

## **Acoustic Emission use for prestressing strands corrosion assessment**

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### **Abstract**

Acoustic emission (AE) is studied to monitor stress corrosion cracking (SCC) of prestressing strands. This nondestructive method seems particularly recommended because it has the capacity to realize a real time and a remote detection of active defects. In this study corrosion mechanisms are generated in an accelerated way. A particular attention has been made on hydrogen embrittlement process by using ammonium thiocyanate solution.

A first study has shown the capacity of AE to detect four damage stages during corrosion test. Each stage can be characterized with two AE parameters: counts and duration.

This second work proposes to analyze AE waves propagation in a real-like prestressed structure. A special focus has been made on sensor location. Results show the difficulty for waves to propagate inside cement grout but some sensors have promising results.

### **Résumé**

La technique d'émission acoustique est étudiée dans le cadre de l'auscultation de la corrosion sous contrainte des câbles de précontrainte. Cette méthode de contrôle non destructive semble particulièrement adaptée puisqu'elle permet de détecter des défauts actifs en temps réel et à distance. Dans cette étude, les mécanismes de corrosion sont reproduits de manière accélérée. Une attention particulière a été faite au mécanisme de fragilisation par l'hydrogène en utilisant une solution corrosive de thiocyanate d'ammonium.

Une première étude avait démontré la capacité de l'EA à détecter quatre phases d'endommagement pendant un essai de corrosion. Chaque phase peut être caractérisée par deux paramètres d'EA : le nombre d'alternances et la durée.

Ce second travail propose d'analyser la propagation des ondes d'émission acoustique dans une mini structure. Un accent particulier a été mis sur le positionnement des capteurs. Les résultats montrent la difficulté des ondes à se propager dans le coulis de ciment mais certains capteurs ont des résultats encourageants.

### **Keywords**

Hydrogen embrittlement, bridge structures

## **1 Introduction**

Eugène Freyssinet has imagined in 1928 a new construction technique accomplishing to the prestressed structures. The principle of this technique is to compress concrete in order to have a better resistance towards tensile strains coming from road or railway traffic. On post-tensioned prestressed bridges, strands are placed inside ducts which are incorporated in the concrete walls. Strands are tensioned at 80% of their Guaranteed Ultimate Tensile Strength (GUTS) to compress concrete by the way of anchorages [1-2].

Unfortunately, prestressing strands can suffer from stress corrosion cracking (SCC) assisted by hydrogen [3]. Despite they are protected by a cement grout injected inside the

duct, strands are subjected to attacks from aggressive ionic species which are present inside the interstitial liquid. Localised corrosion takes place and hydrogen is formed in these occlusive cells due to hydrolysis reactions. Hydrogen diffusion inside the metallic matrix causes its embrittlement [4]. Localised corrosion attacks create also high strain conditions accelerating strand failure.

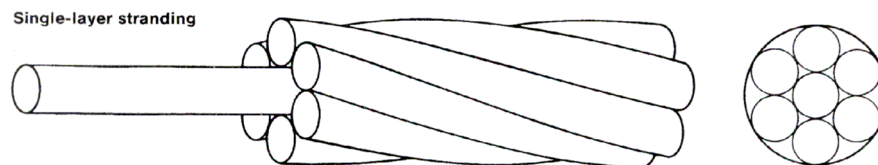
Bridge managers need control methods allowing the real-time monitoring of strands in connection with SCC damages. The constructive arrangements limit the strands accessibility to anchorage area. Today, few methods allow answering to these requirements.

Acoustic emission (AE) permits a real-time and a remote monitoring of defects and then, it seems adapted to the task [5]. Besides, many studies have demonstrated its capacity to detect corrosion [6-8] and it has already been used on bridges to detect different damage types [9-13]. A first study has shown the capacity of AE to detect stress corrosion cracking of prestressing strands on an accelerated corrosion test. This study has also allowed characterizing the different stages of the damage cycle with discriminating parameters [14].

This paper presents the AE monitoring of an accelerated corrosion test on a real-like prestressed structure. A full anchorage is used as well as prestressing strands which are placed inside an injected duct. An optimization of the instrumentation has been made. The AE waves propagation in air and cement grout is also observed. A reference sensor pasted near the corrosion cell allows analyzing the damage cycle of the strand and the comparison with the AE activity collected by sensors on the anchorages.

## 2 Experimental procedure

Strands studied are T15,7 cables including a straight central wire and six helical wires surrounding the central one (figure 1). The special microstructure of the specimen is obtained after a cold drawing process. Pearlitic grains are oriented in the wire axis and offer important mechanical properties (Table 1).

