NDTCE'09, Non-Destructive Testing in Civil Engineering
Nantes, France, June 30th – July 3rd, 2009

Detection by acoustic emission of damage in cable anchorage

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Abstract

Safety of suspension bridges and stay-cable bridges is depending on the durability of the cables. The latter show an apparent healthy aspect over their observable lengths but in fact can be damaged in the hidden parts (anchorages). In this study, Acoustic Emission (AE) is used in order to detect and to locate broken wires in the anchorages areas. The acoustic activity in the presence of broken wires comes from interwire friction. When damaged, the reference cables are put in vibration and some acoustic parameters can be used to highlight difference between them. The main parameters of the acoustic signals are the total number of count and the cumulated energy. To better understand the interwire fretting mechanism, a study of the behaviour of a broken wire in a tight cable subject to dynamic bending has been carried out. This contributes to define the conditions of vibrating for AE detection. The interwire fretting mechanism and its detection are influenced by the change of roughness, lubrication and interwire contact strength.

Résumé

La sécurité des ponts suspendus et à haubans dépend fortement de la durabilité de leurs câbles, ces derniers peuvent présenter un aspect sain sur leurs longueurs visibles mais être en fait endommagés dans les parties non accessibles (ancrages notamment). Dans cette étude, l'émission acoustique (EA) a été utilisée afin de détecter et de localiser des fils rompus dans les zones d'ancrages. L'activité acoustique sur laquelle se base cette méthode provient du frottement du fil rompu avec ses voisins. Lorsque le câble présentant une rupture artificielle est mis en vibration, plusieurs paramètres des signaux acoustiques peuvent être utilisés pour mettre en évidence une différence entre un câble endommagé et sain. Les principaux paramètres sont le nombre total de coups et l'énergie cumulée. Afin de mieux comprendre ce mécanisme de frottement entre fils, une analyse du comportement d'un fil rompu dans un câble tendu soumis à une flexion dynamique a été faite. Cela a permis de définir les conditions de sollicitation du câble favorables à la détection. Ce mécanisme et sa détection par EA sont influencés par le changement de la rugosité, de la lubrification, des forces de contact entre les fils.

Keywords

Acoustic emission, cable, interwire fretting

1 Introduction

The cables are the key component of the durability of the large bridges (suspension, stayed cable bridges) [1]. Thus they require a very important attention from the bridge managers. Specific tools for monitoring their can be implemented in order to detect the development of damage [2,3]. The acoustic monitoring of cables, developed at LCPC for several decades, allows the detection and the localization of wire ruptures as soon as they appear [4,5]. In the other hand a lack of NDT techniques exists to appreciate the cable condition mainly in their hidden parts [6]. Among the potential NDT techniques the acoustic emission was selected because it has several advantages. It is a technique which does not require a direct access to damage, which detects only the active defects and whose results are usable in real-time [7-9]. It has also the advantage of an easy implementation.

2 Interwire friction as AE source

Civil engineering cable is an assembly whose basic structural element is the drawn steel wire [10]. As mono-strand, this cable consists of straight center wire, surrounded by helical wires but various designs exist according to the type of bridge in which it is used. In this study, we are interested in two types: mono and multi-strand (Fig.1).

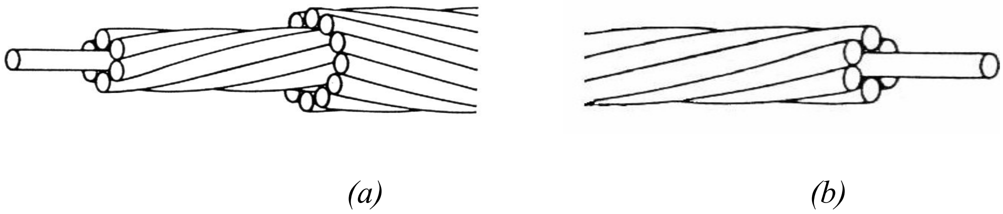
(a) (b)

Figure 1. *Strand structure and geometry for multistrand (a) and monostrand (b)cables*

When a damaged cable is put under vibration, the slip of broken(s) wire(s) generates an interwire friction which acts as AE source.This interwire friction is due to the strand geometry and can be highlighted when wires slip by rubbing against the others during bending tests [11]. The undamaged wires and broken one(s) can slip when a certain radius of bending curvature is reached. That corresponds to a total tension in the wire higher than friction strength.

