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Crossing the motorway: air pressure waves due to lorries transit

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ABSTRACT: When proposing a slender parapet girder as an alternative to an awkward and bulgy tubular truss beam providing pedestrian crossing across the Turin-Milan motorway, the authors were hardly aware of the significant pressure waves caused by the passage of today's giant lorries speeding over 100 km/h. In highly congested motorways, these vehicles tends to march at constant speed and spacing thus creating a pulsating effect that can lead to significant vibrations in overpasses. The pressure waves created by their passage hardly lose its energy before buffeting the deck since overpasses are generally placed as close as possible to the minimum vertical clearance and large lorries tends to use all the available height. The field measurements presented in the paper and the subsequent analyses hopefully provide some helpful guidelines for footbridges overpasses across highway and motorways.

1 INTRODUCTION

The twenty-one pedestrian and cycle-pedestrian crossing along the Turin-Milan motorway were built according the comfort (differential height in the pedestrian path and environmental comfort) with the technical-economical and building phasing aspects.

With this aim were built 19 under passages and 2 overpasses (cycle-pedestrian bridges).

The firsts were easily built during the motorway enlargement (just taking care of a correct works phasing).

About the overpasses, the interferences with the motorway were minimized pre-assembling the whole span and placing it in one time. These two pedestrian bridges were initially designed with two classic trussed lateral beams, with the service path level in between, used as balustrade also. This structurally efficient solution (taking into account the nearly 50m of span) is not so efficient for maintenance, as it brings to many "corners" were it is difficult the removing of dust and where it is thus more probable the starting of corrosion.

We decided to design two solid double T girders, reducing their height but still using them as balustrades. Considering the static scheme of single simply supported beam, the beam height was shaped giving an arch profile, as visible in Figure 1 and in Figure 2, reaching a more light and slender aspect together with a good structural efficiency.

Thus the beams height varies from 1.0m at the supports up to 1.80m in the mid-span. The span between the supports is 46m and the pedestrian path is 2.50m large.

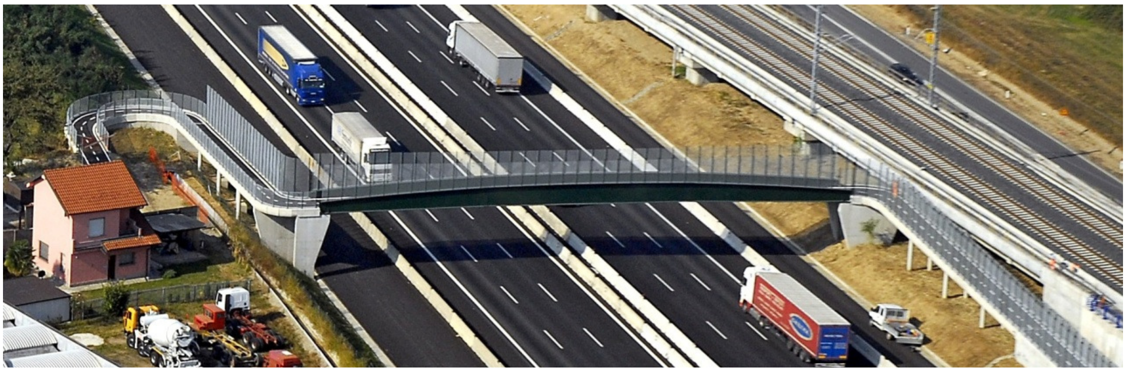

Figure 1. Pregnana's footbridge – overpass of TO-MI Highway.

