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Autor(en): **Robert, Jean Louis / Brachet-Rolland, Marcelle**

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Survey of Structures by Using Acoustic Emission Monitoring

Surveillance des ouvrages par détection d'émission acoustique

Überwachung von Bauwerken mit Hilfe von Schallemissionsmessungen

Jean Louis ROBERT
Ing., chef de groupe
LCPC
Paris, France

Jean-Louis Robert was born in 1939 in France. He graduated at INSA (LYON) as an Engineer in 1962. As a Group Head at LCPC, he is now working on investigations about the means for the survey and the control of structure cables.

Marcelle BRACHET-ROLLAND
Directeur Technique
LCPC
Paris, France

Marcelle Brachet-Rolland was born in 1936 in France. After personal investigations on stress corrosion in LCPC, she was the head of the Metal Section then the one of the Concrete and Metal Division. Now, she is a Technical Director at LCPC and in charge of the Civil Engineering Department at the Ministry of Research and Industry.

SUMMARY
The acoustic survey of civil works, based on the monitoring of waves emited when damaging materials, enables us to detect the fractures of elementary wires, internal or external ones, of tensioned cables and the active cracks in concrete. The equipment chain able to be on continuous service during several months were experimented. As the method is operational in the case of suspension and cable-stayed bridges, it still needs supplementary research for the interpretation of the received signals, in the case of prestressed concrete structures.

RESUME
La surveillance acoustique des ouvrages d'art, basée sur la détection des ondes créées par les endommagements des matériaux, permet de déceler les ruptures de fils élémentaires, internes aussi bien qu'externes, des câbles tendus ainsi que les fissures actives du béton. Des chaînes de matériel capables de fonctionner en continu pendant plusieurs mois ont été expérimentées. Si la méthode est opérationnelle dans le cas des ponts suspendus et à haubans, elle nécessite des compléments de recherche pour l'interprétation des signaux reçus dans le cas des ouvrages en béton précontraint.

ZUSAMMENFASSUNG
Die akustische Überwachung von Bauwerken durch die Aufnahme der durch die Werkstoffschädigung hervorgerufenen Schallwellen ermöglicht den Bruch von Einzeldrähten, innerer und äusserer, in gespannten Kabeln sowie die aktiven Risse im Beton festzustellen. Messgeräte, die während mehrerer Monate funktionstüchtig sind, wurden erprobt. Wenn diese Methode bei Hängebrücken und Schrägseilbrücken wirkungsvoll ist, sind für die Analyse der Schallemissionen bei Spannbetonbauwerken noch weitere Untersuchungen notwendig.

INTRODUCTION :

The pressing need of surveying the change of the conservation state of suspension cables in suspension bridges and the lack of non destructive means for detecting the fractures of internal wires of these cables, pecularly in their non free parts, gave us in 1968 the idea of using the waves resulting from the sudden release of the energy bound to the fracture of one wire in a tensioned cable.

The principle of the method, generally called "acoustic survey", lies in the fact that the waves created at the wire fracture propagate at a given velocity, in a given medium, and can be monitored with appropriate sensors at distances which depend on the released energy value and of the wave damping by the crossed media.

1. EXPERIMENTAL AND THEORETICAL INVESTIGATIONS

The investigations were experimental in a first stage and were completed with a theoretical approach.

1.1. Experiments

The experimental method consisted in inducing, at a given point, the individual fracture of internal and external wires in tensioned cables and in recording the produced waves (fig. 1) at various distances of the breaking point, by using accelerometers in order to determine the properties (frequency, amplitude, damping versus distance). In a parallel way, we searched a simple mean for producing similar waves in a cable, so that we could study the propagation conditions in a structure, pecularly the damping due to suspenders and suspender catches.