A preliminary study of interwire friction of broken wire applied to the strands allows us to calculate some mechanical parameters in relation with others authors' works [12]. First result concerns the calculation of the recovery length according to the radius of curvature imposed. When a wire fractures in a 7-wires strand, it can take again its initial part of tension over a certain length starting from the broken wire end: this is called the recovery length [13,14]. That can be explained by the presence of contact and friction strengths between helicoidal wires. The knowledge of this recovery length allows us to put AE sensors on wires in a more effective manner. In the case of a broken wire in a 7-wires strand, another calculation is developed to determine the maximum curvature producing slip of the broken wire without slipping of healthy wires. The model takes account of real deformation of the tensioned cable, i.e. anchorage and dynamic inertia effects [15]. From these results, we can choose the vibration conditions (amplitude and frequency) of the cable which do not cause in theory the slip of healthy wires avoiding unwanted AE hits.

3 Material and techniques

Tested specimens are mono and multi-strand cables having 8 m as length. For each type of cable, a reference cable is manufactured without defects while the second cable is made with broken(s) wire(s) in the external layer before its installation in the anchorage base. For multi-strand, 3 zones with different scale of damage (2,5,7 broken wires) are realised on a cable section.

For these tests, a specific set-up devoted to cables applications is used (Fig. 2). The cable is put in vibration by applying a transverse force with a pulsating system powered by an electric motor. This last was optimised by add-in a variable speed unit making it possible the cable to vibrate in the vertical direction with displacements from 5 to 15 mm and for frequencies ranging between 10 and 30 Hz. The tensioning is made using a jack until a force of 100 kN (mono-strand) or 200kN (multi-strand).

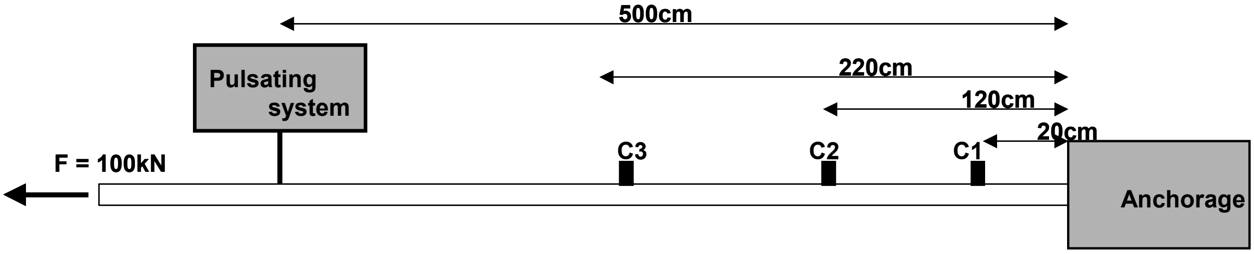

Figure 2. *Configuration of the anchorage-cable system and AE sensors (C1 to C3) along cable*

The acoustic emission system is a 4 channels system coupled to resonant piezoelectric sensors (µ80). Those are stuck on wire using a high rigidity adhesive. The detection threshold is fixed at 40 dB with a pre-filtering of the signals between 20 and 600 kHz. The AE sensors are positioned over the extension of the broken wire in a first configuration. The objective is to appreciate the propagation conditions of acoustic waves in the cable and to identify AE sources. Hsu-Nielsen tests are carried out before each test in order to check that the system is functioning and the sensor-wire coupling is good.

4 Damage detection by AE for different types of cable

A characterisation of the background noise is done for undamaged and damaged cables. When cable is put in vibration with increasing amplitudes, an acoustic activity which not comes from vibration system but from anchorage is recorded [6]. AE on undamaged cable is largely reduced after few minutes of testing and can be attributed to the degradation of resin which fills the anchorage [16]. By deduction, the strong acoustic activity recorded on the damaged cable thus comes mainly from the broken wires.