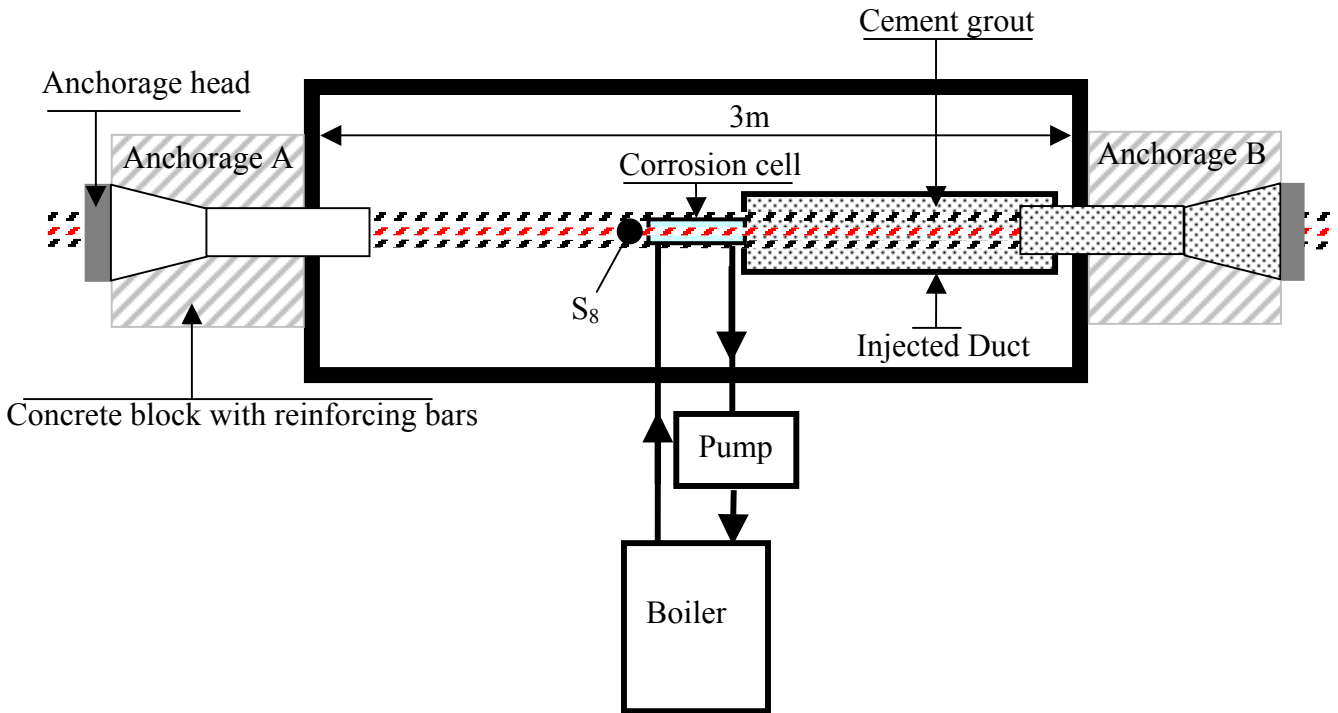


**Figure 1.** T15,7 strand geometry with a central wire and 6 helical wires.

**Table 1.** Chemical composition and mechanical properties of cold drawn steel for T15,7.

Chemical composition [wt%] (main elements)				
C	SI	Mn	P	S
0,8	0,25	0,5	0,02	0,02
Mechanical properties				
$F_{0,1}$ [kN]	$F_m$ [kN]	Elongation [%]	Sectional area [mm <sup>2</sup> ]	Pitch [mm]
274	295	5,3	151,2	240

To simulate in situ conditions, some real-like structures have been developed (figure 2). Strands are tensioned at 80% of the Guaranteed Ultimate Tensile Strength (GUTS) on a rigid frame of 3 meters-long.



*Figure 2. Real-like structure and the experimental assembly.*

The full anchorages are composed by a concrete block with reinforcing bars and an anchorage head. Strands are blocked in the anchorage head with wedges. A duct is placed on a half part of the strands. The anchorage B and the duct are injected with a cement grout. A corrosion cell is placed in the middle of the central strand. The corrosive solution used is composed with  $250\text{g.L}^{-1}$  of ammonium thiocyanate ( $\text{NH}_4\text{SCN}$ ). The solution is kept at a constant temperature of  $50^\circ\text{C}$  due to a liquid circulating from a boiler.