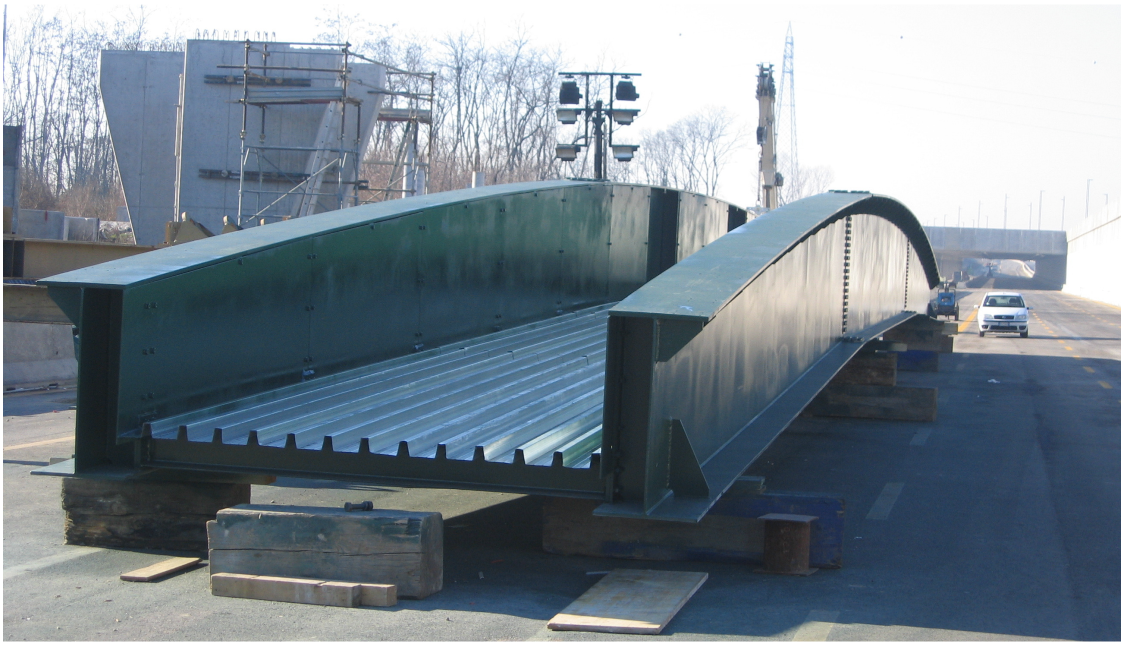

Figure 2. Pregnana's footbridge – the pre-assembling.

The two main beams are inferiorly connected by secondary beams (HEA200) supporting a corrugate steel sheet (HIBOND) collaborating with a concrete slab (12cm of total thickness).

The minimum free height from the motorway level up to the bridge intrados is 5.50m.

Besides the pedestrian load, the other impulsive force, that produces very important effects on the footbridge, is the air impact due to the trucks passing underneath.

The bridge design take however into account intrados overpressures (that may reach maximum values of 0.09kPa, equivalent to a distributed load of 90N/m^2, that is values many times lower than the usual live load) allowing little vertical displacements.

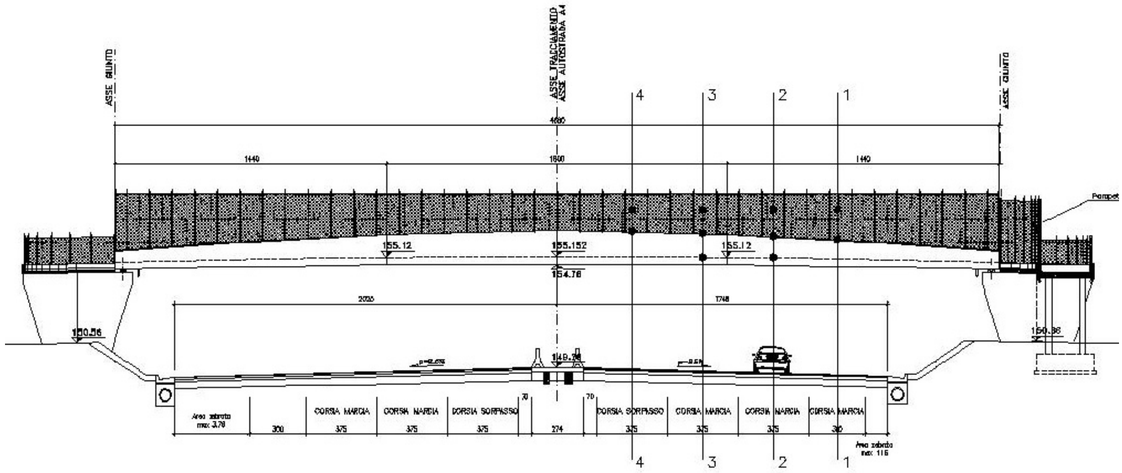

Figure 3. Pregnana's footbridge – Longitudinal view with indication of remark sections.

