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Monitoring of Real Sites affected by Scour: Observation, Analysis and Feedback of Field Data

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Abstract

Infrastructures of public transport networks can be affected by erosion processes. Detecting this risk is thus a major challenge for sustainable development and land use planning and monitoring systems are promising tools in this context.. The current paper reports the experience of monitoring a bridge in a sand bed river affected by incision. After remembering briefly the site identification process, the choice of the scour parameters to be monitored and the choice of the instrumentation, we present the feedback that we can do after about one year of monitoring with a discussion of the positive and negative aspects of the site and the set-up implemented to measure the scour parameters. We make a focus on the analysis of the measurements that have been done with the statistics that can be made and compare with literature data as well as data from the national French data base on water levels. Finally, we discuss the conclusion that can be obtained for structures managers.

Keywords: Scour; Bridge; Open channels; Profilers; Bathymetry

1. INTRODUCTION

With the development of the public transport networks, guidelines (Gauthey, 1832) were published to explain the phenomena that can affect structures used to cross rivers and wet areas. Those guides provide design rules and dimensioning laws to engineers and practitioners and they continue to be updated to take account of the new knowledges and technical progress (Setra, 1979; Temez Pelaez, 1988; Hoffmans & Verheij, 1997; May et al., 2002; DTMR, 2013; Sheppard et al., 2011; Arnason et al, 2012; Setra, 2013). Researches are still active in many countries (Ettema et al., 2017; Chevalier et al., 2021; Guan et al., 2019; Bento et al., 2020), just to give some examples.

Despite of everything, the structures can be affected by erosion processes such as the Coarraze railway (France) embankment destroyed in 2013. Thus detecting the risk of scouring of structures, beds or banks due to natural hazards (floods, extreme hydraulic regimes, dam failures) is a major challenge for sustainable development and land use planning and monitoring can be an interesting tool.

This paper relies to a French research project named SSHEAR (Chevalier et al., 2021) which objective is to improve understanding of the scouring process with innovative observation tools and physical and numerical hydraulic modelling. Larrarte et al. (2019) presented the general approach and Larrarte et al. (2020) detailed the monitoring of an abutment. The current paper reports the experience of monitoring a bridge pier. After remembering briefly the site identification process, the choice of the scour parameters to be monitored and the choice of the instrumentation, we present the feedback that we can do after about one year of monitoring with a discussion of the positive and negative aspects of the site, and the set-up implemented to measure the scour parameters. We make a focus on the analysis of the measurements that have been done with the statistics that can be made, and compare with literature data as well as data from the national French data base on water levels. Finally, we discuss the conclusion that can be obtained for structures managers.

2. SITE SELECTION AND INSTRUMENTATION

Experimental site selection was an important first part of SSHEAR project (Larrarte et al., 2019). Several criteria were defined to select the ones that would be monitored during either brief campaigns or for some longer continuous periods. Several criteria were defined to select the sites that would be monitored during a brief campaign and for some longer continuous periods. These criteria were related to:

- representative sites on which scouring phenomena have been observed and are in progress;
- river conditions (flow conditions, hydro-morphology, nature of sediment...);
- geology and geotechnical parameters (foundations type, bedrock or reinforcement presence...);
- documented sites for which data are accessible (geometry, type of support, inspection and monitoring report, bathymetric, geotechnical, hydraulic data, etc.);
- rules and regulations that have to be respected in the national context.
- site accessibility;
- staff and materials safety...

An inventory of SSHEAR partners sites affected by scouring phenomena was carried out by the network managers (railway and highway), using geographical information system The selection has then been finalized and restricted to 3 sites (Larrarte et al., 2019). In this paper we focus on a motorway bridge. The monitoring of the embankment site is reported by Larrarte et al. (2020).

2.1. Site characteristics

The A71 motorway bridge (owner company: Vinci Autoroutes/Cofiroute) over the Loire is representative of large structures crossing a river in France in an oceanic climate. Moreover, the Loire catchment represents 20 % of the metropolitan area and the A71 motorway is a major highway of France connecting Paris area to central France. At the level of the bridge, the catchment area is equal to 37000 km² and the river flows through sedimentary rocks of the Paris basin. A severe incision of the main branch of the river, owing to a combined effect of the groynes for navigation (nineteenth to twentieth centuries) and intense sediment extraction (1950–1995) led to exposure of the bedrock in this area. Bank erosion and lateral shifting is also constrained by artificial levees built for flood prevention. On the site, the Loire river flows between a hillside on the right-hand side and a levee on the left-hand side. The floodplain extends over a complete distance of 650 m.

