# Comparison of accelerometric response records on a timber footbridge

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## Summary

The purpose of this paper is to report the results of two experimental campaigns on a timber footbridge. They were carried out by the authors, in order to estimate the mechanical behavior of the footbridge, in two different seasons: late Autumn and late Spring. The bridge under study is made by two main parallel timber beams, linked by a sequence of transversal steel elements. The geometry of this structure sees a length of about 83 m length and a width 3.8 m width. To cover the whole length, a special wireless telecommunication architecture was used.

**Keywords:** Pedestrian bridge, Structural monitoring, Timber bridge.

## 1. Introduction

The behavior of wooden elements is very sensitive to some  environmental conditions as for an example the moisture content in the air, the temperature of the air and so forth…[1]-[2]-[3]. Thus, the idea behind this paper is to identify structural response modifications (if any) from modifications due to different environmental conditions. Moreover timber structures, and wooden elements in general, require a continuous maintenance in order to preserve their strength, but also to fix their architectural appearance. The best approach would be to rely on a continuous structural monitoring system [4]-[5]. But  this solution is only possible if the structural system offers adequate lodgment to the equipment and the possibility to check the behavior of the data acquisition system. So the only viable and practicable way is a periodical structural monitoring which holds if and only if one is to separate, once again, structural modifications (if any) from the response modifications associated with different environmental situations.

## 2. The case study

The authors were offered the chance to collect data on a timber footbridge located in Trasaghis (UD), a small village in the North-East part of Italy. The bridge, built between 2009 and 2010, is used to link the two sides of the emissary channel of a natural lake named Cavazzo Lake (see Fig. 1).

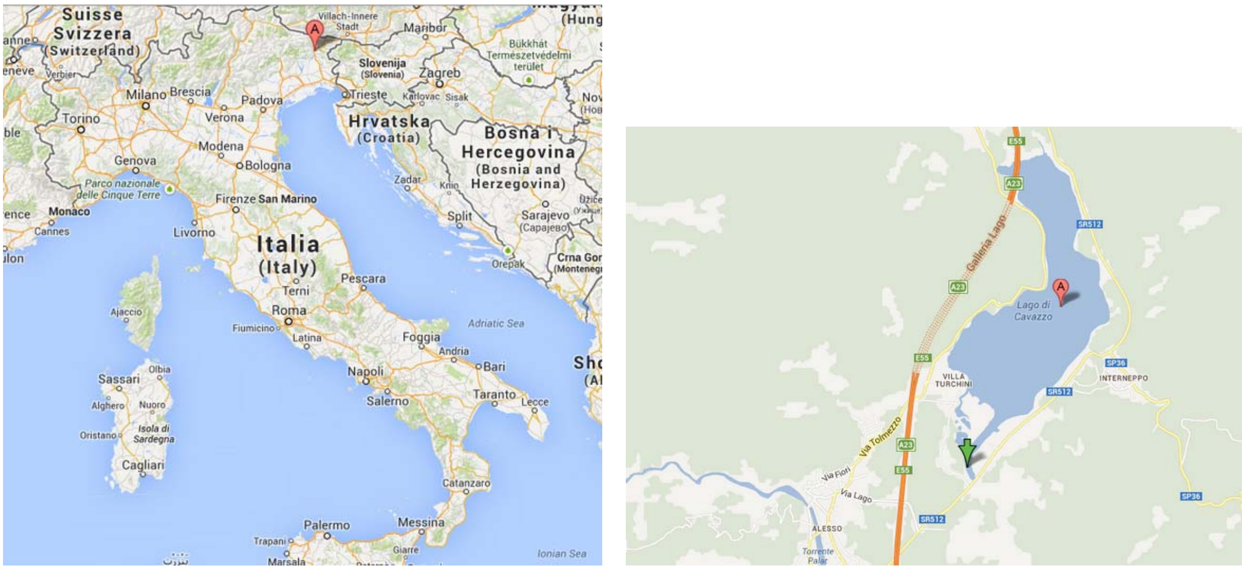



*Fig. 1 Map of the region (left) and a zooming on the lake area (right).*

To harmonize the structure with the naturalist park surrounding the lake, the designer, in accordance with the Municipality, decided to employ only timber and steel as construction material, limiting the use of the reinforced concrete to the foundations (see Fig. 2).

