

# LCPC (Public Works Laboratory) : Industrial achievements

## Institution :

LCPC = Laboratoire Central des Ponts et Chaussées  
(Public Works Laboratory - France)

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- \* LCPC - Instrumentation Division

# Synopsis

- **Introduction - LCPC identity**
- **Zoom on LCPC Industrial achievements**
  - **A SHM development : cable health monitoring.**  
**A Case Study : Aquitaine Bridge,**
  - **Monitoring of Stayed Cables,**
  - **Structures monitoring by means of UAV**
  - **Wireless and distributed sensor network development**  
**Contribution of wireless sensors on a real case study,**
  - **Capacitive sensor for cable–sheath health diagnosis**
- **Roadmap & Conclusion**

# LCPC Identity

LCPC is :

- The French Public Works Research Laboratory
- A national organization for **applied** research and development
- 650 employees (technicians, engineers, searchers)
  - **Maintain** and develop the existing infrastructure heritage
  - **Ensure** road user safety
  - **Mitigate** the environmental impact of infrastructures during their service life (and better control natural hazards)
  - **Optimize** civil engineering structures in urban environments
  - **Promote** Promote the introduction of new materials and new technologies in civil engineering and transport.
- **Industrial and International cooperations**

# Synopsis

**A Structural Health Monitoring development :**

**=> Crack in-cable health monitoring**

**=> A Case Study : Aquitaine Bridge.**

# A SHM development : cable health monitoring

**One of LCPC missions** : cable health monitoring

- Safety,
- Structure durability,
- Cost efficiency.

**Goals of the system :**

Knowing the number of wire breaks and their location contributes to understand the well-being of the structure (diagnosis).

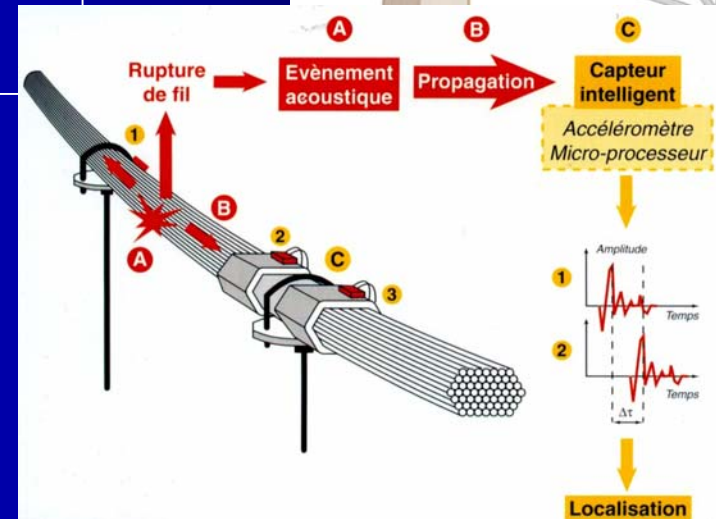
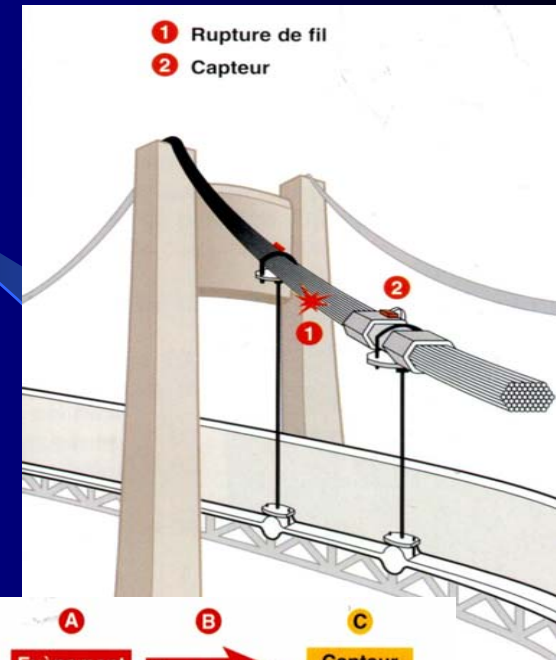
To prevent structure manager from critical accidents. A better structure maintenance.



# Cable health monitoring

## Principle of detection by sensors :

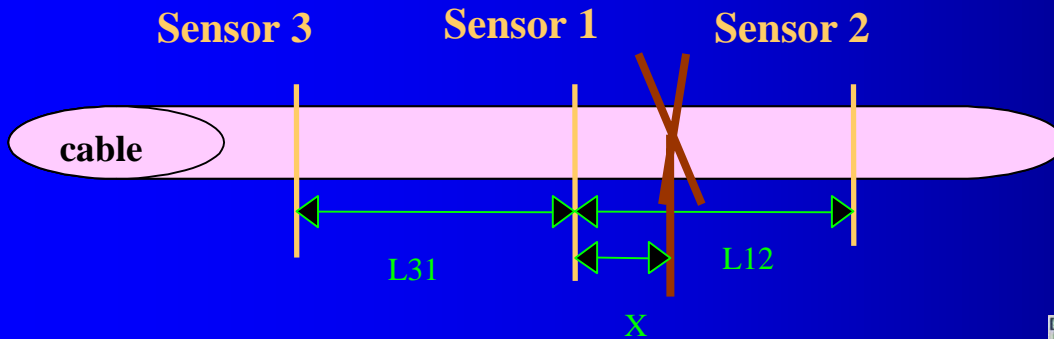
- When a wire breaks, an acoustic wave is generated,
- Wave is detected by sensors, recorded (during 8ms) and very precisely dated,
- Then, sensors transmit those informations to a remote supervisor
- By 3 acoustic sensors informations, the remote supervisor is able to evaluate when and where a rupture occurred



# Cable health monitoring

Principle of localization by supervisor :

- Wave speed “S” is estimated by informations from sensor 1 and 3,
- Localization “X” is evaluated between sensor 1 and 2



$$S = L31 / \Delta t31$$

$$X = \frac{1}{2} * (L12 - S * \Delta t12)$$

Remote supervisor calculation :

The screenshot shows a software interface with a tree view on the left and a table of events on the right. The table has columns for 'EVENEMENT', 'CAPTEUR', and 'MESSAGE'. It lists various events such as 'Demande de mise à jour du capteur' and 'Demande de mise à jour de la ligne' for multiple cables.

Cables diagnosis



Rupture location

This block contains two screenshots. The top one is a Microsoft Excel spreadsheet with columns for 'N° evt', 'heure', 'capteur', 'position', 'vitesse', 'ampl. Crete', 'ampl. Max', 'charge', and 'observation'. The bottom screenshot is a software interface showing a 3D diagram of a cable structure labeled 'Poutre 1'. The cable is shown with several red dots indicating rupture locations, labeled with codes like 'G2-51', 'G2-218G1=252', 'G2-139G1=219', and 'G2-98 G1=60'.

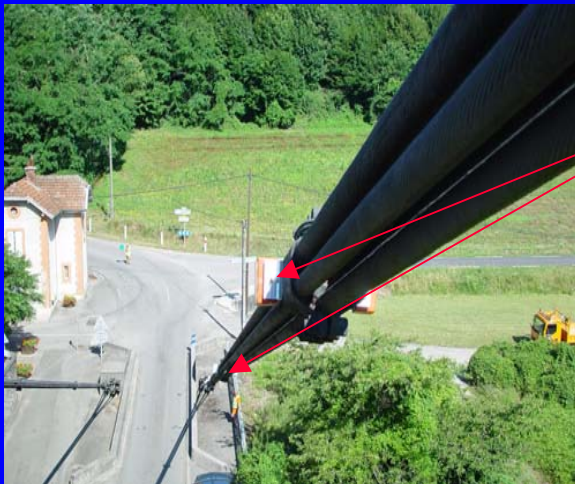
# Cable health monitoring

A first generation of the system has been developed and put into form.