But, as the overpressure wave has length not very shorter than one second, it is not a single impulse but, on the contrary, it is an action with its own frequency spectrum. Therefore was carried out a monitoring campaign to evaluate and to quantify possible dynamic effects.

2 PRESSURE WAVES AND DYNAMIC MONITORING

Twelve installed transducers are used to investigate the dynamic behavior related to air waves impact due to trucks passing underneath, as follow:

- Pressure transducers monitor 4 sections above the 4 lanes towards Milan (Figure 3 and 4);
- Acceleration transducers control 3 sections (Figure 5) at mid-span, at the support and at L/4 (where L is the footbridge span).

In Figures 6 it is reported the more significant minute of registration with the P2 pressure transducer, where was recorded the maximum pressure value (around 0,09kPa), as the P2 pressure transducer is placed on the axis of the lane more used by the lorries.

In Figure 7 it is reported the more significant minute of registration with the A5 acceleration transducer, placed in the mid span, where there are the highest displacements.

3 ANALYSES AND ELABORATIONS

The recorded time histories of pressure (as that in Figure 6) show some isolated pick values, corresponding to the bigger lorries passages (those with larger and higher frontal section), together with minor pick values and also negative values corresponding to the lorries wake turbulence.

The registrations refers to a "normal" vehicular traffic (for the Turin-Milan motorway) with lorries running at velocity of around 80km/h.

In Figure 8 is reported the Fourier spectrum of the P2 registration, in semi-logarithmic scale to better show the lower frequencies.

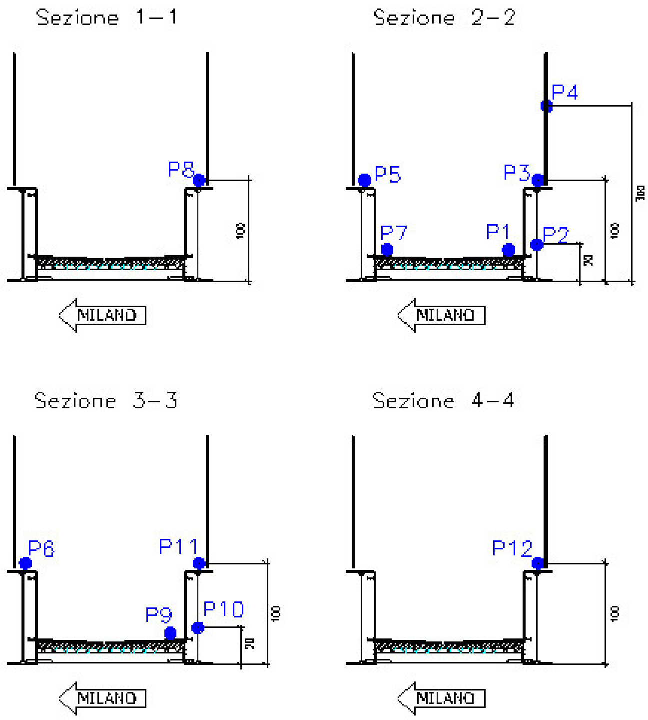

Figure 4. Pregnana's footbridge – Position of pressure transducers in the remark sections.