The Loire river shows a range of fluvial patterns from single channel (straight or meandering) to anabranching. At the study site, the channel course is straight with a sinuosity index of 1 (Latapie, 2011) and an island split the channel course downstream the bridge between a main channel on the right hand and secondary channel on the other side (Figure 1). The width of its bed is 300 m and the average slope is 0.00035 m/m (Latapie, 2011). The bedload of the river is mainly composed of siliceous sediments from sand to gravel particles even if some flint cobbles resulting from the weathering of the calcareous bedrock are present. Thus, the bedload is mainly composed of large grainsize range from 0.4 mm up to 4 mm.

The bridge is approximately 400 m long. This structure is based on 6 supports, 4 of which are located in the riverbed and named P2 to P5 from the right bank to the left bank (Figure 1). Each support (except the abutments C1 and C6) are made up of ellipsoidal columns whose height is about 8 m.

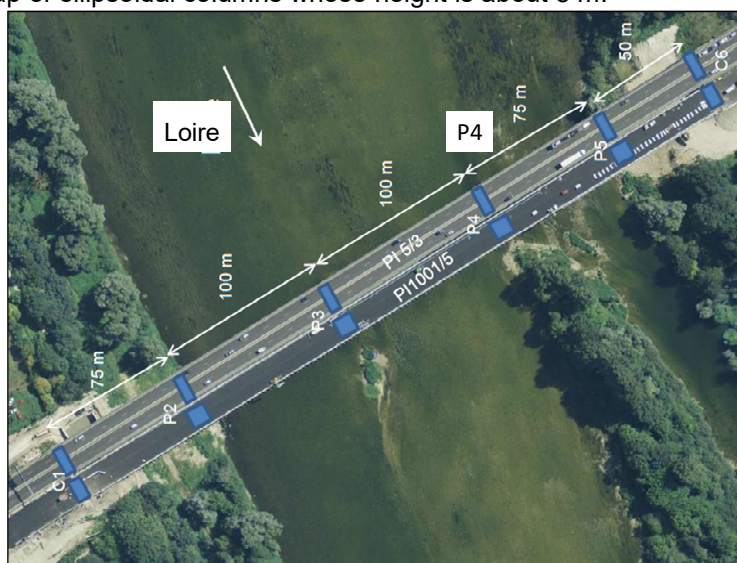
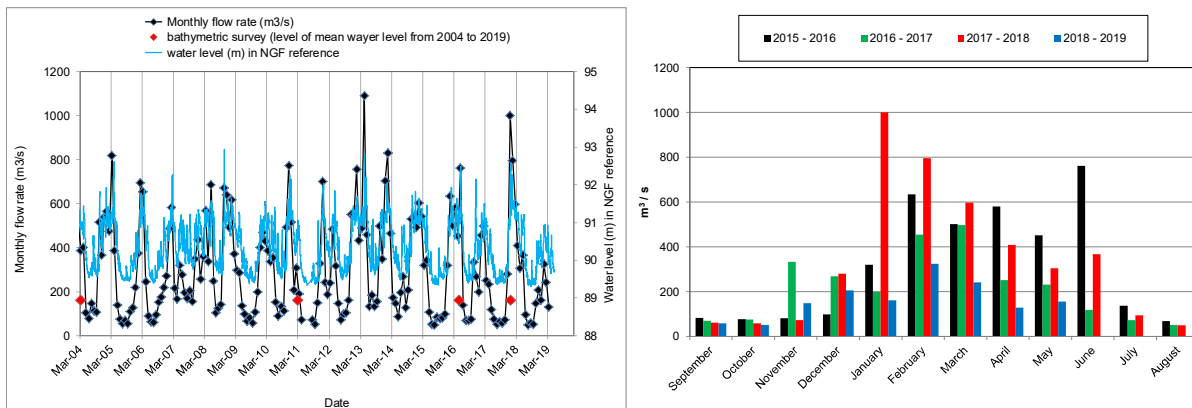


Figure 1. A71 motorway double viaduct close to Orléans (France) over Loire river

The French National database “Banque Hydro” (<http://www.hydro.eaufrance.fr/>) has a point located 5 km upstream (Orléans). This station records Loire flow rates since 1964. The water level, about 90 m, is presented in the NGF reference. The Nivellement Général de la France (NGF) is a network of altimetric landmarks spread over the French continental metropolitan territory, as well as in Corsica. This network is currently the official levelling network in metropolitan France. Water level and monthly flow rate fluctuations, depicted on Figure 2a, are characteristic of the Loire river hydrologic regime determined by two climatic influences: rainfall coming from the Atlantic Ocean (mainly during winter) or rainy storms in the upper mountainous reaches of Massif Central that occur during spring (Dacharry, 1996). The hydrographic year lasts from September to August with floods occurring during winter high flow stage or in spring and low flow stage during summer. Strong fluctuations are seen but cannot explain the observed evolution of the bathymetry in a simple way. The monthly average flow rate fluctuations of Loire river at Orléans station are detailed on Figure 2b that shows strong inter annual variations.



a) Water level and flowrate chronicles
5 km upstream of the bridge.

b) Monthly flow rate fluctuations (Banque hydro data)

Figure 2. Loire river (Orléans) site characteristics.