*Fig. 2 Lateral view of the pedestrian timber bridge under study.*

The static scheme of the bridge can be included within he family of “cable-stayed bridge” where, however, the typical steel cables are replaced by tubular steel elements anchored to the two antennas located on the opposite sides of the channel. The span is 83 m and the double- beam deck width is 3.82 m, of which 3.22 m represents the free crossing width.

Glued laminated timber of high strength GL28c is adopted for all the main structural timber elements, while glued laminated timber of strength GL24c is adopted for the walking deck. For the steel elements only strength S355JR was adopted. The two main lateral curved beams of section (0.20 by 1.941 m) are mounted on neoprene supports at the ends, and are linked by a sequence of “H” shape transversal tubular steel elements. These elements supports five timber beams on which the walking deck is mounted and fixed by high-strength screws (see Fig. 3).

*Fig. 3 A detail of the beam support (left). View of the deck from below: one can see the linking steel transversal beams and the steel braces (right).*

The beams are anchored, at the thirds, to the steel antennas on the two sides. The height of the antennas is about 15 m, and they are made by elements of tubular steel section of external diameter 457,5 mm and thickness 14,2 mm. The link antenna-beam (tubular steel oblique element) is made by tubular steel elements of section of external diameter 273 mm and thickness 8 mm (see Fig. 4).

In this structure great importance has been given to the durability of the timber elements, especially against the environmental attach. In fact, as one can see in Fig. 5, the external surface of the two main timber beams, are covered by a cladding made by larch planks. Moreover, in its upper side there is a layer of synthetic material used as water proof system against the rain.

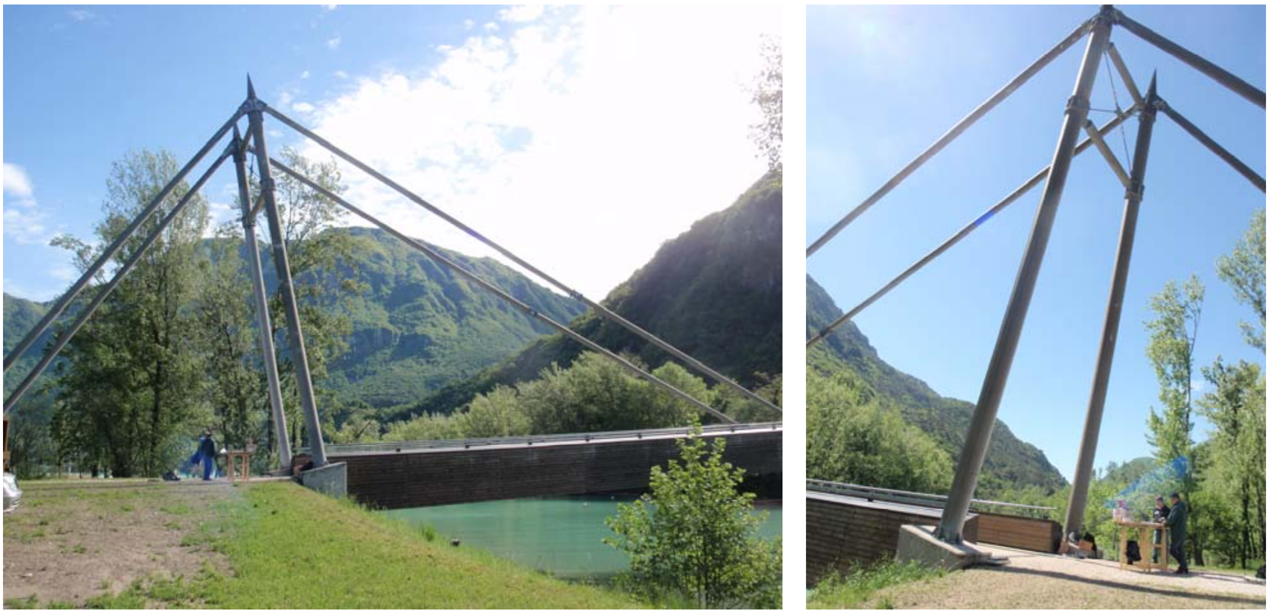


*Fig. 4 A detail of the tubular steel oblique elements (left). A lateral view of the antenna (right).*