The experimental structure has been instrumented with different AE sensors. Two acquisition systems have been used: a MISTRAS system with 8 acquisition channels and a PCI2 system with 4 acquisition channels. The acquisition threshold is 30 dB.

### 3 Results

#### 3.1 Instrumentation optimization

Anchorages have been instrumented with four different sensors: two small resonant sensors (pico and micro 80), a wide-band sensor (WD) and a low-frequency sensor (R6). For anchorage A, sensors have been glued on the anchorage head, on the strand end and on the wedge. Hsu-Nielsen tests have been made on the strand at 900 mm of the concrete block. The amplitude level of waves collected by each sensor allows selecting the four “location/sensor type” ratio having the best results. The figure 3 presents the instrumentation of the anchorage A. A R6 sensor has also been pasted on the concrete block. Concrete is well-known to favor low-frequency waves.

The same experimental procedure has been made for the instrumentation of the anchorage B. Hsu-Nielsen tests have been made in front of the injected duct. The figure 3 presents the anchorage B instrumentation.

A micro 80 sensor has also been pasted near the corrosion cell to collect reference signals (figure 2).

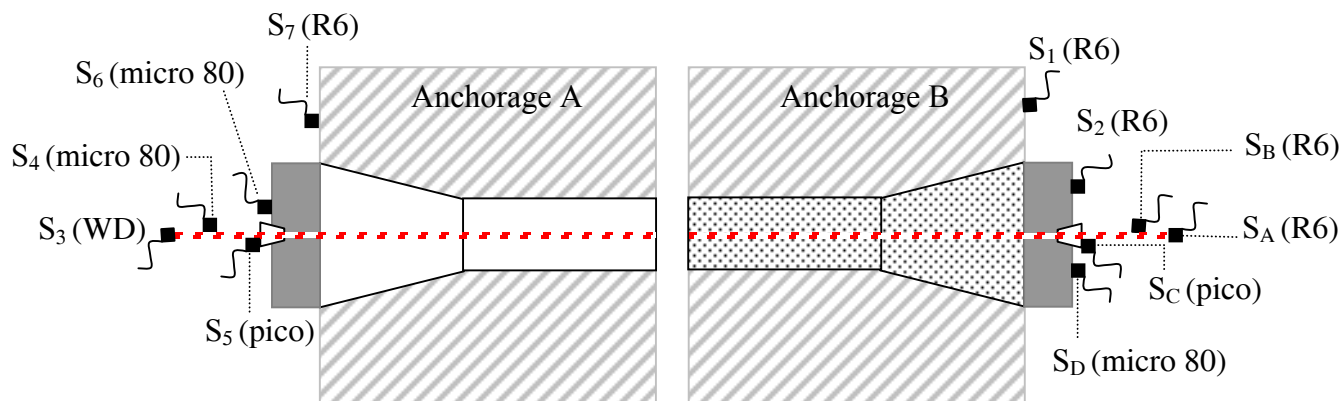


Figure 3. Anchorages instrumentation.

### 3.2 Damages analyze

The analyze of the AE collected by the reference sensor (sensor 8) can reflect the damage mechanisms of the specimen during the corrosion test. The first stage of the figure 4 corresponds to the H<sub>2</sub> bubbles bursting on the strand surface. Stages 2 and 3 come from the same damage mechanisms: the crack initiation and the hydrogen embrittlement of the steel. The acoustic activity difference comes from an increase of the corrosive solution temperature. The last stage is the crack propagation conducting to the wire failure. This step duration is about 16 hours. It is in the same order of a previous study [14].

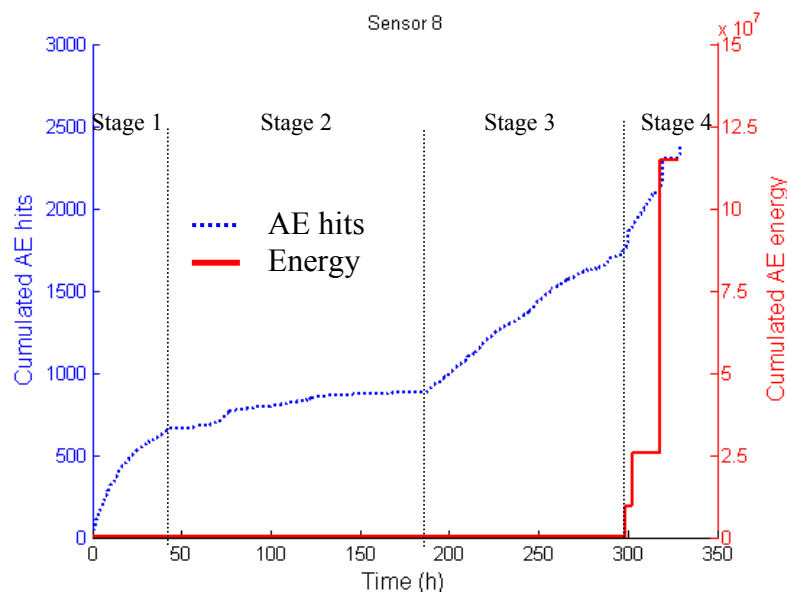


Figure 4. Cumulated AE hits and energy collected by sensor 8.