Each sensor is a **smart system** that embedd :

- An accelerometer as the sensitive element (for wave detection),
- A micro-controller that ensure data digitalization and runs algorithms

Sensors and supervisor are connected by a RS485 serial link,



Sensors on cable

Remote  
supervision



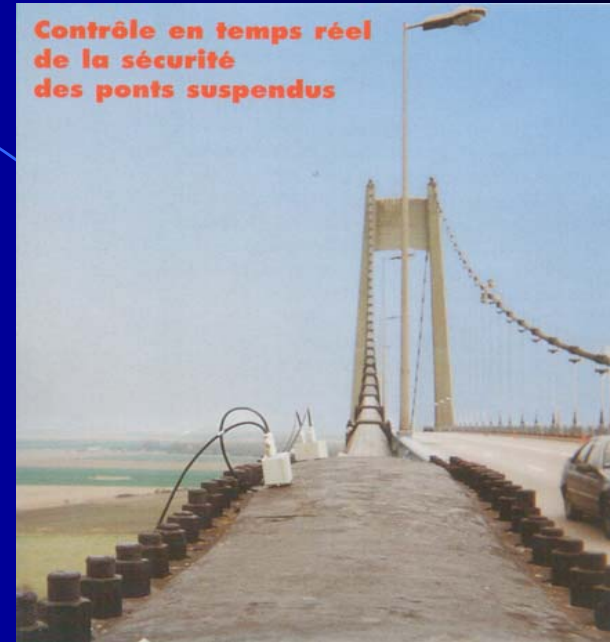


# Cable health monitoring

- Sensors are 10m equispaced,
- Threshold is around 0.8g,
- Speed wave is around 5000 m/s



Iseron Bridge

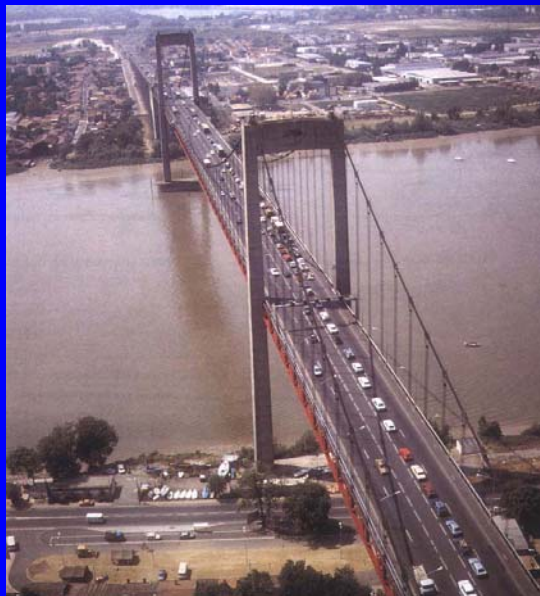


Tancarville Bridge

**Results : an accuracy of +/-15cm in wire breaks localization.**

# Cable health monitoring : Case study of Aquitaine Bridge

Aquitaine suspended-bridge put under acoustic surveillance (corrosion, fatigue) during 1995-1998 period.



Sensors on cable



# Cable health monitoring : Case study of Aquitaine Bridge

## Results :

- Several ruptures detected,
- Acceleration of the ruptures phenomenon (average of 14 ruptures / month),
- Complementary analyses of the cable and its collar proved that numerous ruptures occurred



# Cable health monitoring : Case study of Aquitaine Bridge

## Conclusion :

LCPC acoustic SHM system contributed to decide the **cables replacement** (2000-2003).



# Cable health monitoring : Case study of Aquitaine Bridge

## Industrial cooperations :

- Quasar Concept Company,
- AdVitam (Freysinet Group) Company.
- ...

**QUASAR CONCEPT** **LCPC**

**Système de surveillance acoustique**

**Contrôle en temps réel de la santé des ponts suspendus**

**Le système de surveillance acoustique développé par le LCPC basé sur la détection des ruptures de fils en temps réel apparaît comme un moyen de surveillance innovant des câbles de ponts.**

**Avril 1999**

Laboratoire Central des Ponts et Chaussées

**Advitam**

**LA SEMAINE ILE-DE-FRANCE** **QUEST ET CENTRE** **EST RI**

**VOTRE CONTACT**

**PROJETS page 62**

**CARNET**

**AGENDA**

**PARIS CONÇU POUR LES ŒUVRES D'ART. LE LOGICIEL SCAM PRÉVOIT UNE NOUVELLE APPLICATION AVEC LES COLLECTEURS**

**Un état des lieux complet des égouts parisiens va être réalisé**

«Paris est conçu pour les œuvres d'art, le logiciel SCAM prévoit une nouvelle application avec les collecteurs...»

**LA SEMAINE ILE-DE-FRANCE**

**QUEST ET CENTRE**

**EST RI**

**MORILLON CORVOL PRIVILÉGIÉ LA VOIE D'EAU**

«Morillon Corvol est privilégié la voie d'eau...»

# Synopsis

**A Structural Health Monitoring development :**

**=> Rotation of stayed cables monitoring.**

**=> A Case Study : Saint Nazaire Bridge.**

# Cable health monitoring : Rotation of stayed cables

## Problem :

Cable displacements at stayed cables anchoring causes ruptures due to fatigue.



# Cable health monitoring : Rotation of stayed cables

## **Solution : Monitoring system**

- Measures cable displacements,
- On two axis ( on bridge and orthogonal-to-bridge directions),
- For each axis : 4 displacements (mm) measurements,
- A supervisor : record measures (at 300 Hz sampling) and provide statistics.