Cerema has a long term partnership with the highway company Vinci Autoroutes/Cofiroute and evaluates scour on various bridges for many years. Sonar bathymetries were carried out in 1993, 2004 and 2011 and significant local erosions in the vicinity of bridges piers were identified especially on the left bank of support P4. But the next survey, in 2016, has shown accretion phenomenon close to these pier (Figure 3) underlying, on one hand, that this is an active site for erosion/deposition and, on an other hand, that punctual surveys are not sufficient to follow the phenomena. The monitoring was thus decided to be implanted close to support P4 (black dashed circles on Figure 3).

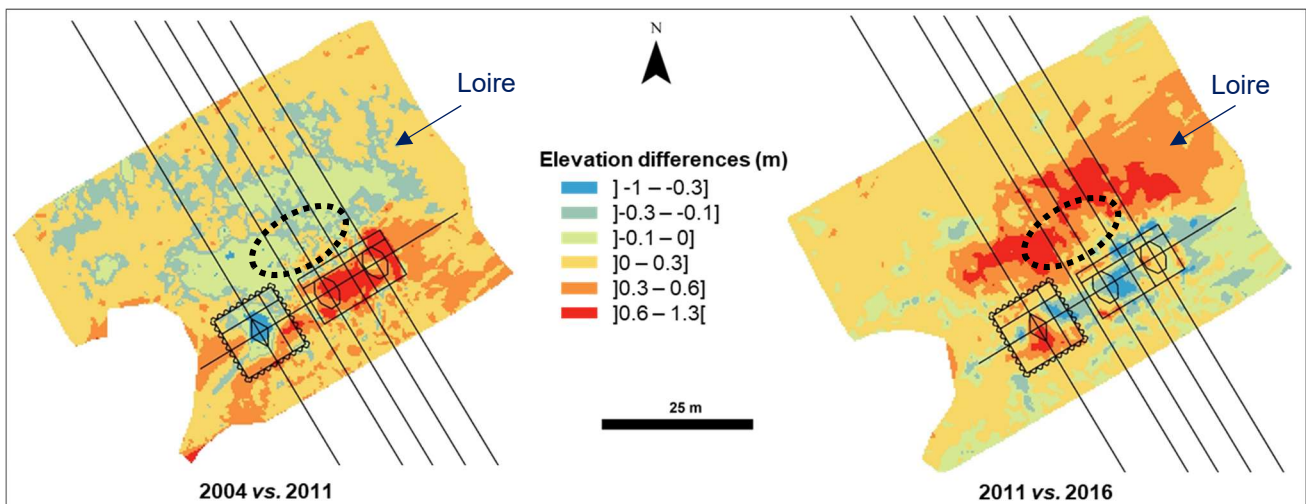


Figure 3. Results of comparison between 3 bathymetric surveys (2004, 2011 and 2016) near the support P4 (see Figure 1) of the A71 highway viaduct over the Loire river. Black dashed circles: expected place of the monitoring set-up.

2.2. Instrumentation

A first major influence on scour is related to hydraulics acting on the structure. A huge consequence can be the generation of scour holes close to the piers. So the choice has been made to have continuous measurements of both hydraulics properties and bathymetry. In parallel to scour monitoring, accelerometers have been installed on the bridge to monitor the sites through the responses of the bridge structure. Indeed, using structures responses makes it possible to monitor the scour at the bottom of the pier (Boujia et al., 2021).

We have tried to look at what exists in countries whose context seems similar to the French hydro-geological context, that ranges from oceanic to Mediterranean climate through mountainous one, if we limit our present study to the metropolitan area, for practical reasons. After a long discussion process to precise monitoring expectations and technical specifications and taking account of the financial constraints, the choice has been to implement:

- a Valeport VRS-20 radar level sensor on the bridge to measure the water level relatively to a fix point;
- a Kongsberg Dual Axis sonar to scan the bathymetry;
- a Teledyne RDI Monitor 1200kHz ADCP to measure the 3D velocity field;
- three accelerometers (one tri-axial PCB 629A11 and two mono-axial PCB 393B31).