*Fig. 5. View of the upper protection system of the beam made by copper (left). A detail of the external larch cladding (right).*

According with the Italian code [6], the pedestrian bridge under study can be regarded within “category 3”; this means that two main static loads have to be considered:

- $q_{1.d}$ = isolated load of 10 kN over an area of 0.70 by 0.70 m;
- $q_{1.e}$ = distributed load of 4 kN/m$^2$ resulting from a dense people gathering.

In addition, the effects of snow, wind and earthquake were taken into account in the design.

A numerical model of the system was built within MSC Marc-Mentat2010 environment [7]. Moving from the design technical documents, particular attention has been paid to modeling every single element of the structure. The two main timber beams were modeled with *shell* elements (0.20 m by 1.941 m). In the same way the deck has been modeled by *shell* elements 6.3 cm thick. To represent the static scheme of the deck, steel elements with H shape were introduced. The deck modeling was finally completed introducing five squared timber beams (employed to carry the wooden deck), and the bracing elements under the deck. To better simulate the interaction between the deck and the beams discussed above, *ad-hoc* rigid links were used. The model was completed by introducing the main steel element of the antenna and the tubular oblique elements, simply as beam element (see Fig. 6). More details about the structural modeling are reported in [8] and [9].

*Fig. 6. View from the bottom of the deck (left), and details of the antenna and the tubular oblique elements (right) as implemented in the MSC Marc-Mentat2010 software.*

## 3. Experimental campaign: plan and configuration of the instrumentations

The experimental campaign was planned in two stages, both focused on acquiring the accelerations in sensitive points of the bridge under environmental loads. Standard tri-axial and uni-axial Kinematrics accelerometers were deployed. The position of the sensors was selected as resulting by numerical analysis *ad hoc* planned.

Two challenges were soon met. Indeed the use of a standard wired acquisition system would have covered a distance up to the 30 m. To overcome this experimental gap, the authors employed a wireless technology (see Fig. 7) developed in [10]. The second, and main, challenge was to develop a reliable process to clean the effects of current environment conditions, that might afflict different experimental campaigns [11].

The authors, in agreement with the Municipality owner of the bridge, defined several experimental campaign in different periods of the years in order to cover the purpose of their research activities. In this paper the results of the only two available tests on field are discussed. In particular the first campaign was carried out in November 2012, while the second one in May 2013 (the further test are at the moment just planned).