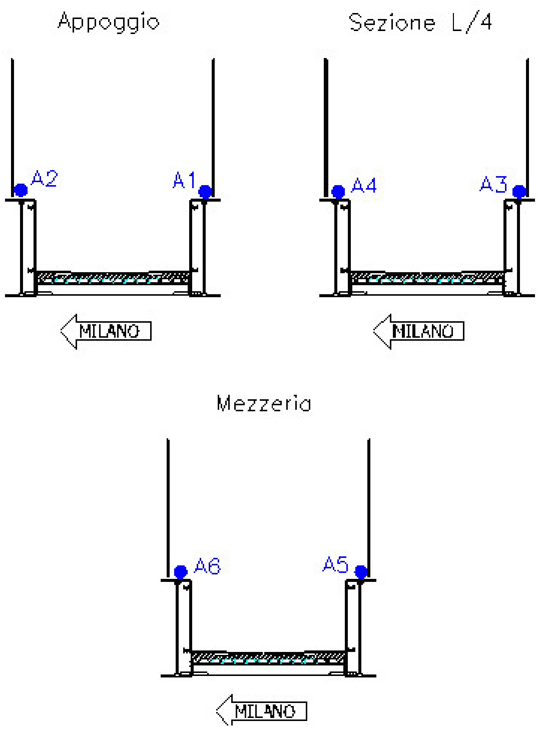

Figure 5. Pregnana's footbridge – Position of acceleration transducers at one support, at ¼ of span and in the mid span sections.

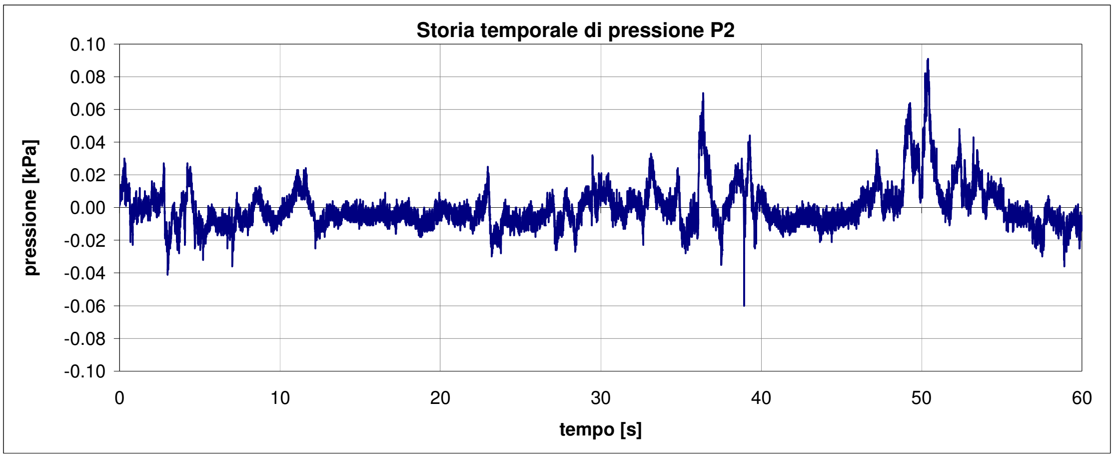

Figure 6. Pregnana's footbridge – Pressure transducer P2, the more significant minute of registration.

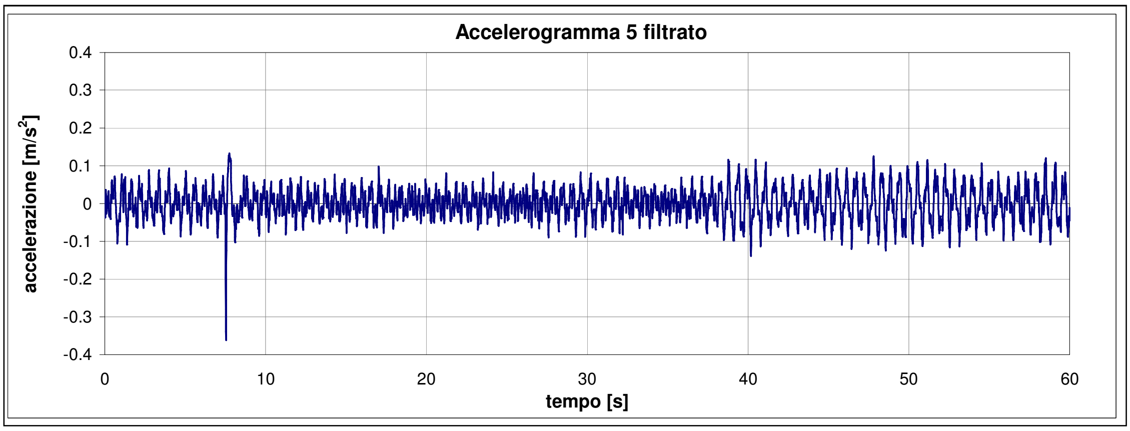

Figure 7. Pregnana's footbridge – Acceleration transducer A5, in the mid span, the more significant minute of filtered registration.

