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# Noise and Vibration Induced by Train: The Case of the Messina Bridge

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## Summary

The paper reports the main results of researches aimed at designing the railway box and the superstructure of the 3300m span bridge proposed for the crossing of Messina straight.
To this end, besides experimental experiences described in previous work, a mathematical model of train-track-structure interaction has been used to evaluate the performances of the alternative solutions proposed. In particular, to kinds of track are considered, a traditional direct fastening one and a slab track; the latter shows considerably better performances in terms of noise and vibration attenuations, making attractive its adoption, despite its greater weight.
The paper also points out the role in the design activities of a mathematical model of train-track interaction, in order to assess the efficiency of the different alternatives considered.

## 1. Introduction

Railway box girders of long span suspension bridges are relatively light and flexible structures, which can be subjected to high dynamic effects induced by the passage of the trains. These effects must be carefully analysed in order to verify that no structural damage will be caused by repeated train passages and that the generation of noise and vibrations is kept under control. Moreover, the structure must satisfy restrictive requirements regarding global and local deformations under train passage, in order to ensure the safety of ride of the train and passengers' comfort.
An overview of railway runnability problems is given in [1], where an important distinction is established between global train-structure interaction, involving deformations of the whole structure, and local interaction, due to components of deformation of the deck with wavelengths equal to the longitudinal separation of the hangers. Other local effects are related with deformations of the upper side of the deck, having wavelengths of the same order of magnitude of the sleeper bay (distance between two consecutive sleepers).
The present paper focuses on the problems of local interaction, which is particularly critical for box girder decks, due to the presence of local resonances of the upper plate of the deck which can be excited by the passage of the trains. In this regard, the design of the superstructure, that is a set of devices (generally including sleepers, rubber pads, fastenings) connecting the rails to the deck, is of paramount importance, as this component performs as a low-pass filter in the transmission of forces and vibrations from the wheelsets to the structure.
Within the design activities regarding the Messina bridge project, extensive experimental and theoretical researches were carried out, with the aim of defining a suitable typology of superstructure to be employed for the definitive setup of the bridge. As a first step of the work, several tests on a full-scale section of the railway box girder of the bridge were performed: different typologies of superstructure were tested, including direct fastening systems and slab track. The measure of the transfer function between a vertical force applied to the rail and the acceleration of the upper plate of the railway allowed the evaluation of the filtering effect

introduced by the different when connected to the railway box [2]. Moreover, the results of numerical simulations allowed to evaluate the dynamic forces transmitted to the deck [3]. Recently, an improved version of slab track was proposed, on the basis of field experiences acquired for metro and urban railway lines, which were carried in 1996 [4]. The problem of optimising the design of the superstructure is therefore still open, and the present work aims at contributing to this matter by comparing traditional and innovative solutions, the target being to ensure low levels of structural noise, good dynamic performances of the vehicle, low weights and low maintenance costs.
To this end, the passage of the train on the deck has been simulated by means of mathematical model of train-track-structure interaction developed at the Department of Mechanical Engineering of Politecnico di Milano and implemented in a computer code called A.D.Tre.S. [5].

## 2. Key factors affecting local train-structure interaction

As discussed above, the local interaction is mainly governed by the structural properties of the superstructure. Nevertheless, for box girder bridges, also the design of the deck assumes great importance: in fact its local deformations must be kept as small as possible, and the excitation of local resonances of the upper plate by the forces transmitted by the superstructure should be kept as small as possible.
Therefore, different strategies have been considered in order to increase the local stiffness of the upper side of the railway deck: figure 1 shows a section of the railway box, where longitudinal ribs are recognisable, moreover, diaphragms have been inserted each 2.65 meters along the deck in order to connect the upper and lower sides of the box.

