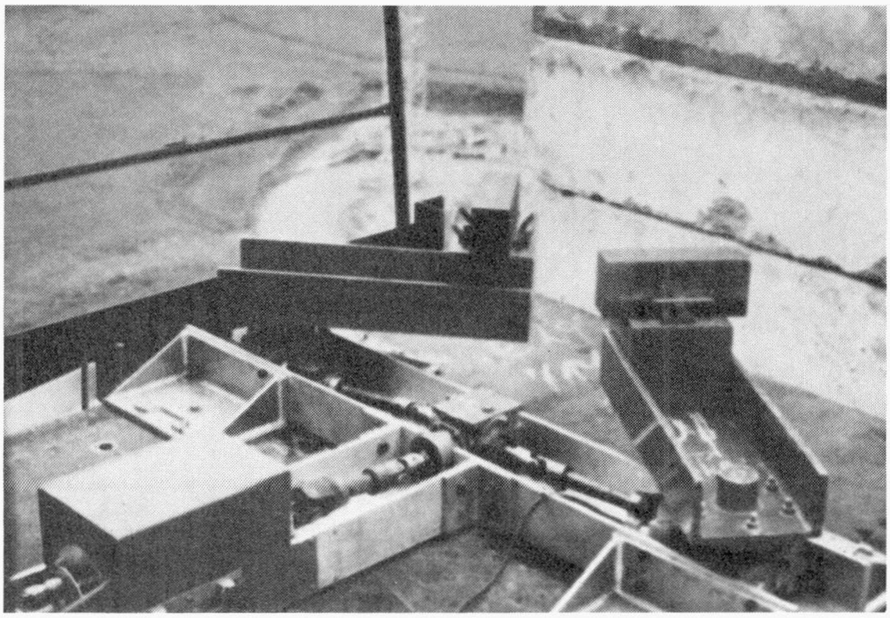

Fig. 27 Device for horizontal dynamic excitation

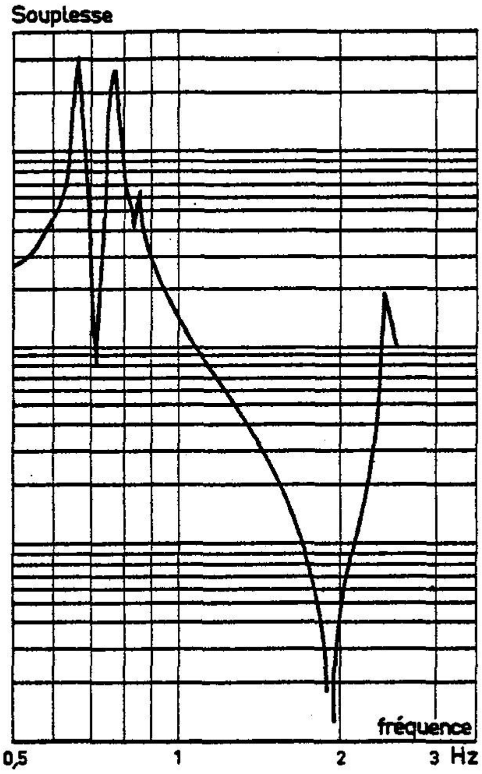

Fig. 28 Displacements corresponting to different frequency of horizontal excitation

10. AUTOMATIC REGISTRATION OF MEASURES

It is often useful to be able to have an automatic registration and an immediate representation of measured values. It is compulsory in some case, for instance if a limit of danger has to be avoided, or if the program of loading depends on the first measures.

It was necessary in the case of figure 26 to have an automatic registration of measurements as the effect of passage of trains was studied on 24 hours.

Automatic registration of measures, calculation of needed values, graphic or tabular presentation of them are possible with the use of computer program. If the results presented are obtained by a calculation using measured values, these last values have anyway to be registered, to enable to verify the validity of results by using directly measured data.

11. LABORATORY TESTS

As explained above, laboratory work is used to know the properties and behaviour of materials present in the structure, from tests made on samples taken in situ : chemical analysis, stress strain curves, etc...

But experimental studies in laboratory are also necessary to obtain a general knowledge of the behaviour of materiels and structures. Structural tests can be made on elements taken from the building or elements of similar construction. Pathological cases can be reproduced in laboratory. For instance the formation of cracks under the effect of diffusion of prestress from anchorages placed in a concrete slab has been studied experimentally on specially conceived and made elements ; a knowledge of what happened in bridge caisson beams was thus obtained.

Effect of thermal expansion and thermal gradient on concrete beam and reservoirs has been studiedon models in laboratory, with measures of temperature and deformations : a comparaison between the observed behaviour and proposed calculation methods enables to check the validity of theoretical methods which can them be applied to real structures.

So laboratory tests are made to know the fundamental properties and behaviour of structural materials, the peculiar properties of the materials of a real building, they are also made on structural elements to check calculation programs, and on reproductions of parts of the building to study special pathological cases.

12. CONCLUSION

We have tried to give a general description of possible methods to be used and of the specific problems concerning different types of materials. It is possible also to classify there methods following the properties to be checked. For instance methods for detecting moisture in all types of materials. It would be also interesting to have good information on the accuracy of measurements made in different cases, and the useful combinations between different types of tests. The result of the application of experimental methods have to be taken in good consideration for studies of remaining strength and repair or strengthening operations. They have to be applied and interpreted by qualified and experimental personal, the latter must have a good documentation on similar pathological cases and on possible causes of damage.

The present report is not intended to be exhaustive and complete, but to be a basis for further discussion, comments, complements and contributions in the field of diagnosis and assessment of the state and behaviour of building structures.

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