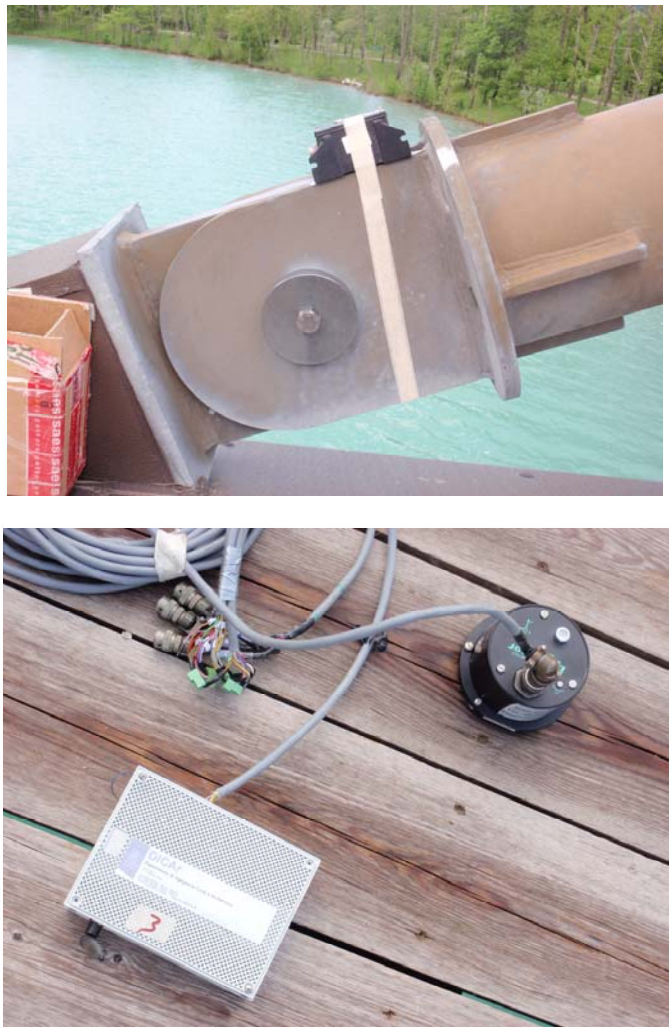


*Fig. 7 Uni-axial accelerometers located over the tubular steel elements (above).The tri-axial accelerometer connected with a wireless sensor unit (WSU) posed over the bridge's deck (below).*

The first set of experiments was carried out on November 30, 2012. The average temperature of air along the data acquisition was about 10 °C. The configuration of the sensors is given in Fig. 8.