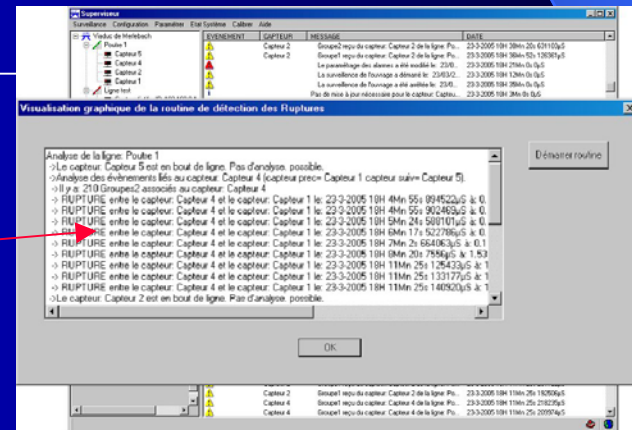


# Cable health monitoring : Rotation of stayed cables

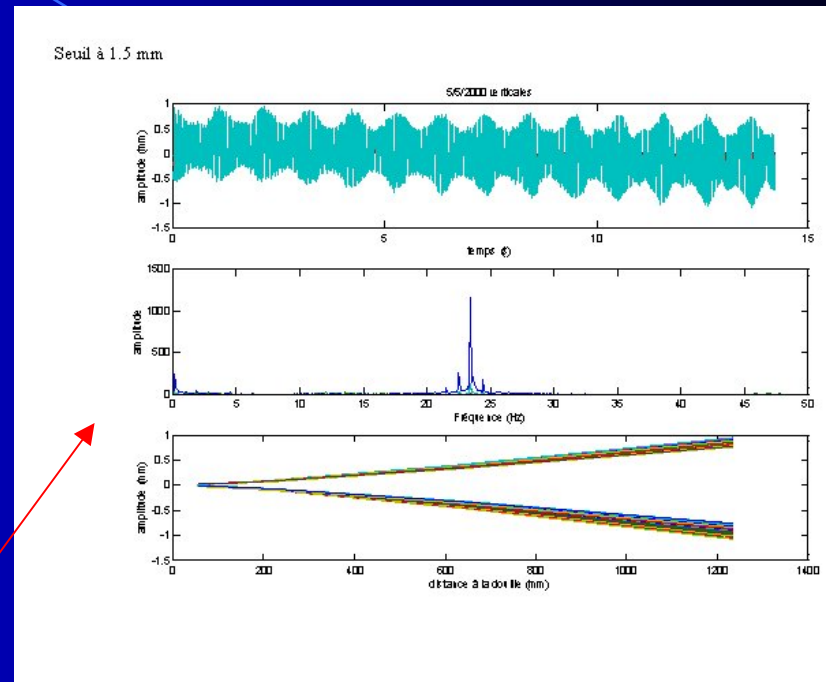
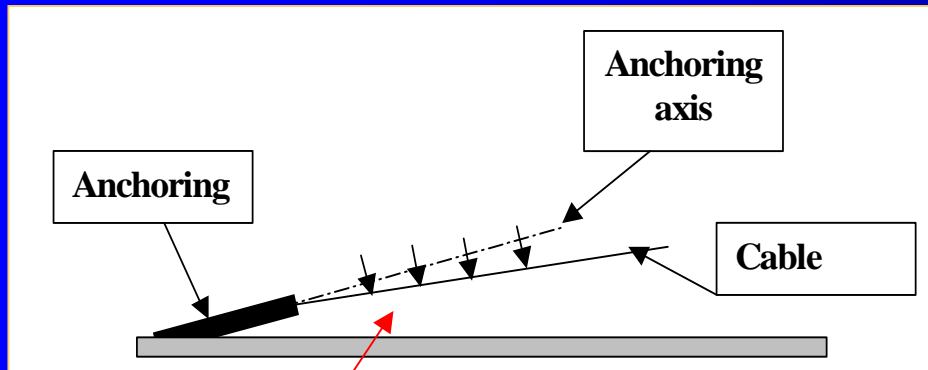
## Results : Monitoring system installed on Saint Nazaire Bridge

A interesting diagnosis could be established :

- Major displacements in bridge direction (while the reserve was expected),
- Displacements could be due to wind as much as trafic (correlation was made)
- Frequency analyses and Rainflow chart furnished the frequencies to attenuate on the cable



# Cable health monitoring : Rotation of stayed cables



SHM system

Rainflow chart

Frequencies  
analyses

**Prospects :** Attach to cable a controlled active dumper system to stabilize cable...

# Synopsis

## Monitoring of structures by means of **Unmanned Aerial Vehicles**

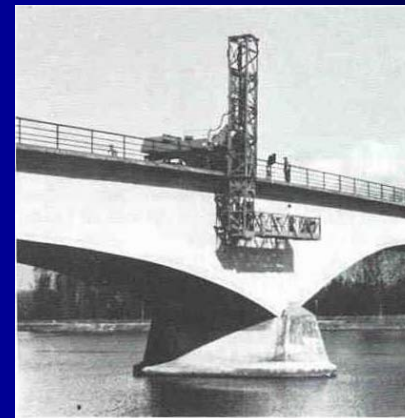
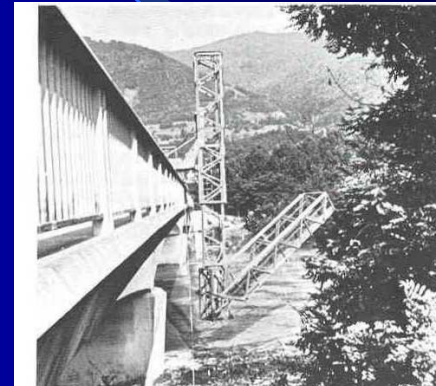
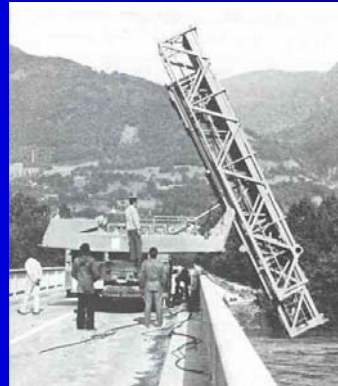
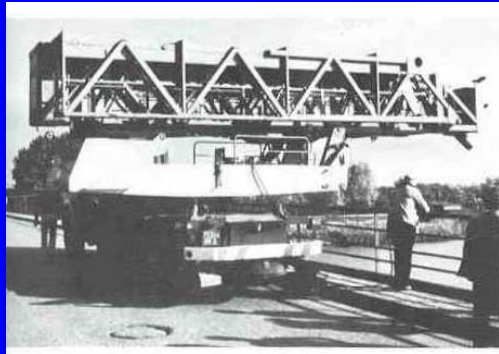
- ⇒ Investigation of bridges using a mobile platform :  
**Why ?**
- ⇒ Actuals inspection methods
- ⇒ An experimentation case study
- ⇒ Results

# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

- ☐ To improve human security conditions
- ☐ To reduce the financial cost
- ☐ To increase the frequency
- ☐ To develop automated investigation methods

# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

## Actuals inspection methods



# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

## Actuals inspection methods



**Scorpion**



**Epsilon**

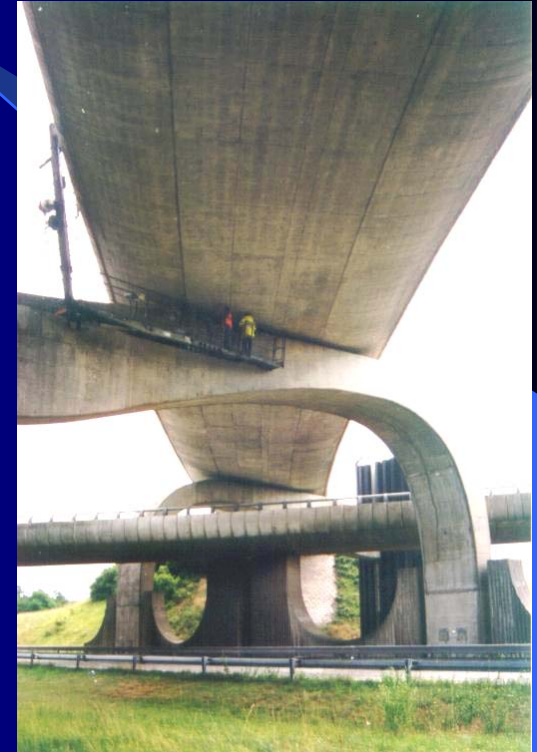
# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)



Difficult to access



Structures over rivers



Complex shape structures



Inside bridges : cables, few place...

# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

Manual measurements :

Crack width ruler

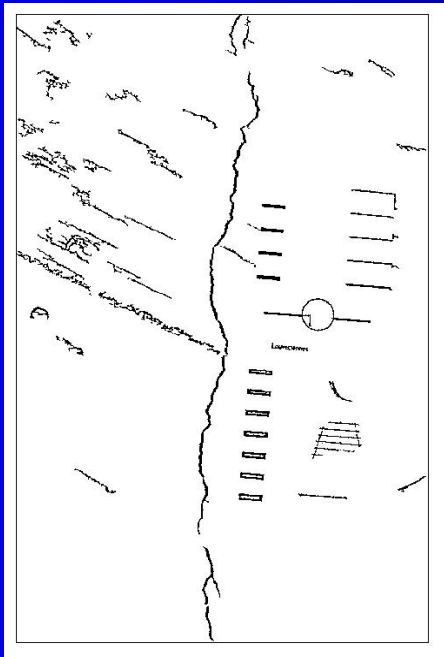
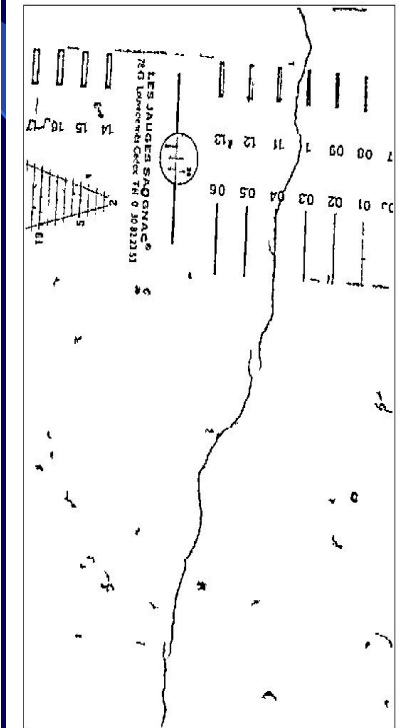
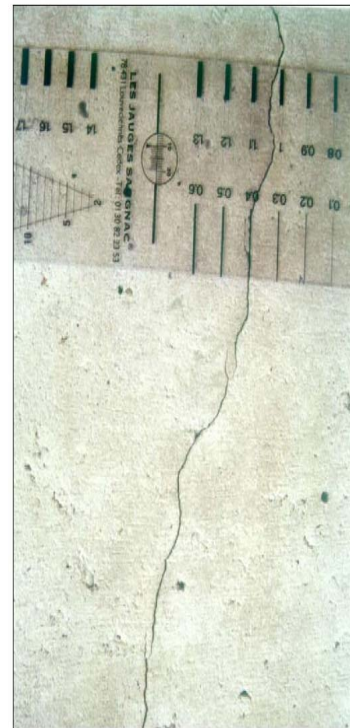