The sonar and the profiler have been implemented on a raft made of two boards (Figures 4, 5a.). The sensors are connected to a laptop and measurements are transmitted to a data server. The international standards and recommendations have been followed in collaboration with sensor suppliers.

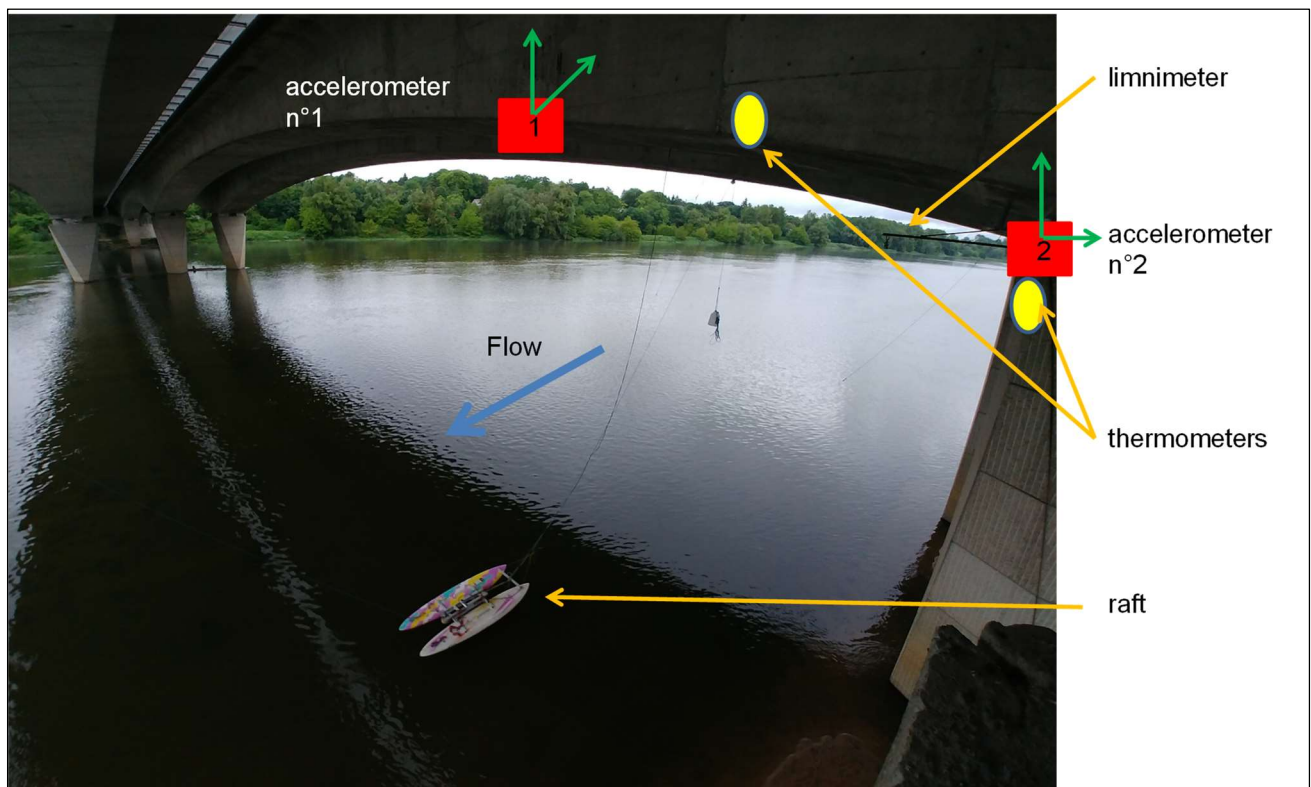


Figure 4. General view of bridge and instrumentation location.

The first accelerometer has been installed in the deck (internal walls of the box-girder) and is recording the vibrations of the bridge in the two directions (vertical and in the direction of the hydraulic flow). The second ones are installed at the top of pier P4, and monitors the accelerations of the pier in the same directions (Figure 4, 5b, 5c).



Figure 5. Details of the instrumentation set-ups.

3. RESULTS

The site instrumentation started on October 2020 and was supposed to end 18 months later in order to handle both a full range of annual seasons and 2 examples of the most rainy period of a hydrological year. However, the process has faced various problems from raft cap-sizing to intrusions into the bridge leading to acts of vandalism. Nevertheless, it was possible to acquire a first experience of site monitoring.

