A French experience of Structural Health Monitoring of scour affecting river infrastructures

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Because of their ability to connect territories and populations, any bridge failure can have a significant financial, human and social impact. As an example, the weakening of the Mayou Bridge following a flood in 2009 permanently disrupted traffic in the centre of Bayonne even though an inspection carried out two years earlier had not identified any defects/ problems. In fact, flow/structure interaction can lead to scouring process of river beds or banks that represents a significant contributing factor in the deterioration of structures and which can lead to their collapse during major floods. Moreover, in a rail or road transportation infrastructure system, bridge maintenance represents a high operating cost. For example, the French rail network has approximately 8,000 river crossings, of which 1,700 are potentially exposed to scouring processes. The stakes are even higher in the case of the national road network. Cofiroute, manager of approximately 10% of the French motorway network has, out of the 1,200 structures it manages, 20 viaducts under a specific monitoring programme to identify scouring problems. Across the US, 60% of reported bridge failures are due to scour of which about 20,000 bridges are identified as “scour critical” and the same number as “scour susceptible”. These examples clearly show the importance and fragility of transport structures in the face of the environmental risks of floods and the importance of having observation and warning systems in place to identify disorders and their consequences in order to move towards an integrated forecasting system and integrated risk management procedures.

Financed by the French National Research Agency (ANR), the SSHEAR project, "Soils, Structures and Hydraulics: Expertise and Applied Research", comprises six partners, whose complementarity offers a major asset to the project. Specialists in soilsand in fluid mechanics; geotechnical and hydraulic engineers together with sedimentologists, physicists, infrastructure management companies and a technological research institute contribute to the project (Chevalier et al, 2018).

The project proposes an intensive research effort on scour erosion based on a multi-scale and multi-scientific approach using:

- physical processes of flow and erosion in the vicinity of structures (e.g. bridges, dams, embankments, quay walls),
- laboratory experiments featuring multi-scale observation,
- an innovative numerical approach built around a two-phase model,
- observations and field recordings of actual structures subjected to hydro-sedimentary forcing imposed due to environmental or anthropogenic actions.

The first step has been to identify pilot sites representative of scour vulnerability. This selection has been undertaken using the databases of SSHEAR project Partners (SNCF, Cofiroute), and validated by some field campaigns. Several criteria were defined to select the sites that would be monitored :

- bridge vulnerability to scour,
- bridge geometry (type of bridge and its representativeness, type of piers, …),
- river conditions (flow conditions, hydro-morphology, nature of sediment…),
- geology and geotechnical parameters (foundations type, bedrock or reinforcement presence…),
- site accessibility,
- staff and materials safety…

The selection has then been finalized and restricted to 3 sites:

- Site 1corresponds to the scouring of a backfill in a meander. Such situations are common in valley bottom structures, while all infrastructures are concentrated near the river, as is the case in the mountainous regions of France. This is associated with a semi mountainous climate. It has been chosen to make precise hydraulic and bathymetric surveys once a year.
- Site 2 (A71road bridge over la Loire at Orléans) is representative of large structures crossing a river in France in an oceanic climate. This structure is founded on 6 piers, 4 of which are located in themain channel. It has been chosen to implement continuous monitoring devices.
- Site 3(Aurence railway crossing near Limoges) is a characteristic arch bridge built on the banks of watercourses. It is also in the oceanic zone. It is representative of the structures of secondary road and rail networks. It has been chosen to implement continuous monitoring devices.

According to Breusers et al. (1977), scour can be described by equation (1)

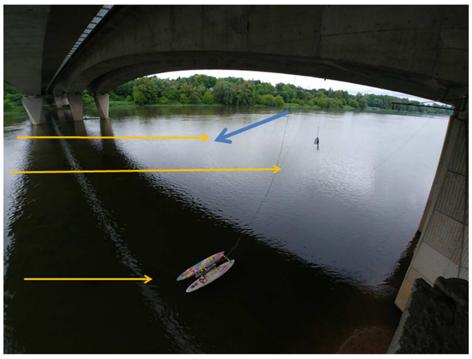
$$dse = f(\rho, \mu, U, Y, g, d, Uc, D), : \quad (1)$$

where g is the acceleration of gravity; Y is the depth of water; U is the average upstream velocity; D is the diameter of the pile, ρ is the density; μ is the dynamic viscosity of the fluid, Uc is the critical value of the velocity associated with the movement of the bed particles, d is the diameter of the particles. For each measure the following items have been taken into account:

- the min-max measuring range,
- the desired characteristics (uncertainties, resolution,...)
- intrusiveness
- innovative techniques / more robust techniques
- homogeneity of a fleet of equipment (on 1 site if redundancy or between sites)
- equipment acquisition costs

- operating and maintenance costs
- data recovery costs
- on-site deployment constraints
- installation constraints
- power supply (mains, battery, if batteries what autonomy…)
- post processing (validation criteria, operation ,...)

A bibliographic review of experimetal technics have been undertaken, a table of specifications has then been sent to potential suppliers. For the two sites selected for continuous monitoring, the proposed set-ups have been developed and implemented as part of the project. On the A71 site, radar level sensor have been fixed on the bridge to measure the water level relative to a fixed point. In addition a raft made of two boards (figure 1a) is used to support a sonar instrument, used to scan the bathymetry, and a velocity profiler used to measure the velocity field. The sensors are connected to a data logger that is also sending the data to a superviser. On the Aurence site, we have implemented an aerial water level gauge, an ultrasonic velocity profiler that is mounted on a floating device in order to follow the free surface variations and a fixed drone network camera that allows us to watch the sensors periodically in order to identify any emergency situation. Due to the rural location of the site , both energy and data transmission are made by GSM (Figure 1b).



a) A71 site b) Aurence site

Figure 1 : set-up implemented for continuous monitoring

On the Aurence site, the instrumentation has been working for 5 months and we already have feedback information. The first on is the usefulness of the camera. It has allowed the team to visualize a tree that had damaged the raft so we have been able to act quickly and repair the damaged apparatus. The second is the reactivity to the flow rate to rain events, that is also corroborating the data acquired by the French data base "Banque Hydro" (http://www.hydro.eaufrance.fr/) about 1.5 km upstream. The third reason is the importance of measuring the velocity profiles. Concerning this aspect, the first results show a hysteresis effect in relation to flowrate variations. More time is needed to analyse the hydraulic behavior in order to automatize the data processing for management purposes.

On the A71 site, the datalogger has been damaged and it has not yet been possible to recover data. However,

Those two sites give a useful feedback for continuous monitoring of scour affected structures over rivers.

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