Those lower frequencies (0,281Hz, 0,439Hz, 0,647Hz and 0,940Hz) are corresponding to pressure pick values of higher energy content.

However those main frequencies are all relatively far from the bridge main own frequencies evaluated by a numerical model (Figure 9) and also obtained through the Fourier spectrum of the registrations taken by the acceleration transducers.

Combining the registrations of the two accelerometers in the mid span, it is possible to identify the flexional first mode at 1,77Hz, while analyzing the differences between the same two registrations is obtained the first torsion mode at 4,77Hz.

Combining the registrations of the two accelerometers at ¼ of the span, it is possible to identify the flexional second mode at 81,36Hz, the torsion second mode, etc..

It is important to note that these last anti-symmetric modes of vibration may be those more excited by the anti-symmetric actions of the lorries running in the two opposite external lanes,

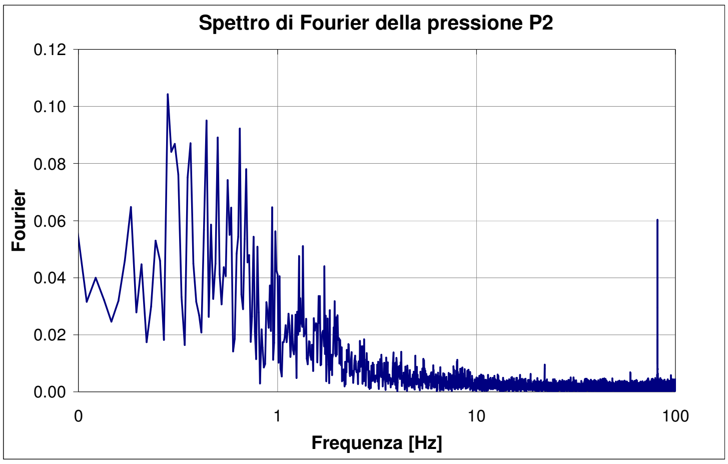

Figure 8. Pregnana's footbridge – Fourier spectrum of pressure transducer P2 registration.

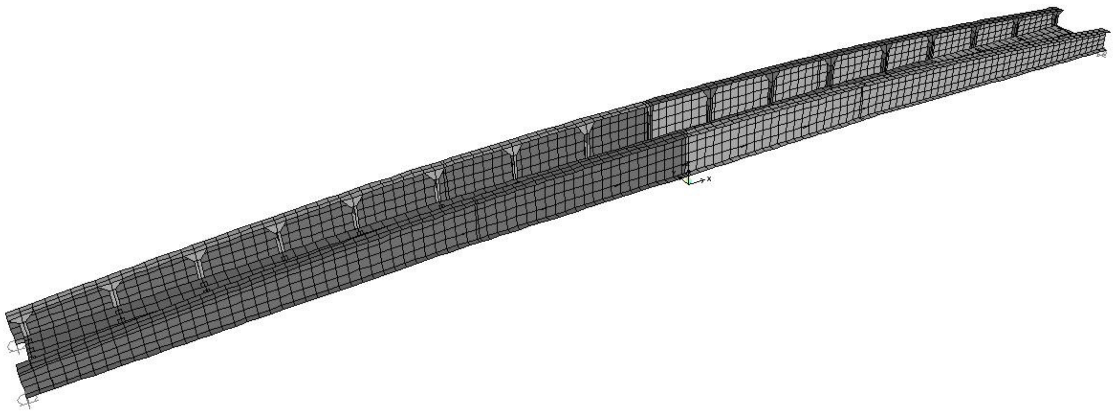

Figure 9. Pregnana's footbridge – F.E.M. Model.

but the pressure waves frequency content is very far from the frequencies of these superior modes of vibrations.