3.1 Water levels

Figure 6 presents an extract of the water level chronicles recorded with the limnimeter every level every 5 minutes, with the sonar every 60 minutes and data from the banque hydro. It is interesting to notice that the dynamic remain the same for all the data. However a gap can be observed with the banque hydro data, this is attributed to the strong difference between sections. There is no floodplain at the gauging station, the riverbed of 330 m large is constrained by the hillside on the right-hand and the levee on the left-hand side. In addition, the flow is influenced by an old navigation groyne. At the monitored bridge section, on the left-hand side there is 250 m large of floodplain between riverbed and levees. Moreover, island could influence flow levels. It can be noticed that the water level reacts to flow events but with a quite slow behavior attributed to the wide area of the catchment, unlike the highly reactive Aurence watershed (Larrarte et al., 2020) where the other site with a continuous monitoring in the SSHEAR project.

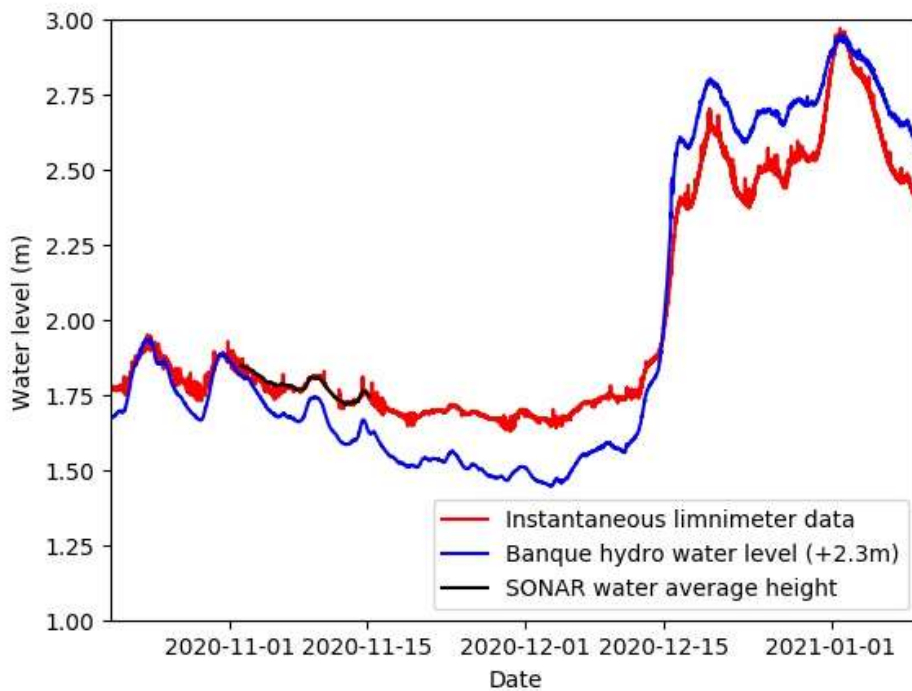


Figure 6. Water level chronicles (in local reference).

3.2 Velocity

Figure 7 presents an extract of the water level chronicles, in local reference, recorded with the limnimeter every level every 5 minutes as well as the upper velocity chronicle. Here we call upper velocity the mean value of the velocities measured in a distance between 0.60 and 1.20m from the surface. We can observed that the dynamic of both data are similar with a decrease during the first 15 days and fluctuations after, the almost steady water level correspond to low water level of the end of the hydrological year.