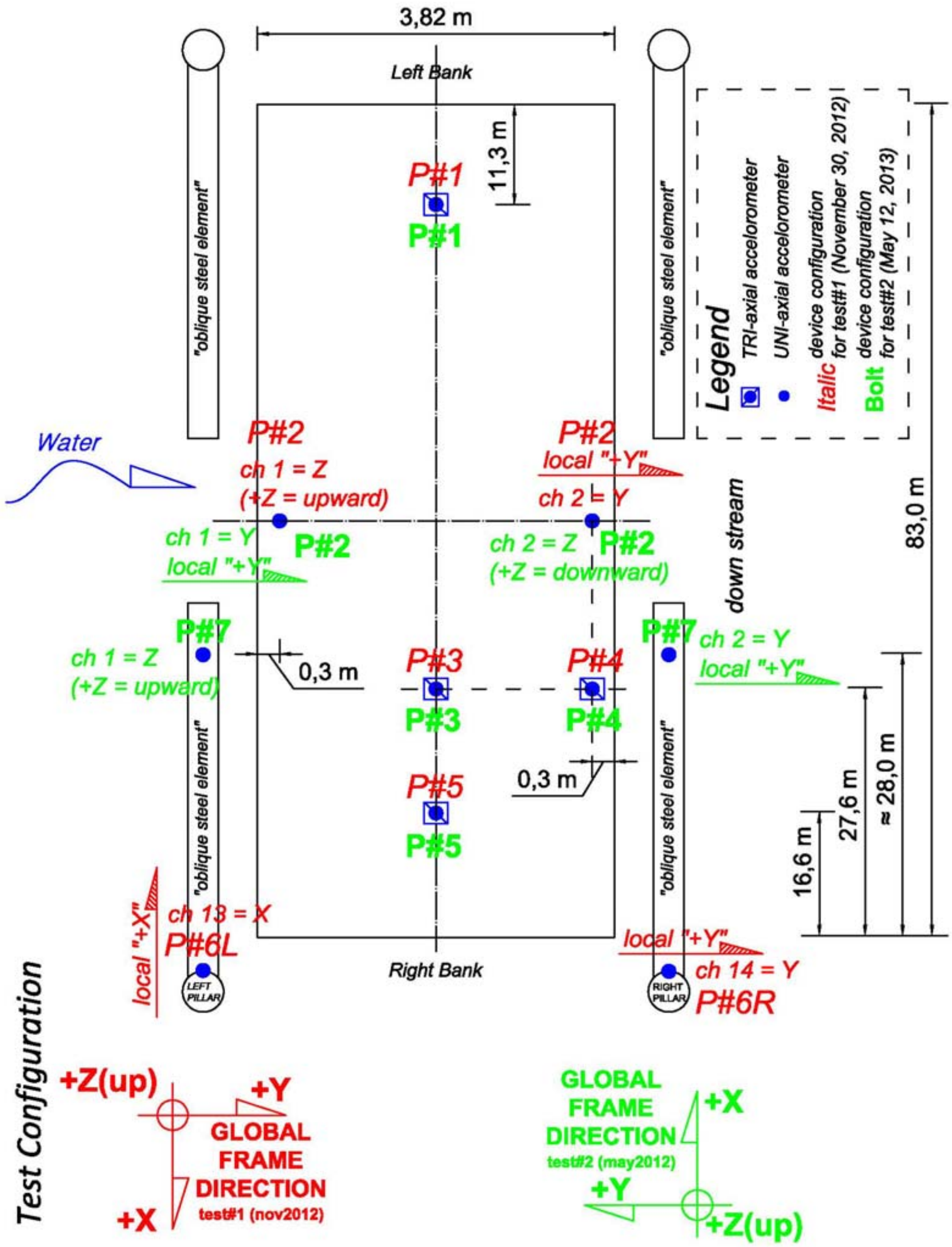



*Fig. 8 Sensors configuration for the two experimental campaign (November 30, 2012 and May 12, 2013).*

The second campaign of experiments was carried out on May 12, 2013 under the sensor configuration sketched again in Fig. 8.

Two set of data are reported: the first one was collected in the morning (9.30 a.m. – temperature of air about 15.5 °C), and the second one at noon (12:00 a.m. – temperature of the air about 25 °C). This test repetition was planned for investigating changes in the structure behavior related to environment condition variations.

The periodograms for the acceleration components along the transversal and vertical axes are given in Fig. 9 and Fig. 10. The three tests provides the same ranges for the frequencies which correspond to the vibration of the different structural elements.