Image processing perspectives





# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

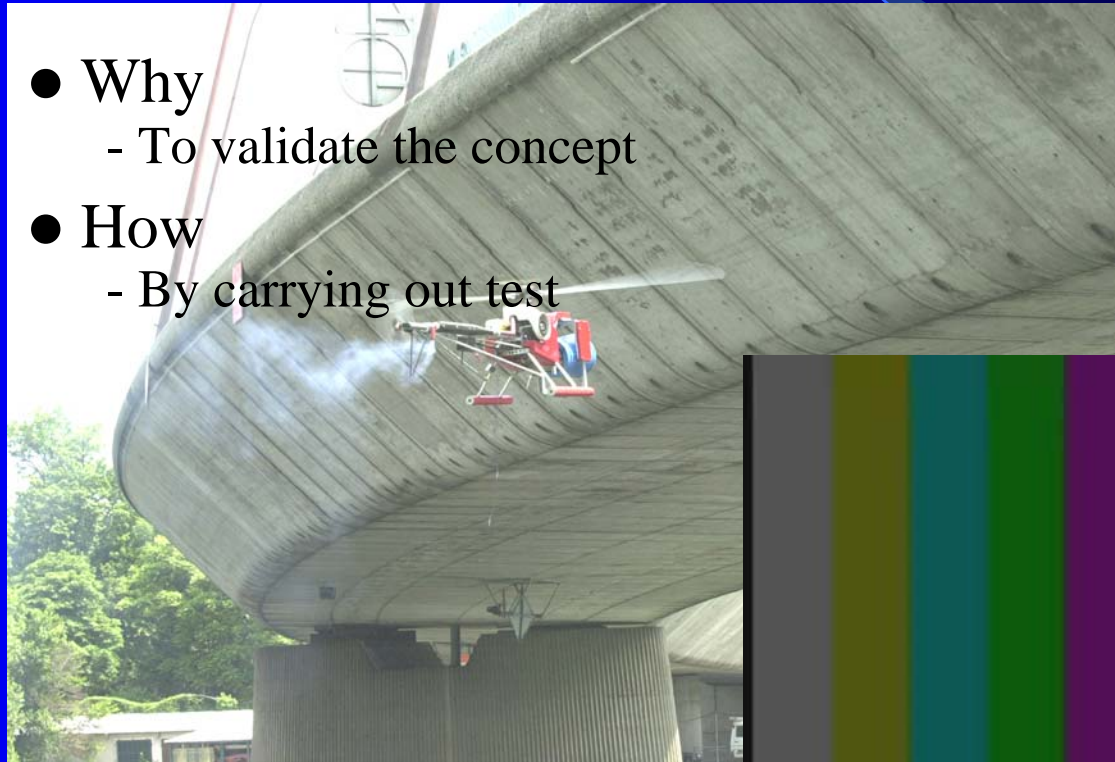
Goals of the Mobile Platform for Instrumentation (PMI project) :

- TO VIZUALISE STRUCTURE DEFECTS
- TO CARRY OUT NON DESTRUCTIVE MEASUREMENT
- TO LOCALIZE THE DEFECTS ON THE STRUCTURE
- TO STORE AND TRANSMIT COLLECTED DATAS
- TO SET UP AN INSTRUMENTATION
- TO CUT OFF SAMPLES OF THE STRUCTURE

# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

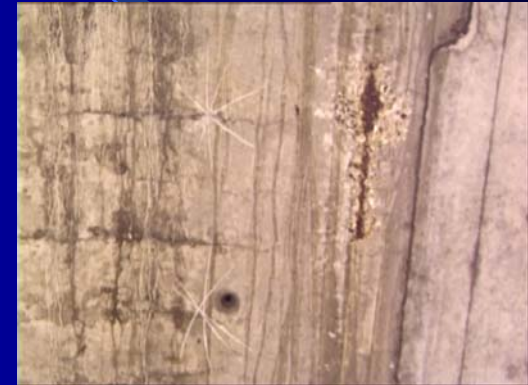
## A Feasibility study on the « Saint-Cloud » bridge

- Why
  - To validate the concept
- How
  - By carrying out test



# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

IMAGES EXTRACTED FROM THE VIDEO OF THE TRIALS :



# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

## Results :

- ☒ A video of the structure was recorded and stored
- ☒ First image analyses were done by a structural engineering manager and discussed
- ☒ Extracted pictures and video have the sufficient quality to consider development of **Automatic Image Processing algorithms** for defects detection.

# Monitoring of structures by means of Unmanned Aerial Vehicles (UAV)

## Roadmap :

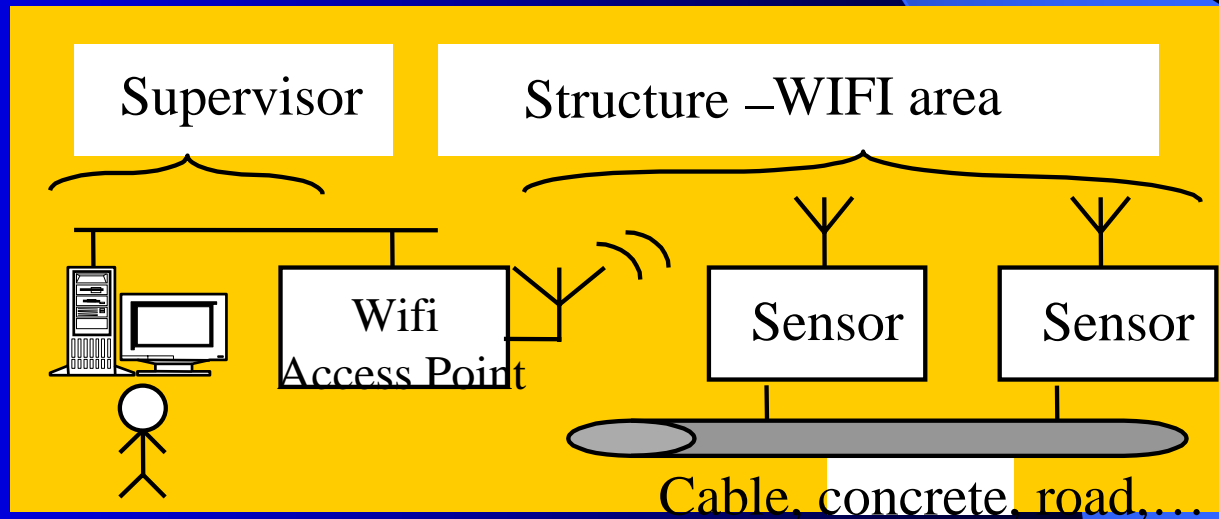
- ☐ Concept is validated
- ☐ Defects identification have to be located on the structure
- ☐ An UAV platform is under development with an Industrial Partner : Bertin Company