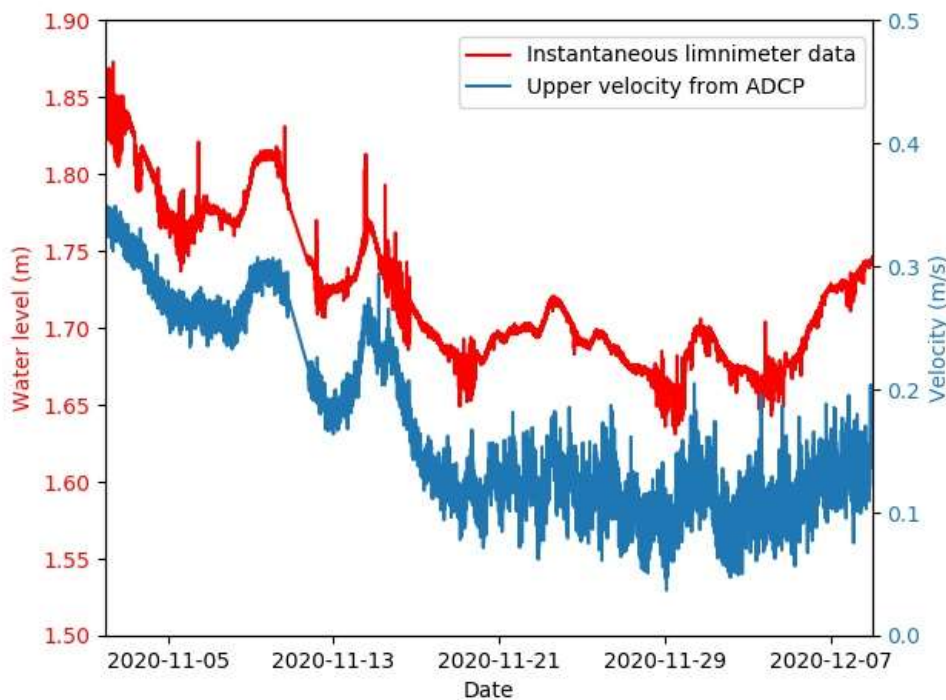


Figure 7. Water level (in local reference) and upper velocity chronicles.

3.3 Bathymetry

Figure 8 presents the bathymetry measured for a water level of 1.72 m on the 12th of November. The river bottom is flat. The observed increases on the right hand site is due to the sonic beam intercepting the basement of the pier.

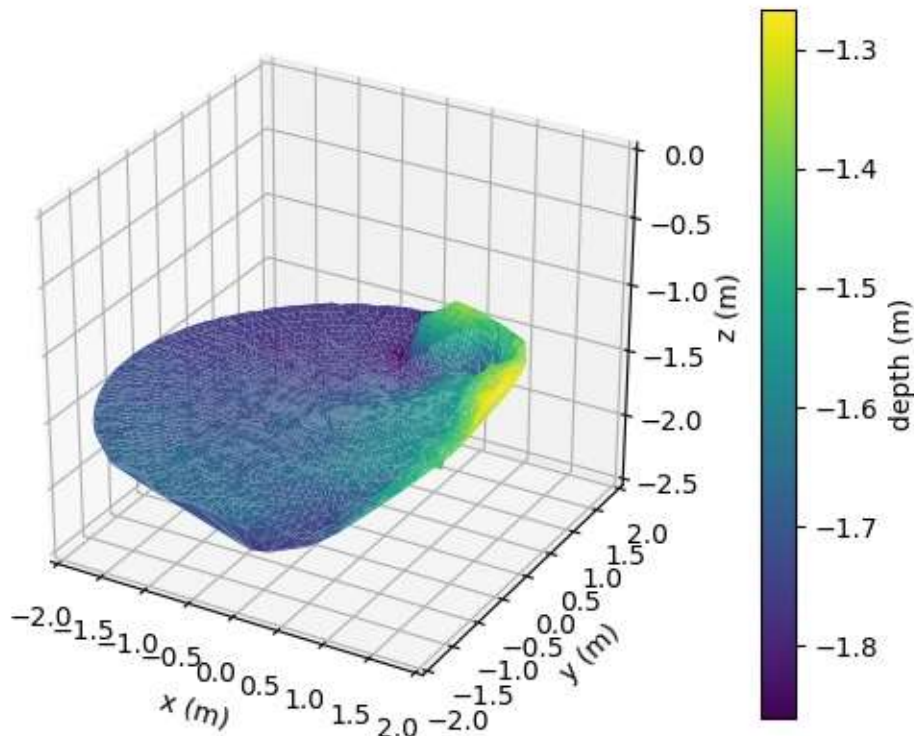


Figure 8. Example of observed bathymetric.

3.4 Dynamic behavior of the structure

In order to monitor the scour depth and the hydraulic speed, a solution is to measure their consequences on the dynamic behavior of the bridge: indeed, many researchers show the interest of vibration-based monitoring in order to monitor external phenomenon as scour (Peter Carden et al., 2004; Foti et al., 2011). In our case study, the accelerations of both the deck and the pier have been recorded for a long time (over 320 days), and can be accessed remotely. These time series (Figure 9) are the answer on one vibration recording, and are directly linked to the scour conditions.

Many information are available through a frequency analysis.

By averaging signals all over a day, the subspace procedure for eigenfrequency extraction showed that a 3rd subspace let us monitor the scour phenomenon. In fact, this space is close to the bridge pier responses in Figure 10 and some natural frequencies change over time (see Figure 12).