On the contrary, it is possible to notice that 0,940Hz (the pressure waves higher frequency pick value) is nearly a sub-multiple of both the first and the second bridge mode frequencies (first flexional and first torsion modes), but these modes are those less involved because of the position of the more used lanes.

Moreover it is important also to take into account the spatial 3D form of the pressure waves: in Figure 10 it is possible to note the time shift of the pressure pick value from the lane axis with the lorry (P2 and P7) to the adjacent lane axis (P9 and P10). This time shifting in the actions, on different near sections of the bridge, means that the wave front has an arch shape in its horizontal sections and this fact reduces the possibility of resonance with the bridge's modes of vibration.

Thus it is possible to say that the registered pressure waves have geometrical and dynamic characteristic that cannot cause significant resonance phenomena in the bridge.

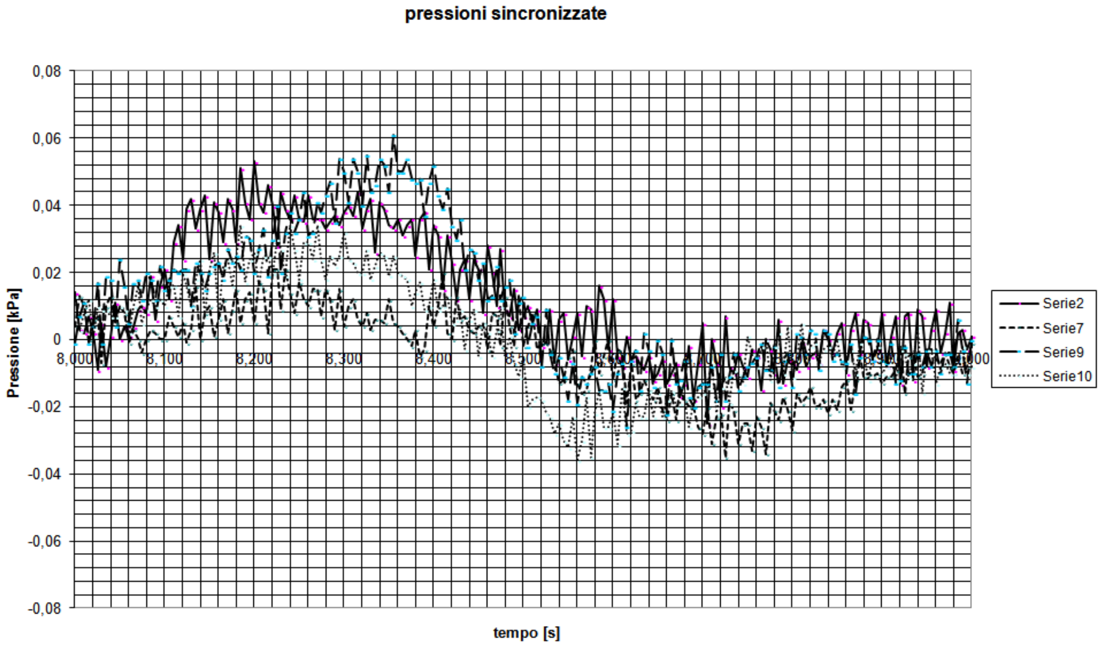

Figure 10. Pregnana's footbridge – Pressure transducers P2, P7, P9 and P10, the synchronized registration at one pressure wave passage.

This because the energy content is relatively low, because the 3D wave front causes time shifting among the actions in adjacent bridge sections and also because the lorries run on lanes from which are more excited the bridge modes of vibration with frequencies more far from the air pressure frequencies.

Moreover, the waves actions have so short durations that the bridge rapidly reach a free oscillations state, before the arriving of another pressure wave action.

The low dynamic effect of this actions is corroborated by the acceleration transducer registrations (Figure 7). After some necessary signal filtering (to eliminate aliasing phenomena due to noise) the registered acceleration may be integrated to have the velocity histories (as in Figure 11) and another time integrated to have the displacement histories (as in Figure 12).