# Synopsis

## Wireless and distributed sensor network. Smart Sensors

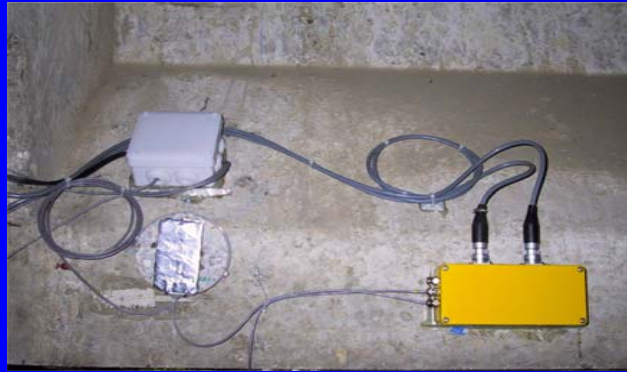
- ⇒ Motivation and needs
- ⇒ The LCPC generic wireless platform
- ⇒ A case study : Wireless monitoring of Merlebach Bridge
- ⇒ Roadmap



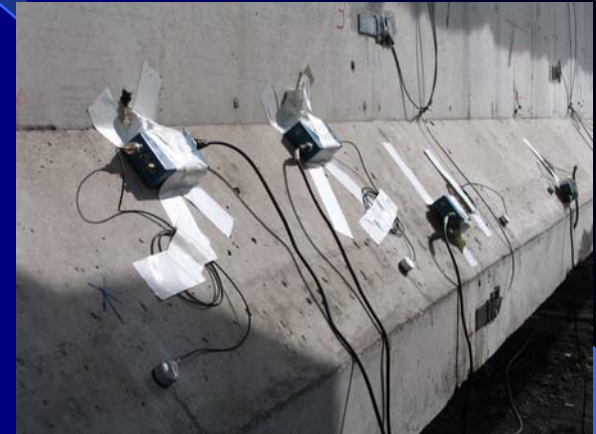
# Wireless and distributed sensor network.

## Smart Sensors

Even if use of sensors is a need and a reality, cables of **wired instrumentations are a source of limitations.**



Wires



- > Poor flexibility
- > Geographically limited
- > Non-massive instrumentations



- > Fragile
- > Sensitive to electromagnetic noise

# Wireless : Motivation and needs

## Conclusions :

Wireless technologies offer more than a practical simplification ! It **enables new way of monitoring.**

Wireless technologies are **in adequation with** growing needs and developments of **smart sensors and distributed networks.**

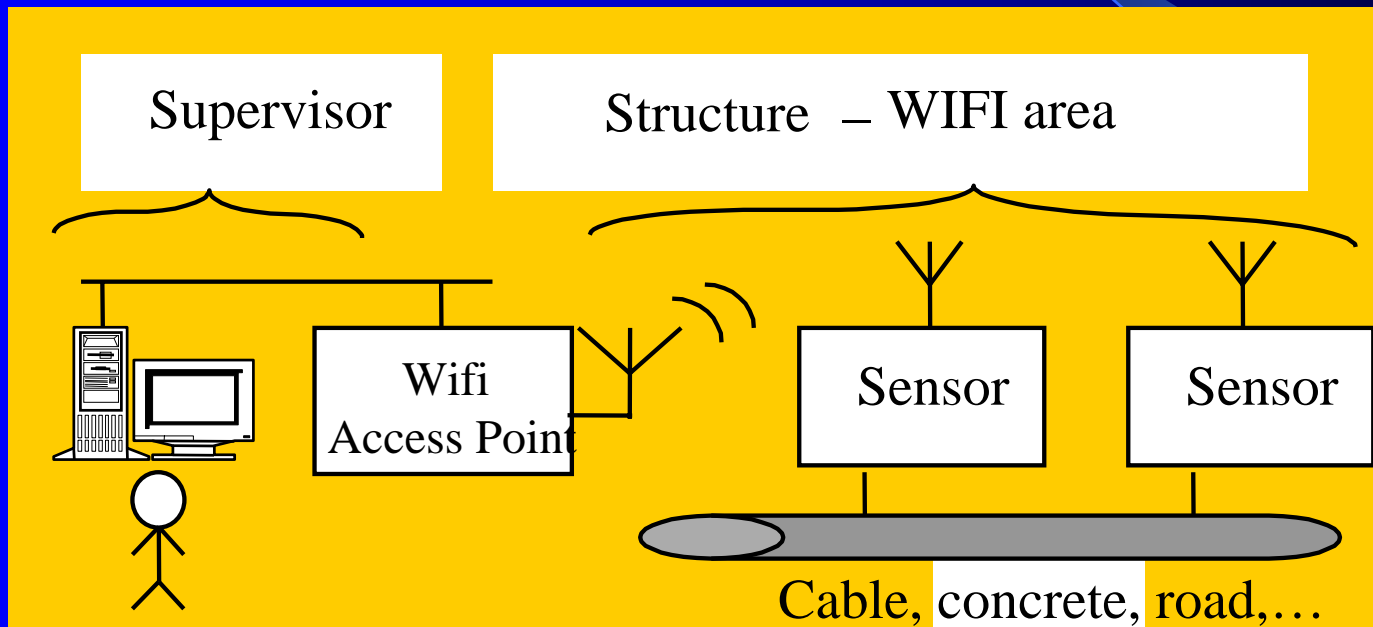


**Thus, wireless instrumentation emerges as a source of progress.**



# LCPC Wireless platform description

LCPC has developed a wireless sensor network platform with the following characteristics : **the platform is a “N sensors 1 supervisor” distributed network.**

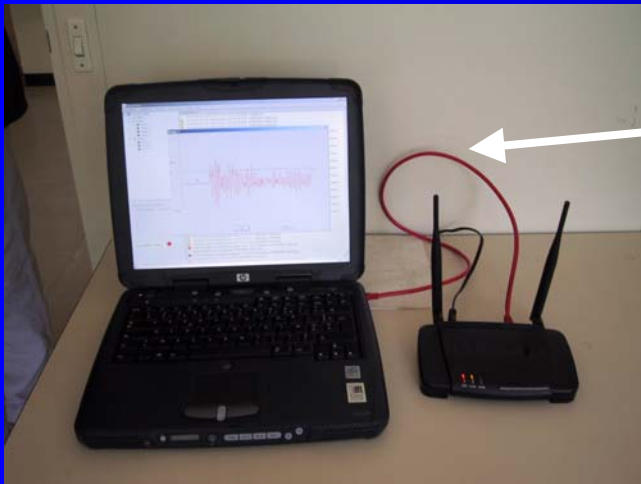


**Sensors are seen like computers of a traditional computer network**

# LCPC Wireless platform description

## Network communication : TCP/IP

Wireless implementation of TCP/IP exists : WIFI (802.11x),  
TCP/IP is an open-source low-cost world-wide protocol,  
Point to point, connected and reliable protocol,  
Easy to embed and customize in small electronic components,  
Wifi areas can easily be adapted to Bridges context.

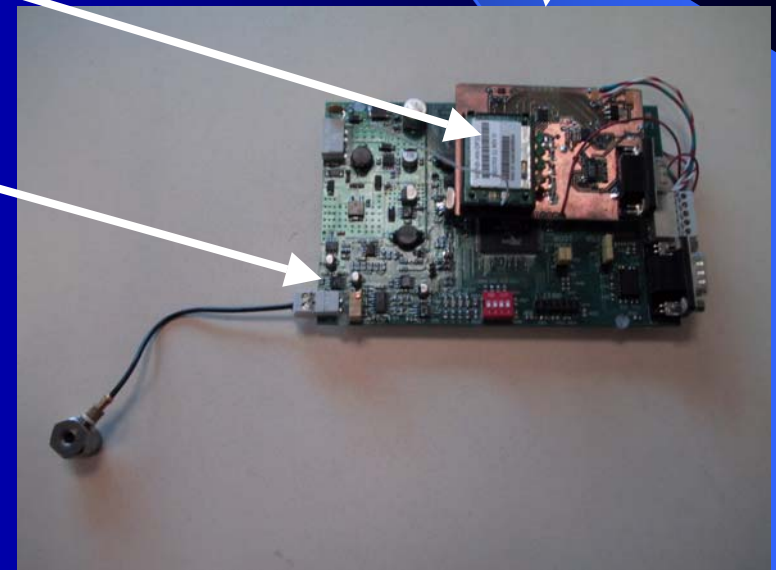


A simple access point  
connected to a  
traditional PC provides  
a wireless TCP/IP area.