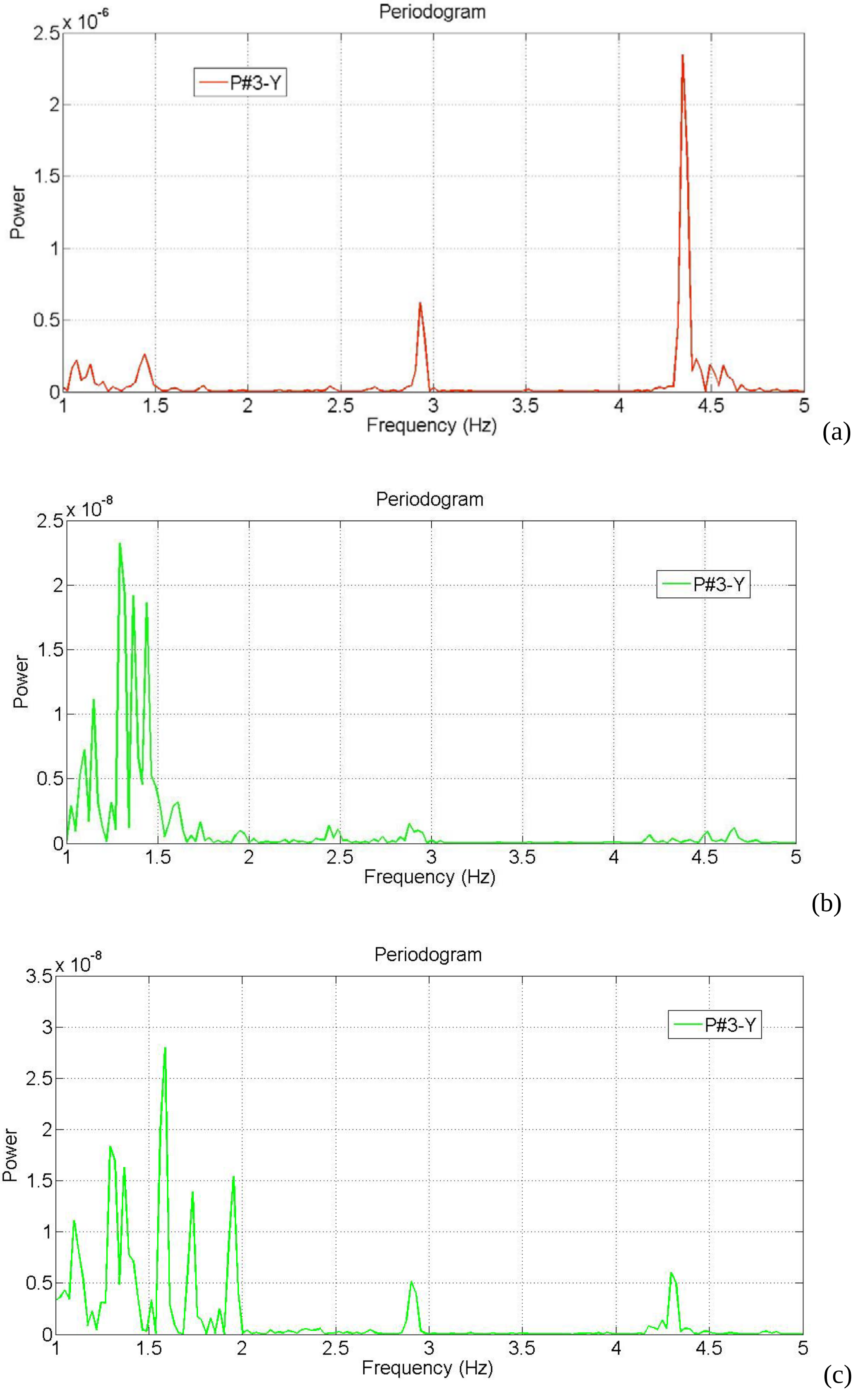
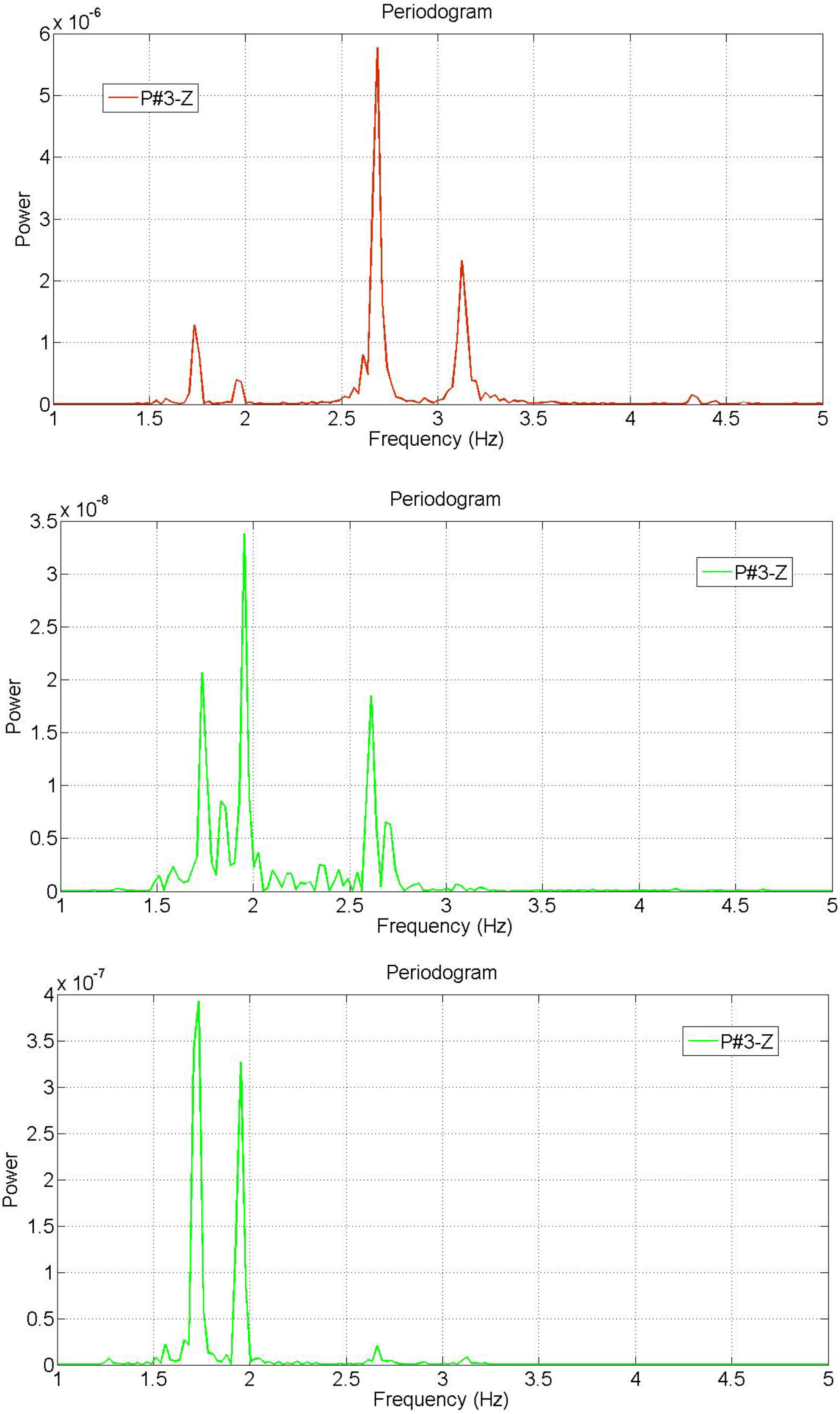