The maximum displacement are obtained in the mid-span (Figure 12, acceleration transducer A5) and it is around 2mm, in vertical direction, sufficiently modest to confirm the substantial absence of resonance phenomena.

4 CONCLUSIONS

The pressure waves have a) a 3D geometrical shape, b) a lateral position respect the mid span of the bridge and c) dynamic characteristic with low energy contents, in such a way that cannot cause significant resonance phenomena in the bridge.

At the same time, the bridge shape and the choices about the materials used assure an high optimization in terms of time for the building up and in terms of total costs.

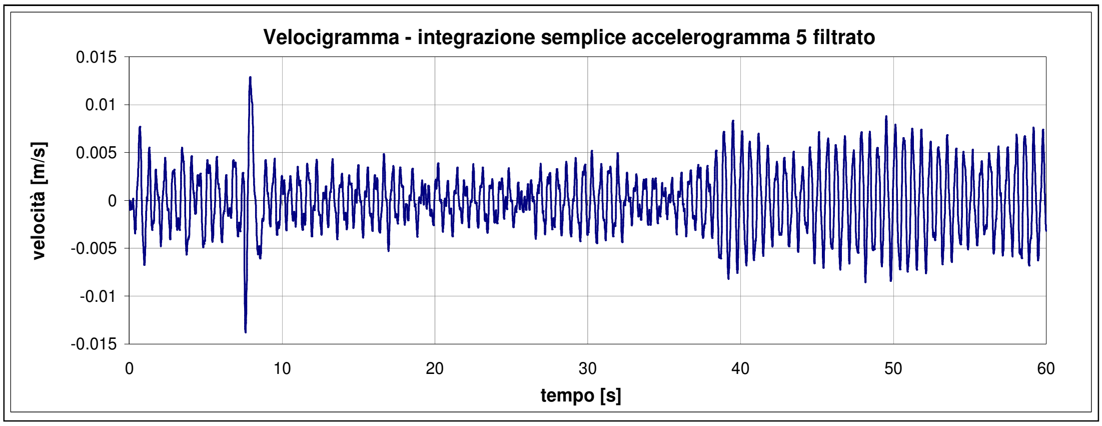

Figure 11. Pregnana's footbridge – Velocities history after integration of the accelerations in A5.

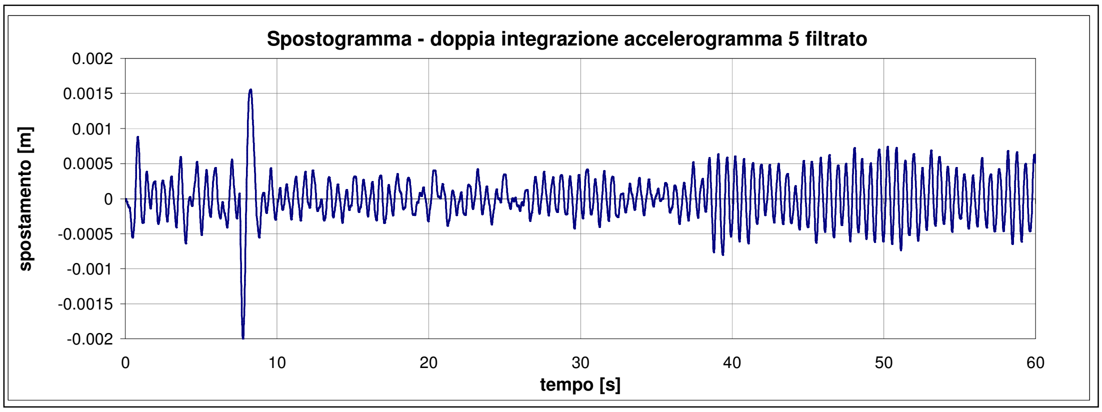

Figure 12. Pregnana's footbridge – Displacements history after integration of the velocities in A5.

Steel bridges are fast to be mounted (reducing interferences with the motorway users), easily cover spans around 50 meters without intermediate supports (spans necessary to pass over the motorways with up to four lanes in each direction) and have reduced dead loads in such a way to need reduced supporting structures and foundations.

5 REFERENCES

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