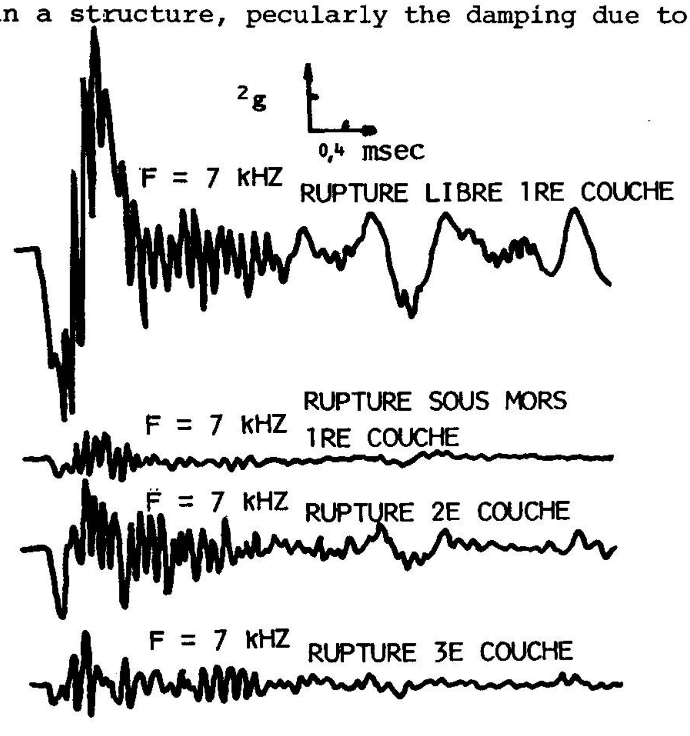


FIGURE N° 1 - Recording of the first wave in various cases of individual wire fracture in a cable, at 21 m far from the breaking point

1.2. Theoretical approach

The general theory of wave propagation in a cylinder [1] results in the POCHHAMER's "frequency equation" rather difficult to be practically used. Thus, an approximate theory was developed for describing the encountered phenomena solely in the practical domain which interested us : the wave length is great as compared to the cable radius. When transverse effects are token into account, it results in the differential equation :

$$c_b^2 \frac{\partial^2 u}{\partial x^2} - \frac{\partial^2 u}{\partial t^2} + \frac{\nu^2 a^2}{2} \frac{\partial^4 u}{\partial x^2 \partial t^2} = 0$$

which gives the propagation velocity :

$$c = \frac{c_b}{\sqrt{1+\frac{\nu^2 a^2}{2} k^2}}$$

where C_b is the bar velocity $\sqrt{\frac{E}{\rho}}$, ν the POISSON's ratio, a the cable radius and k the wave number.

The experimental verifications are in good agreement with this theory which makes us take a propagation velocity equal to about 4 500 m/s, changing mainly with the frequency (geometrical effect due to the medium) and very little with the cable tension load.

2. EQUIPMENT

Since the first equipment chain made in 1971, which might enable, using sensors distributed along a cable, the propagation velocity and the damping versus distance to be determined, two new generations were designed and experimented on various structures. A particular attention was paid for the reliability of the whole set of the chain components which must be on continuous service on a structure during one year or 6 months, depending on the case. Now, the equipment chain is constituted of :

- a set of sensors connected in a series and fixed on the cable at ranges of 10 to 20 m, depending on the wave clamping proper to each structure. Every sensor has a monitoring element composed of an accelerometer and electronic circuits necessary for the transmission to a box centralizing the carried out measurements ;

- a box centralizing the data and processing, using a microprocessor, the signals given by every sensor (maximum number 100 sensors) and making it possible their recording with a printing machine (local result processing) or on a mini-cassette tape recorder (further study with a computer). The obtained information is as follows :

. date and time (hour) of the recorded event
. signal amplitude
. arrival time of the waves under a sensor. The initial time (zero) is given to the first impressed sensor, and so the propagation velocity can be obtained and the wave origin location be calculated

- at last, the microprocessor in the box makes it also possible to test periodically the right order of the set box-sensors.

3. APPLICATION TO SUSPENSION BRIDGES

3.1. Structure n° 1

It deals with a bridge having a 82 m long span, and having in each bundle four cables (66 mm diameter) continuous from one anchorage to the other one. Only the center span is suspended. After a total failure of the holding cable on the right side upstream, the acoustic survey was settled on the other cables, seeming to be intact, on the right side bank upstream and downstream. No new wire fracture was detected downstream but on the contrary, upstream two fractures for a day were, as a mean value, observed on the three remaining cables, on a length of 23 m and during 15 days (fig. 2), this time deviation was necessary for the immediate settling of a provisional suspension in order to prevent the total failure of the structure.

A destructive examination of the cable n° 4 which was the most damaged, after its removal (4 months later) showed out the presence of 55 broken wires in the controlled area. For 10 fractures, the bright aspect indicates that they were very recent.

3.2. Structure n° 2

For this structure, the situation was less critical and enabled an acoustic survey to be carried out during 6 months before the cables were replaced.