When combining these results with the other monitoring data (from the other monitoring techniques), the frequency changes due to scour and/or hydraulic flow can be discriminated from the changes due to a damage of the structure. Nevertheless, if we consider that the bridge remains –during a given time– in the same structural

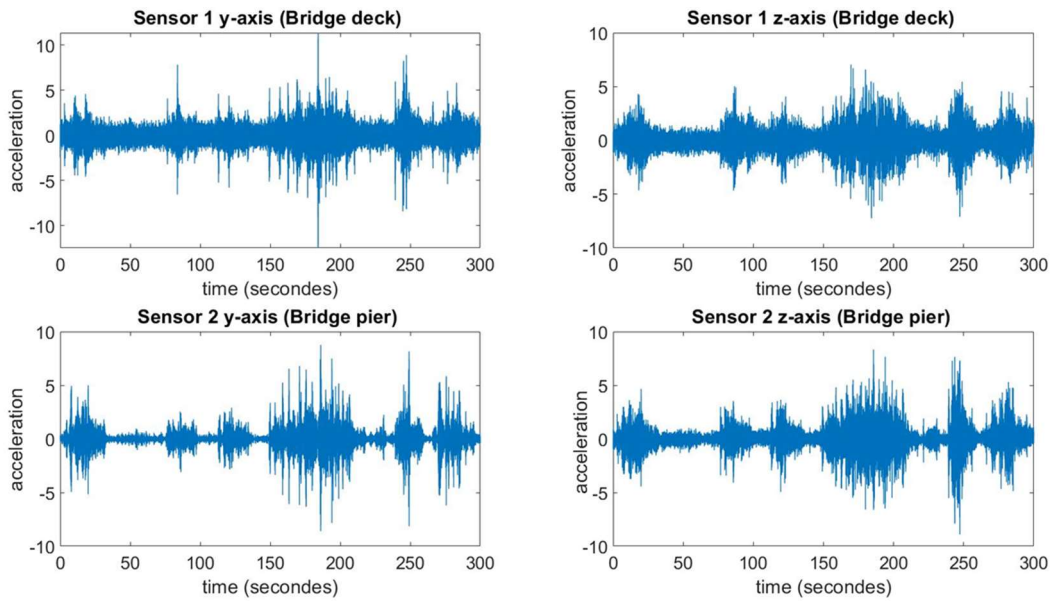


Figure 9: Example of the recorded time series (30 oct. 2020, 16h44).

A new method developed by Belmokhtar et al. (2021) makes it possible to monitor the natural frequencies every day. In Figure 10, Fast Fourier Transform has been applied to the time series showed (Figure 9).

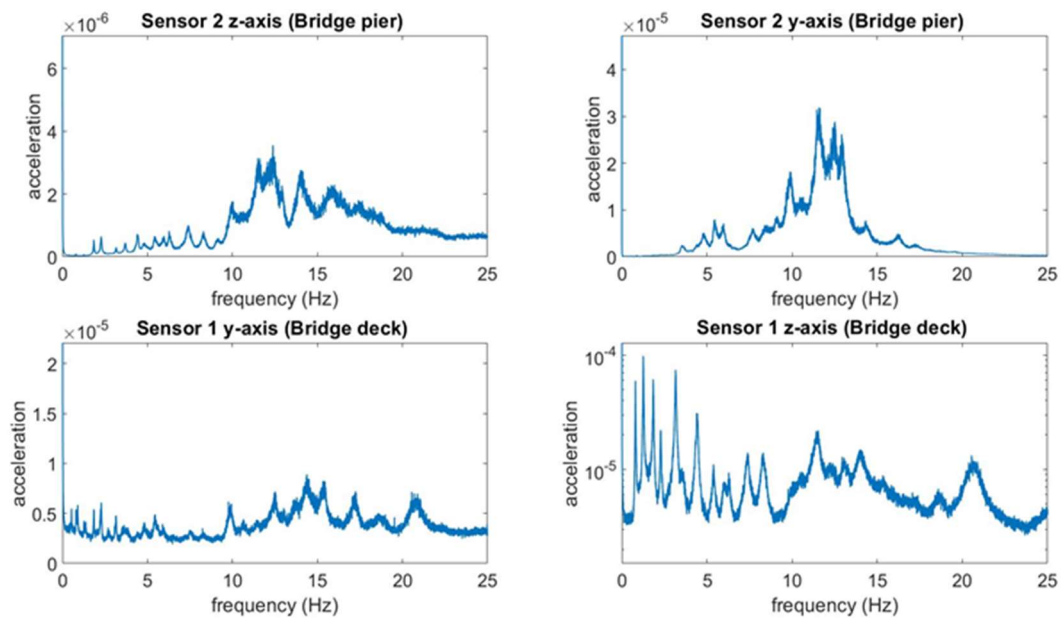


Figure 10: FFT applied to the 4 recorded time series.