4.1 Multi-strand cable

A global comparison of acoustic activity between cables produces promising results. The AE parameters selected for this analysis are the number of hits and counts and their energy. They are large-scale parameters but for an in situ application of this technique, the data processing must be simple. The distinction between undamaged and damaged cables is relatively easy by comparing AE parameters (Fig. 3). This interwire friction strongly depends on the importance of the damage. Thus, the acoustic activity is roughly proportional to the number of broken wires (Fig. 4). The most relevant parameter is the number of counts.

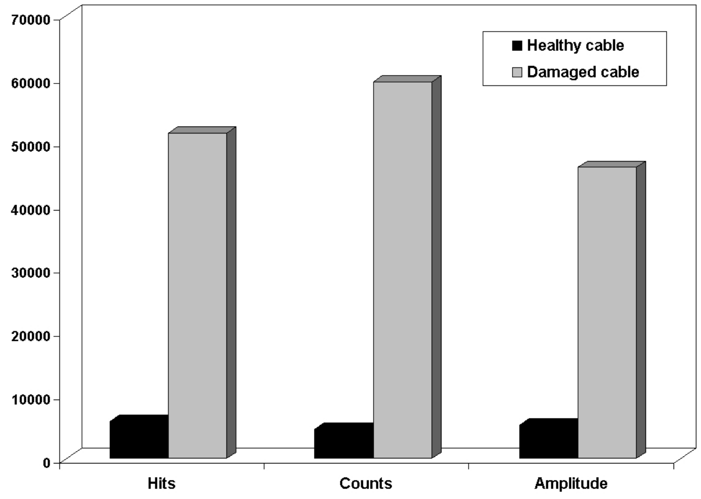

Figure 3. *AE activity according to the presence or not of defects in cable*

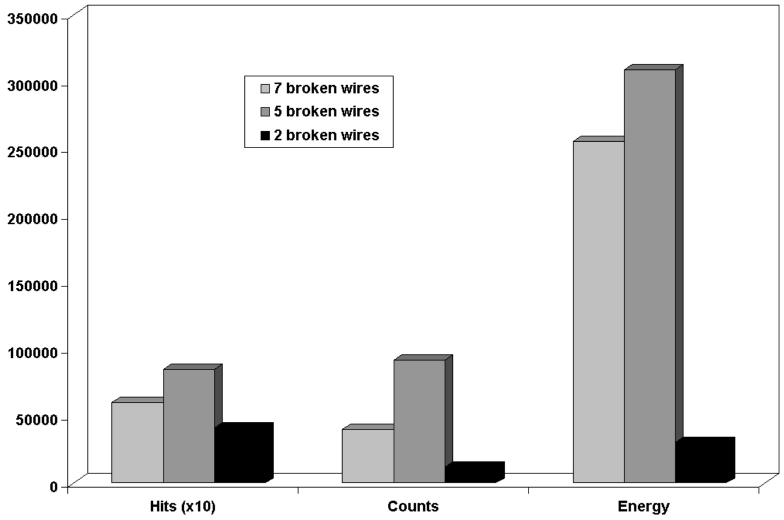

Figure 4. *AE activity for 3 degree of degradation of a multilayer cable*

It is possible to give a first diagnosis of the state of degradation of a cable but this analyse is semi-quantitative only. Moreover, during our tests an important data scattering was observed. To better understand this interwire friction mechanism and correlation between its mechanical behaviour versus AE response, test on a simplified cable type, i.e. a 7-wires cable, were done.

4.2 Mono-strand cable

It is easier with this type of cable to verify the output of the mechanical model already mentioned in § 2. For low vibration frequency (less than 1 Hz), wires "stick" together giving no AE activity. By increasing the vibration frequency, the tangential forces change between wires in contact. When they exceed the intensity of interwire friction, they induce the sliding of wires which produce AE (Fig. 5). This behavior is consistent with the analytical model.