The bridge has a 160 m long span and 4 cables (67 mm diameter) in each bundle, continuous from one anchorage to the other one. In one of the downstream cables, about 20 wire fractures were observed in the second layer, and the acoustic survey was immediately settled on the 4 cables of the downstream bundle, on a length of 60 m which was evaluated to be the most critical for the whole structure.

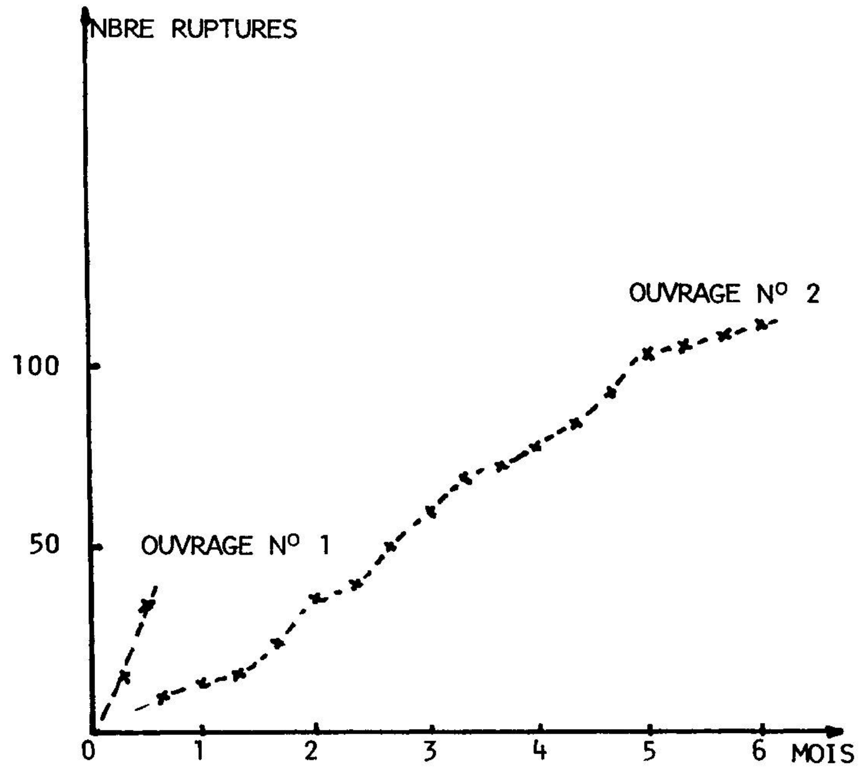


FIGURE N° 2 - Number of fractures monitored by acoustic survey of cables in two suspension bridges (on service)

In this area, the number of fractures monitored with the acoustic survey was 1 for a day, as a mean value, from July to December. Then the phenomenon seemed to be stabilized, starting from December.

After the cable removal, a 5 m long piece, where the acoustic emission had monitored 10 fractures, was examined : 63 fractures were observed in the internal layers (the external layer being perfectly safe). This result enabled us to verify the validity of the acoustic survey of the suspension bridge cables, which makes it possible to monitor the individual fracture of elementary wires at the time when it occurs, with a location precision in the order of 0,10 m.

4. EXTENSION TO THE SURVEY OF PRESTRESSED CONCRETE STRUCTURES

As the acoustic survey method is operational for the suspension bridge cables (or stay cables), it is not yet the case for prestressed concrete cables.

The two ways into which we lead our experimentation were as follows :

- monitoring the fracture of one wire in the prestressing cable
- monitoring the concrete crack growth.

They are full of promise, but the all encountered difficulties are note quite resolved.

In the first way, if the energy released at the fracture is high, the conditions of wave propagation in the complex structure of the bridge are not yet know enough so that a fracture is identified, with a faire assurance, starting from a recorded signal.

In the second way, more over, the released energy is weak and the result interpretation is ticklish.

4.1. Monitoring a wire fracture in a prestressing cable

The acoustic survey was used since September 1973 to February 1976 on a box girder bridge with 3 continuous spans 21, 30 m and 18 m long, for surveying 3 girder webs in the center span (30 m). During this time duration, 8 wire fractures were identified using the recorded signals. Before the structure was repaired a gammagraphy control was carried out on the whole structure. One fracture could be confirmed, but the 7 other ones unfortunately corresponded to parts of the structure where gammagraphy was impossible and the "autopsy" of the cable was not yet carried out.

4.2. Monitoring and survey of concrete active craks

The structure put under acoustic survey was a bridge on a motorway, with 4 spans (28, 46, 84 and 50 m long) built by cantilever method.