# LCPC Wireless platform description

## LCPC smart sensor:

- Sensor core is a DSP : dedicated to signal processing (FFT, filtering...). Hosts an OS
- DSP embedd the real-time  $\mu$ Linux OS. Permanently runs the **application** algorithms
- A TCP/IP – Wifi module for wireless communications
- A 12 bits converter that runs data digitalization up to 1 Mhz. Sensitive element : piezzo, strain-gauges, T°c...
- A GPS module for sensor absolute time synchronization



# LCPC Wireless platform description

## LCPC Supervisor :

- An Oriented Object developed software : easy to customize from one **application** to another. Reusable software bricks.
- Runs on any standard PC : that all include a native TCP/IP stack = communication with sensors is **fully transparent**
- Offers intuitive interfaces to **manage and configure the sensor network** :
  - To add/remove sensors object in the monitoring system
  - To change a sensor parameter,
  - To dis/enable a sensor in the network,



EVENEMENT	CAPTEUR	MESSAGE	DATE
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 38m 20: 631103µs
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 38m 53: 123209µs
		Le paramétrage des alarmes a été modifié le: 23/03/...	23-3-2005 18h 21m 0s 0µs
		La surveillance de fournage a démarré le: 23/03/2...	23-3-2005 18h 12m 0s 0µs
		La surveillance de fournage a été arrêtée le: 23/0...	23-3-2005 18h 35m 0s 0µs
		Pas de mise à jour nécessaire pour le capteur: Capte...	23-3-2005 18h 3m 0s 0µs
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18h 3m 0s 0µs
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 12m 6s: 737090µs
		Pas de mise à jour nécessaire pour le capteur: Capte...	23-3-2005 18h 42m 0s 0µs
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18h 42m 0s 0µs
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 49: 238329µs
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 46: 018199µs
		Pas de mise à jour nécessaire pour le capteur: Capte...	23-3-2005 18h 33m 0s 0µs
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18h 33m 0s 0µs
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18h 33m 0s 0µs
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 37: 163034µs
		Pas de mise à jour nécessaire pour le capteur: Capte...	23-3-2005 18h 26m 0s 0µs
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18h 26m 0s 0µs
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 5: 868441µs
		Pas de mise à jour nécessaire pour le capteur: Capte...	23-3-2005 18h 26m 0s 0µs
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18h 26m 0s 0µs
	Capteur 5	Groupe2 reçu du capteur: Capteur 5 de la ligne Po...	23-3-2005 18h 11m 25: 141629µs
	Capteur 5	Groupe2 reçu du capteur: Capteur 5 de la ligne Po...	23-3-2005 18h 11m 25: 133851µs
	Capteur 1	Groupe2 reçu du capteur: Capteur 1 de la ligne Po...	23-3-2005 18h 11m 25: 141159µs
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 11m 25: 139759µs
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 25: 140929µs
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 25: 133719µs
	Capteur 1	Groupe2 reçu du capteur: Capteur 1 de la ligne Po...	23-3-2005 18h 11m 25: 133159µs
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 11m 25: 132014µs
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 25: 125439µs
	Capteur 5	Groupe2 reçu du capteur: Capteur 5 de la ligne Po...	23-3-2005 18h 11m 25: 126104µs
	Capteur 5	Groupe1 reçu du capteur: Capteur 5 de la ligne Po...	23-3-2005 18h 11m 25: 209579µs
	Capteur 1	Groupe2 reçu du capteur: Capteur 1 de la ligne Po...	23-3-2005 18h 11m 25: 125443µs
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 11m 25: 124270µs
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 11m 25: 616707µs
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 11m 25: 219179µs
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 11m 25: 201723µs
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne Po...	23-3-2005 18h 11m 25: 192569µs
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 25: 218256µs
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne Po...	23-3-2005 18h 11m 25: 209574µs

# LCPC Wireless platform description

LCPC platform main contributions :

**Abstraction** : TCP/IP protocole makes the supervisor-sensors system independent of the physical link (wired or wireless) and of the distance (from meters to 1 km)

**Transparent communications** : applications hosted by the platform fully profit from the abstraction level of the network protocole

**Important** : Thanks to the embedded OS and the TCP/IP protocole, running softwares can be upgraded without uninstalling the sensor of the structure.

**Generic** : Platform could host different types of sensitive element : piezzo-electric, anemometer, strain gauges, etc.

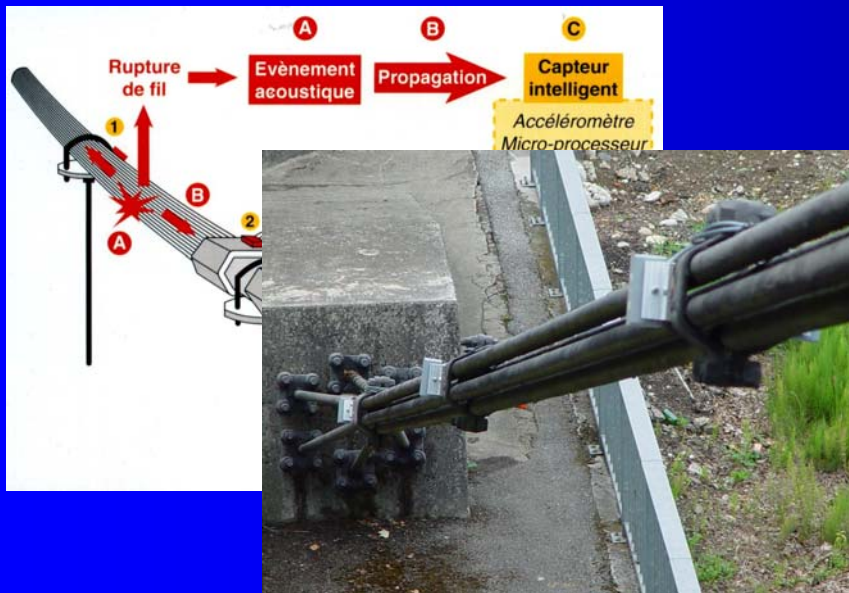
**High time synchronisation** (1  $\mu$ s) thanks to GPS module



# Case study : Wireless monitoring of Merlebach Bridge

## The idea :

The cable health monitoring system (that detect wire breaks in cables) is transferred to be hosted by the LCPC wireless platform.