The evolution of AE activity versus frequency is explained by the repetition of the sliding process of wires which increases for higher frequency.

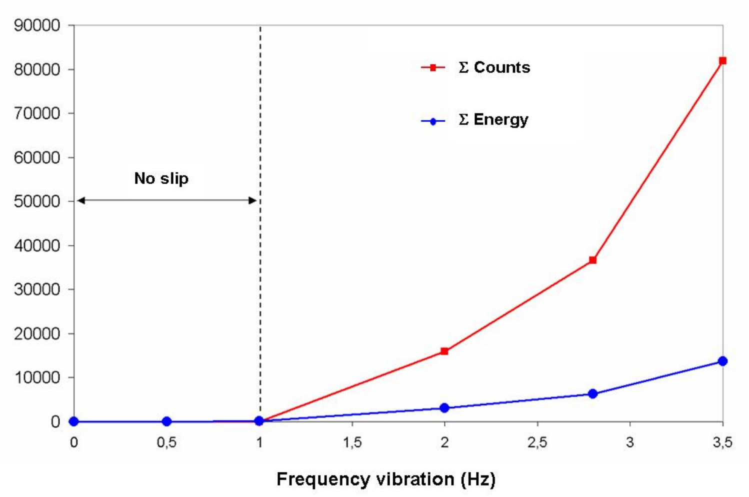

Figure 5. *Number of counts and AE energy detected versus vibration frequency*

For a mono-strand, an unexpected result on AE activity is that an undamaged cable produces acoustic emission. After many mechanical testing, we found that AE detects two distinct phenomena which are the slip of broken wire and that of healthy wires. These two mechanisms are more or less important according to the vibration conditions imposed on the cable. The distinction between them is possible by an analysis based on correlation of the AE parameters. After FFT of the acoustic signals detected, frequency parameters are also employed. The correlation analysis between amplitude and frequency centroid is able to separate the AE sources as illustrated for tests on cables having or not a defect (broken wire). Two AE populations appear in distinct frequency ranges (Fig. 6).

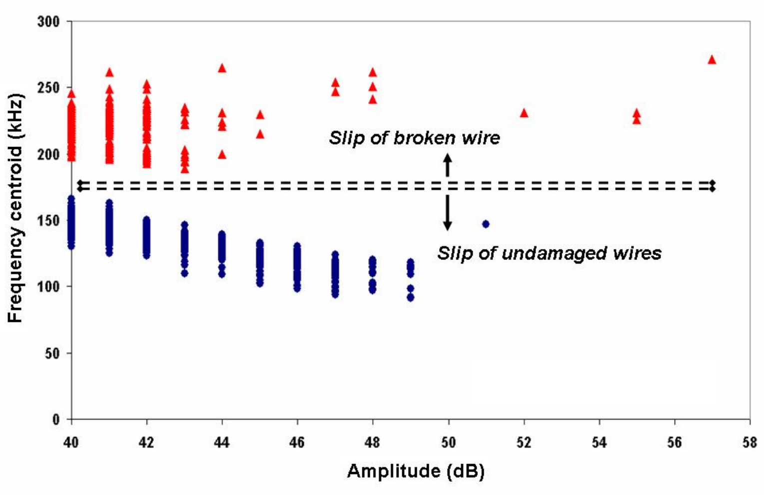

Figure 6. *Distinction between healthy and damaged cables based on analysis of AE parameters*

5 Conclusions

In order to meet a need for the bridges managers to detect cable's damage in their no-accessible parts, we have evaluated the AE technique. A typical configuration was chosen, a cable under an anchoring base. The damage carried out is broken wires. The source of detected AE is interwire friction between wires when cable is put under vibration. A global analyse of AE events on multilayered cable can shows a difference between a healthy and damaged cable. For a more accurate and reproducible result, a correlation technique is required which can isolate the AE populations corresponding to other AE sources. From this study, it is possible to discriminate a damaged cable from undamaged one by AE technique. The application of this technique and its processing methods on a bridge is underway.

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