In a first step, the acoustic survey was distributed along the structure and enabled active cracks to be detected an located in 2 webs of the voussoirs in the center span (84 m long).

In a second step, the high density of sensors in the area with active cracks enabled us to localize 2 preferential areas of acoustic emission, of about 1 m^2 (fig. 3). The basic data on the properties of the waves emited by concretes and on their propagation conditions were not sufficient for the identification of the source of the received waves : opening or growth of cracks. But we are allowed to assess that these waves indicated the activity of these cracks because they were off since additional prestressing cables were tensioned (before cracks were injected).

Now, theoritical and experimental investigations are at hand for our knowledges to be improved on the conditions of wave propagation in concrete specimens, respectively sound, microcracked and cracked.

FIGURE N° 3

A - Sensor on a structure

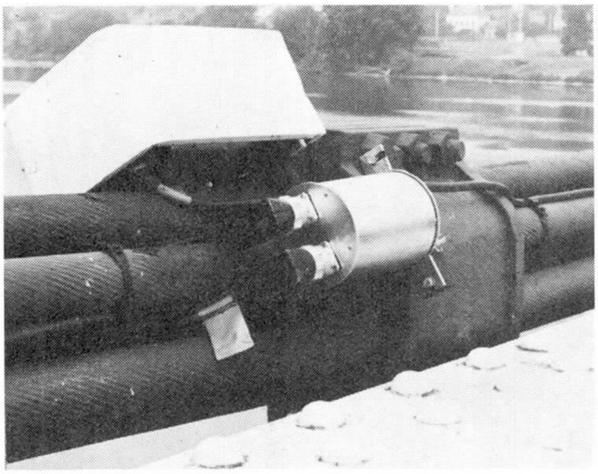
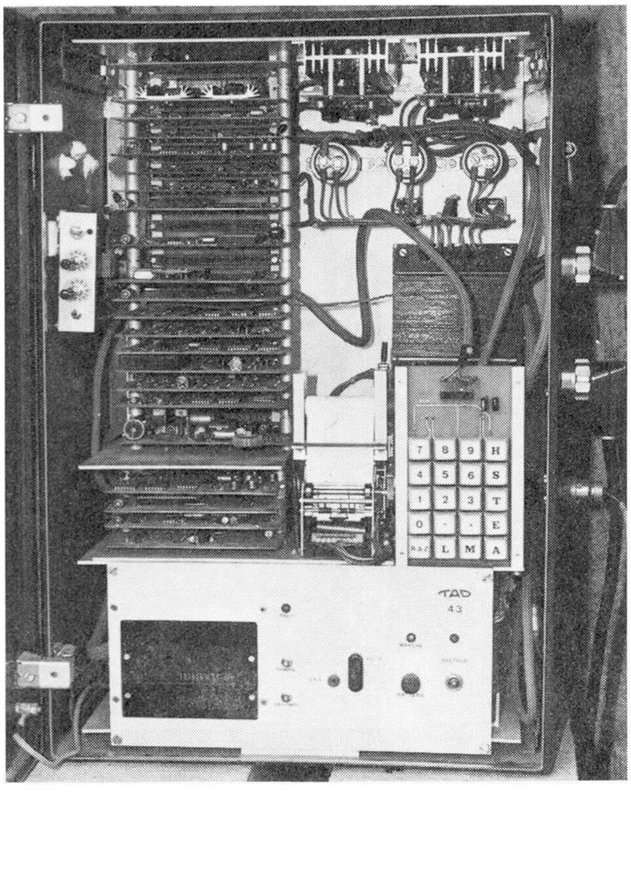


FIGURE N° 3

B - Central box



5. CONCLUSION

The acoustic survey of suspension and cable stayed bridges enables now the fracture of elementary wires to be detected in cables, which may induce the sudden failure of the structure. It is not excluded that it enable us to estimate the residual ligetime of a cable in a given structure, using the change of the wire fractures occurence and their location. In order to reach this purpose, systematic works are to be made for surveying cables in structures under construction or old ones and examining them after removal.

The case of prestressed concrete structures is more difficult. But it already appears that it is possible to monitor, using acoustic survey, the presence of active cracks and the pending investigations on the properties of waves emited during the initiation or the growth of cracks in concrete, and on the propagation of these waves in microcracked or cracked concrete should enable us to check the change of the concrete damage, thus to give a help in diagnosing the residual safety of a structure.

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