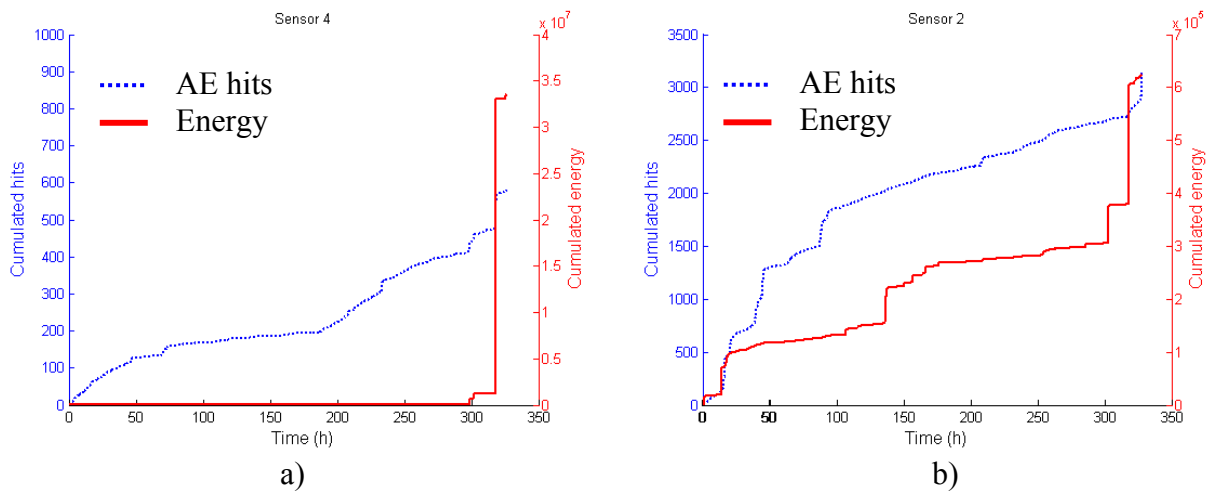
### 3.3 Monitoring on the anchorage system

The waves propagation until anchorages is very penalizing. If cumulated hits and cumulated energy collected by each sensor are compared, only sensor 4 shows a damage cycle comparable to AE response on sensor 8 (figure 5a). AE waves attenuation between this two sensors can be characterized with the amplitude of the AE corresponding to failure, the number of hits collected or the cumulated energy (Table 2).

**Table 2.** AE characteristics after propagation

	AE failure	Cumulated AE hits number	Cumulated energy
S <sub>8</sub>	100 dB	2300	12.10 <sup>7</sup>
S <sub>4</sub>	92 dB	580	35.10 <sup>6</sup>
S <sub>2</sub>	71 dB	3000	6.10 <sup>5</sup>

A stage of the damage cycle which can be clearly identified and could be an alarm criterion for bridge managers is the crack propagation. One sensor has been able to detect this crack propagation on anchorage B: sensor 2. Despite its damage cycle does not highlight clearly each damage stage, the increase of energy during last hours is an indicator of crack propagation. Sensor 2 detects the wire failure at 71 dB. The important hits number is due to waves reflection inside the anchorage head.



**Figure 5.** Cumulated hits and energy collected by a) sensor 4 and b) sensor 2.

## 4 Conclusions

AE is an efficient nondestructive method to detect active corrosion. Laboratory studies have clearly demonstrated its capacity to identify different types of corrosion mechanisms. More difficult conditions like prestressing strands and full anchorages cause the loss of acoustic information. Nevertheless, some sensors have shown that an optimized position and a good choice of sensor type can improve results. Sensor 2 placed on the anchorage head has detected the crack propagation occurring before the final failure. This damage stage duration is only 16 hours for our accelerated corrosion test. New tests in more realistic corrosion conditions have to be made to know if the crack propagation stage may be a good alarm criterion for in-situ monitoring.

## Acknowledgements

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