transfer



Wired SHM system

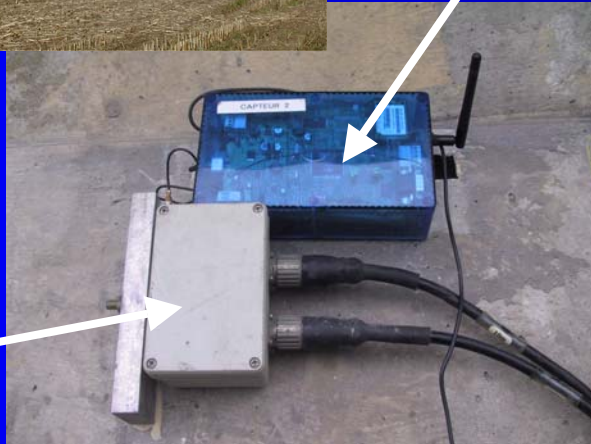
Wireless platform

# Case study : Wireless monitoring of Merlebach Bridge

**Instrumentation of Merlebach Bridge by the wire and the wireless version of the SHM platform.**



**Wireless version**



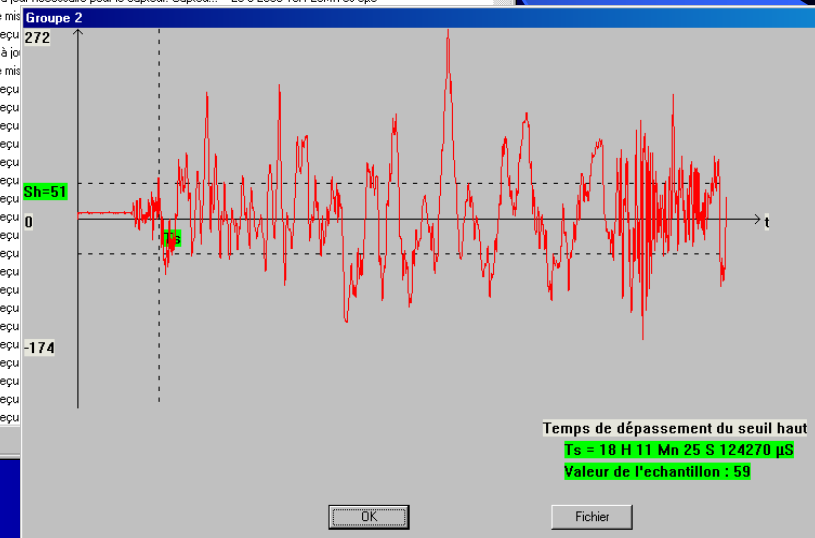
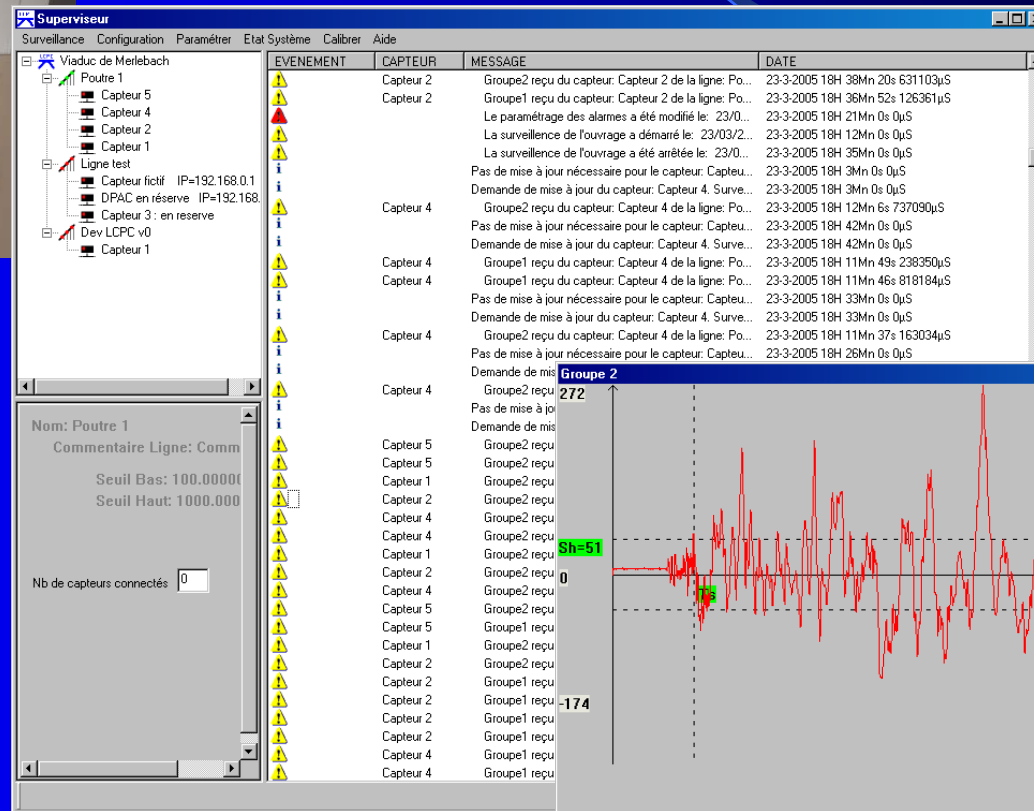
**Wire version**



**Loading tests on a beam to evaluate residual stress**

# Case study : Wireless monitoring of Merlebach Bridge

Many acoustic signals recorded due to cable ruptures

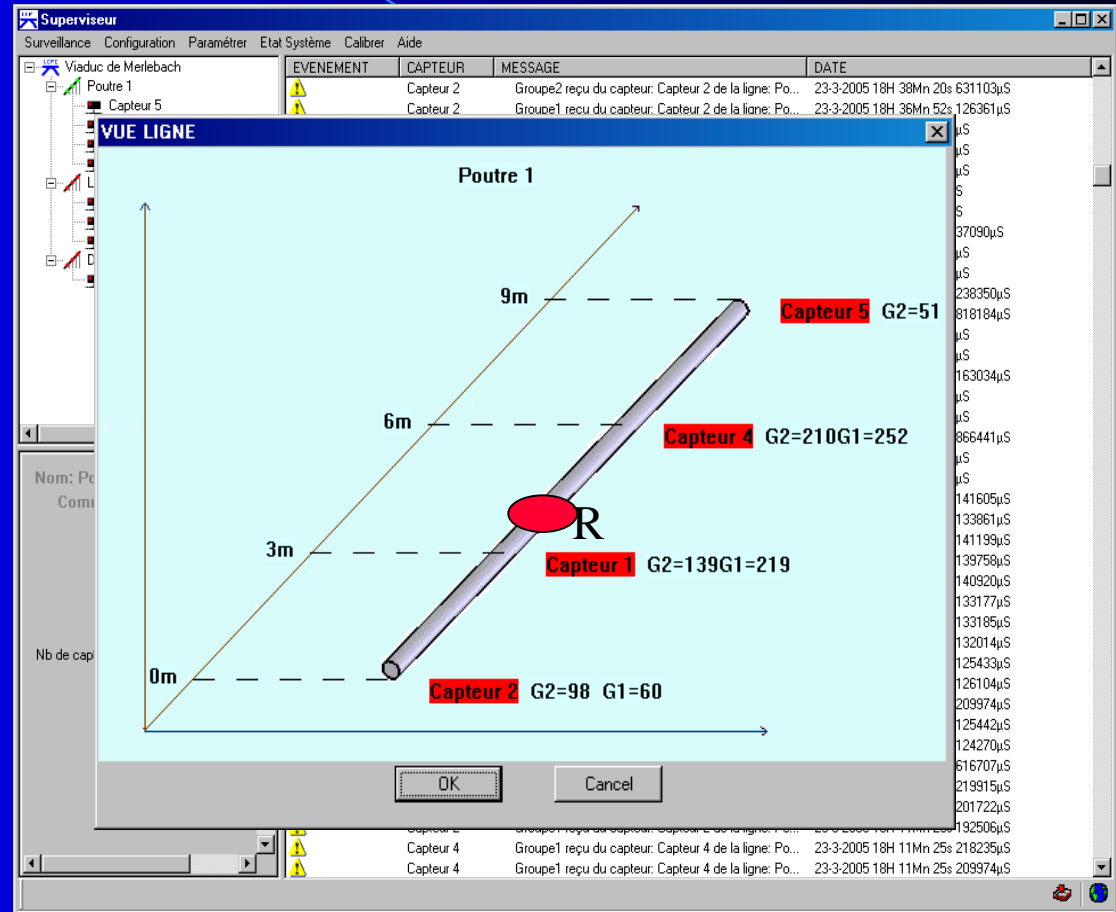




# Case study : Wireless monitoring of Merlebach Bridge

## Results :

The wireless system detected and located ruptures of cables in the beam !



# Case study : Wireless monitoring of Merlebach Bridge

That application validated the contribution of a real wireless SHM system on a real structure.