*Fig. 9 Periodograms of the signals recorded at position 3 (P#3): from the top to bottom, one sees the elaboration of the signals (along direction Y) collected in November, in the early morning of May 12, 2013 and in the late morning of the same day. The number of points in the temporal window of the signal is 2170.*




(a) (b) (c)

*Fig. 10 Periodograms of the signals recorded at position 3 (P#3): from the top to bottom, one sees the elaboration of the signals (along direction Z) collected in November, in the early morning of May 12, 2013 and in the late morning of the same day. The number of points in the temporal window of the signal is 2170.*

## 4. Conclusions

The wireless structural monitoring system adopted in the experimental campaign reported in this paper was working in a very satisfactory way. Indeed standard wired solutions, applied to structures like the one under study (with span length of 83 m), would have obliged to a suitable design of the cables, with intermediate storage stations.

Despite the two longitudinal beams realized in wood, the structural system has a hybrid nature, with all the antenna and the transversal links on the deck being realized in steel. The experimental results reported in this paper confirmed by the low sensitivity of the dynamic response to temperature variations, i.e., the prevalence of the steel skeleton on determining the footbridge vibration.

## 5. Acknowledgements

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### References

[1] G. Giordano, A. Ceccotti and L. Uzielli, *Tecnica delle Costruzioni in Legno* [in Italian], Hoepli, Milano, Italy, 1999, 850 pp.

[2] M. Piazza, R. Tomasi and R. Modena, *Strutture in Legno* [in Italian]. Hoepli, Milano Italy, 2005, 736 pp.

[3] S. Casciati and M. Domaneschi, Random imperfection fields to model the size effect in laboratory wood specimens, *Structural Safety*, 29 (4), 2007, pp. 308-321.

[4] H. Wenzel, *Health monitoring of bridges*, John Wiley & sons, Chichester, 2009, 621 pp.

[5] C.F. Beards, *Structural vibration: analysis and damping*, Arnold, London, 1996, 276 pp.

[6] Norme tecniche per le costruzioni - D.M. 14 Gennaio 2008 (NTC2008) [In Italian].

[7] http://www.mscsoftware.com.

[8] Sara Casciati, Lucia Faravelli, Daniele Bortoluzzi, *Pedestrian Timber Bridges: Experimental Investigation and Modelling*, The 10th International Conference on Damage Assessment of Structures, Dublin, Ireland, 8-10 July 2013.

[9] Sara Casciati, Lucia Faravelli, Daniele Bortoluzzi, *Human induced vibrations in a pedestrian timber bridge*, The 4th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN2013), Kos, Greece, 12-14 June 2013.

[10] S. Casciati and Z. Chen, *A multi-channel wireless connection system for structural health monitoring applications*. Structural Control and Health Monitoring Journal, 18 (5), 2011, pp. 588–600.

[11] C.M. Casado, I.M. Diaz, J. de Sebastian, A.V. Poncela and A. Lorenzana, Implementation of Passive and Active Vibration Control on an In-service Footbridge, *Structural Control and Health Monitoring*, 20,2013, pp. 70-87.