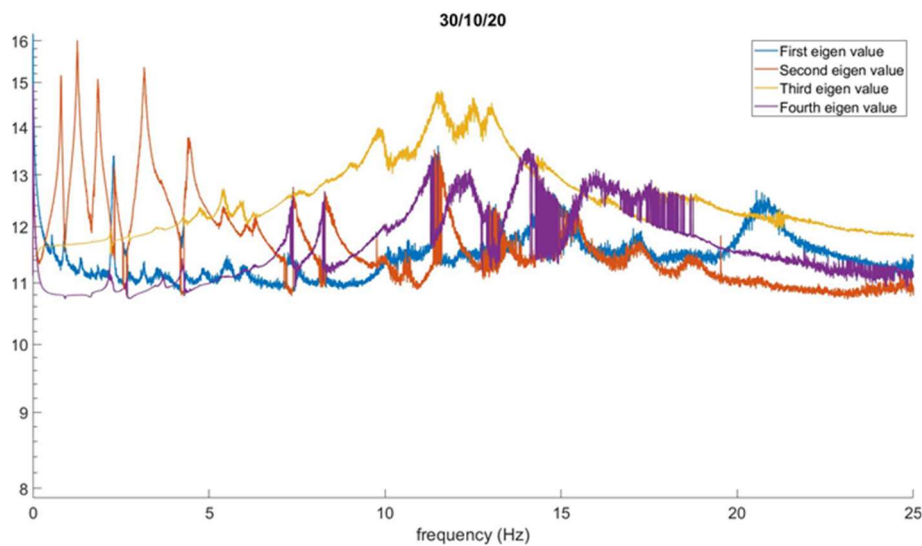


Figure 11: Analysis in subspaces in frequency domain (EVD-MAC).

health, this procedure makes it possible to calculate and monitor the scour depth at the supports of the bridge.

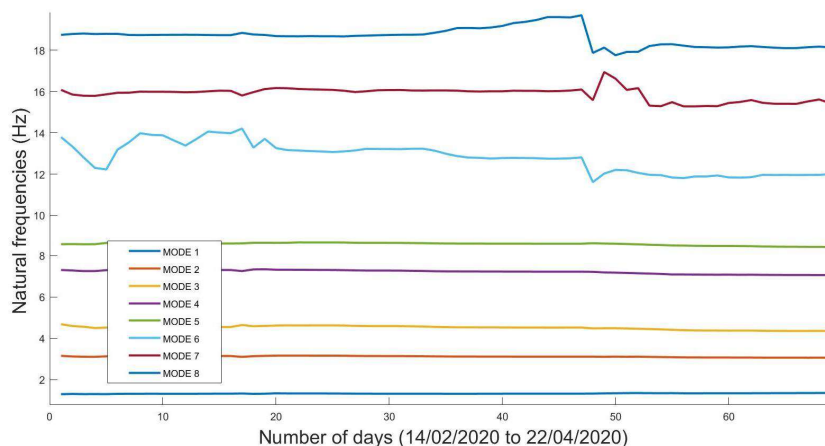


Figure 12: Evolution of natural frequencies every day with method developed by Belmokhtar et al. (2021).

4. CONCLUSIONS

Infrastructures of public transport networks can be affected by erosion processes thus detecting this risk is a major challenge for sustainable development. Monitoring of the affected structures could help to prevent scour related failures. The current paper reports the experience of monitoring a real bridge located near a French city. The in situ monitoring device presented in this paper shows that such complex instrumentation is now possible thanks to the progress of sensors. The apparatus allow following the various hydraulic conditions (flow depth, velocity profile...), the local response of the sediments (scour/erosion or deposit) and the dynamical behavior of the bridge (vibration measurements) with a high acquisition frequency, especially in comparison with annual survey.

Other teachings can be drawn from this project. First of all, whatever its technology, a sensor will not give any results if it can not be implemented and maintained properly. Doing measurements in a river proved means that all the set-up and instrumentation has to support drought and floods. Moreover, human interactions can disrupt the experimental campaign. In this site, a low cost raft has been selected to minimize the cost as well as to not draw too much attention to the sensors.

Anyway, these first observations are very encouraging for the future data exploitation as flow characteristic and dynamical properties of the bridge can be extracted from the measurements. The crossed study of all these parameters in relationship with the specific site environment characteristics will then allow increasing our knowledge of in situ scour processes and their link to structural dynamical properties of structure.

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