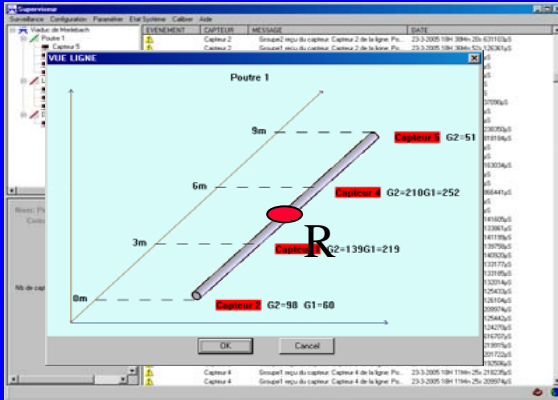
Sensor distribution



Wave digitalization



TCP/IP  
Wifi transmission



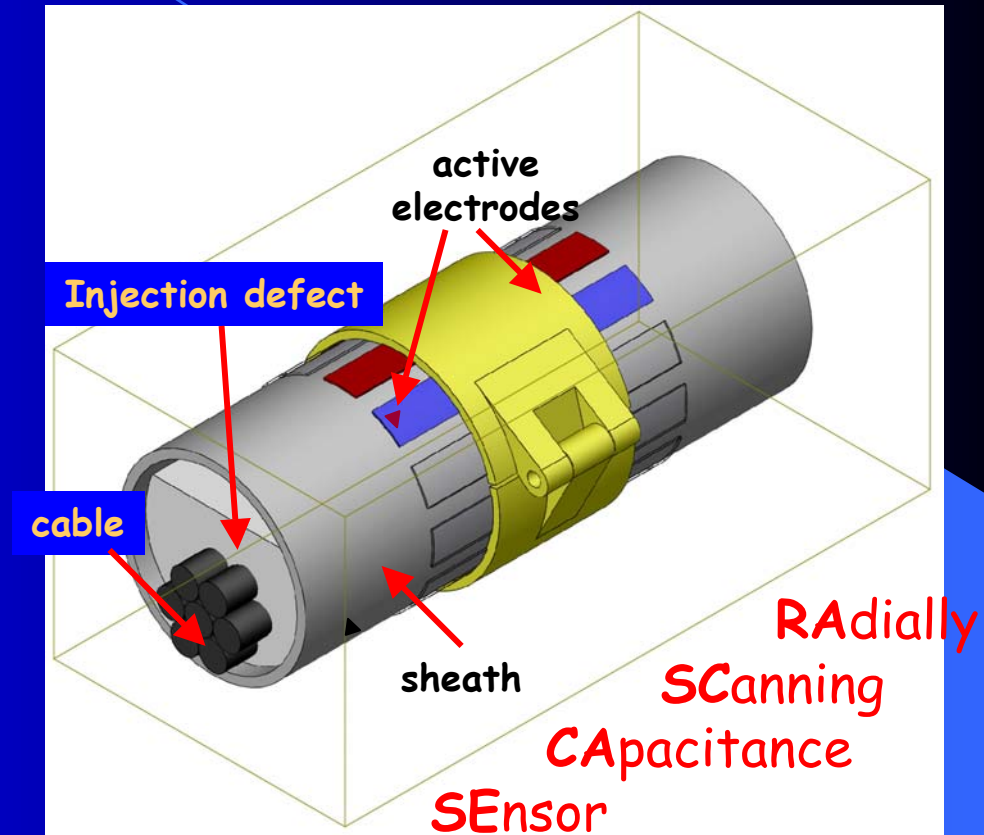
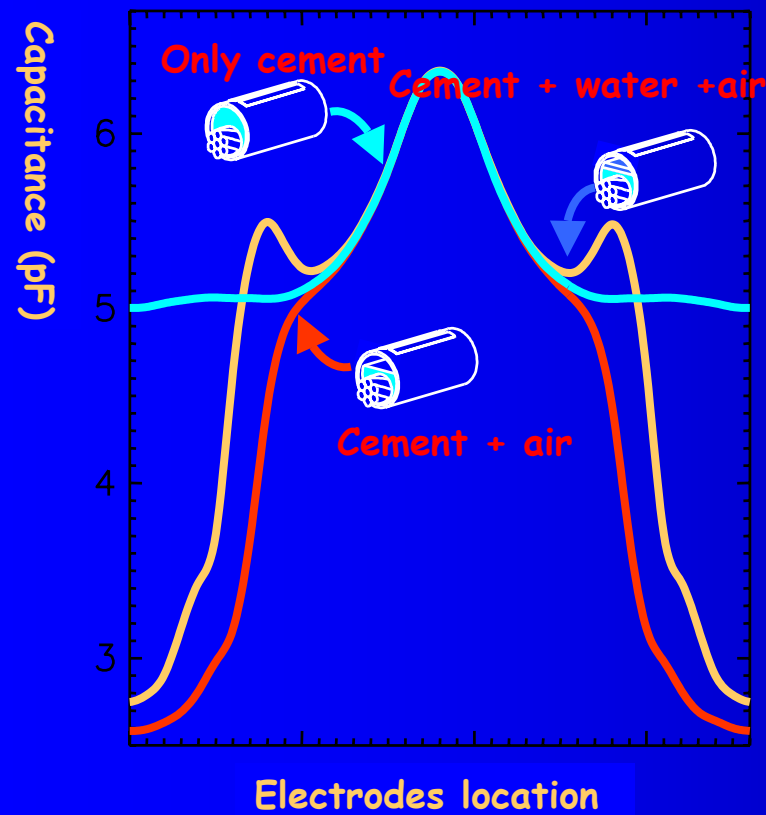
Supervisor analyses

	A	B	C	D	E	F	G	H	I
1									
2	N° evt	heure	capteur	position	vitesse	ampl. Crete	ampl. Max	charge	observation
3				cm	m/s	g	g	T	
4	1	14:59:59	5	163	4992	11	222	95-90	plusieurs fils
5	2	15:00:00	6	-164	4581	32	123	85-90	plusieurs fils
6	3	15:00:31	6	-104	4716	7	53	85-90	plusieurs fils
7	4	15:00:46	6	-163	5067	8	36	85-90	plusieurs fils
8	5	16:45:18	6	-164	4660	6	129	90-96	plusieurs fils
9	6	16:47:53	6	-8	2344	3	15	90-96	à voir ?
10	7	16:50:06	6	-40	5057	10	175	90-96	plusieurs fils
11	8	17:37:21	3	68	5255	5	19	95-100	2 fils
12	9	17:58:12	6	77	2715	2	7	95-100	1 fil
13	10	17:58:28	6	-77	5154	4	79	95-100	plusieurs fils
14	11	18:00:05	6	-20	5765	13	42	100-105	plusieurs fils
15	12	18:00:23	6	-81	5021	15	96	100-105	plusieurs fils
16	13	18:00:51	6	-136	5520	5	124	100-105	plusieurs fils
17	14	18:01:40	6	-90	5192	4	79	100-105	plusieurs fils
18	15	18:02:37	6	43	4498	4	62	100-105	plusieurs fils
19	16	18:03:53	6	-157	6021	9	41	100-105	plusieurs fils
20									

Structure diagnosis

# CAPACITIVE SENSORS

## Electromagnetic interrogation of prestressing cables



Electrodes coupled to an oscillating electric circuit system constitute a condenser whose capacity varies according to the nature of the components

# Roadmap

## Developments focused on :

- SHM products (infrastructures are getting old),
- Sensor network & smart systems to integrate more and more relevant algorithms for structure diagnoses (embedded OS, ...),
- Wireless communications to enable a breakthrough in structural monitoring (Wifi, Zigbee,...)
- Automatic instrumentation (UAV inspection),
- Supervising systems that provide a global and synthetic comprehension of the phenomenon
- Technological barriers : battery limitations, energy recovering,...
- Cooperation with important industrial partners, other laboratories, answers to international call for proposition...

# Conclusion

- **New technologies (smart systems, wireless) are a breakthrough but real conditions must be taken into account,**
- **Structures lifespan are often longer than instrumentation lifespan**
- **Real and efficient smart systems exist and prove the relevance of our works,**
- **In an international context, standard developments must be required,**
- **International cooperation is a need. You are welcome !**