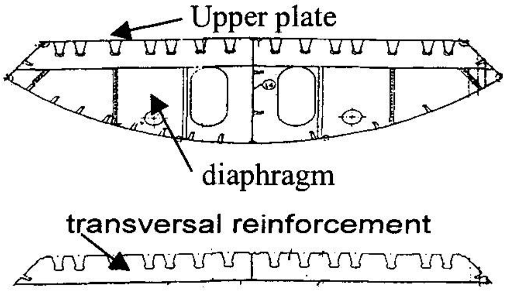


*Fig. 1 Section of the railway deck and transversal reinforcement*

Finally, the use of two supplementary reinforcements per each 2.65 m sub-span of the deck has been considered as a way to further reduce local deformations. A first question this paper is concerned with is whether or not the use of these reinforcements is necessary.
The second problem addressed in the paper, which is strictly related to the first, is what kind of superstructure can reach the best performances in reducing the effects of local interaction between the train and the deck. To this end two kinds of superstructure have been compared, a direct fastening track (D.F.T.) and a slab track (S. T.), where a concrete slab acts as a foundation elastically suspending the rail from the deck.
The direct fastening system is shown in figure 2: the rails are connected to separate steel plates, fastened by means of bolts to the upper plate of the deck. This kind of track is widely adopted, especially for subway lines, its main advantages are low maintenance costs and low weight while, from the point of view of its dynamic properties, a fundamental role is played by the rubber pad interposed between the deck and the steel plates: previous experiences showed that low values of the stiffness of this pad improve the performances of the superstructure in terms of isolation of vibrations but, conversely, an excessively low stiffness makes difficult to control the geometry of the track, causing problems to vehicles' safety of ride.
The improved version of the slab track considered in the project is shown in figure 3: the rails are fastened to steel plates connected through rubber pads to a concrete floating slab. The slab is then laid on a continuous layer of resilient material, in order to create an elastic foundation insulating the deck from the rails.
For each of the two solutions, an optimization of stiffness and damping parameters has been performed based on the knowledge acquired in previous experiences on both prototypes for the Messina bridge and in-line applications for high speed and underground railways, so that the two

solutions which will be compared can be considered as optimised versions of the two kinds of superstructure. Slab track is expected to show a better behaviour than direct fastening track [6], but a quantitative evaluation of the advantages of this solution are mandatory in order to judge if they can justify the important increase in the weight of the structure introduced by this solution.

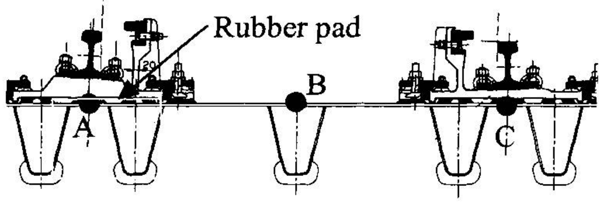


*Fig. 2 Direct fastening track*

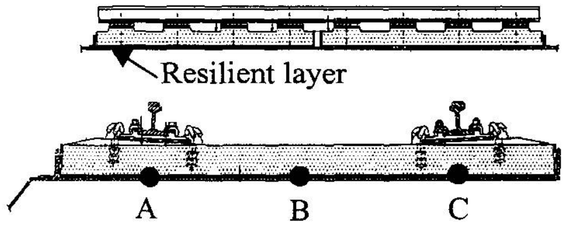


*Fig. 3 Slab track*

## 3. Track and structure modelling

The deck and the superstructure are modelled by means of a three-dimensional finite element scheme; since the attention is focused on the local track-structure interaction, only the upper plate of the railway box girder is modelled. To this end, plate elements are used, while the diaphragms are introduced in the model as rigid supports constraining the vertical motion of the plate. The presence of the reinforcing ribs is kept into account by considering an appropriate equivalent thickness for the plate elements, the value of this parameter has been adjusted on the basis of a more sophisticated f.e.m. model of the railway box girder. Upper-plate reinforcements have been also included in the model as beam elements, in order to evaluate their efficiency in reducing the local deformability of the deck and improve upper plate dynamic response.
As far as the scheme of the track and superstructure is concerned, the rails are modelled by means of Euler-Bernoulli beam elements, while the fastening devices and rubber pads are reproduced by means of concentrated or distributed stiffness and damping elements. Finally, the slab carrying the rails in the slab track is modelled by four nodes plate elements.
The stiffness and damping values of the rubber elements are reported in Tables I and II. It is worth mentioning that for rubber elements those parameters are frequency dependent [7]: the values adopted in the finite element model refer to the frequency of the first vertical resonance of the track coupled to the wheelset.

| | Rail fasteners | Rubber pads under the steel plate | Rubber layer under the slab |
|---|---|---|---|
| Direct fastening | 200 | 27 | --- |
| Slab Track | 200 | 27 | 4.04 |

*Table I Stiffness values of the fastenings [MN/m]*

| | Rail fasteners | Rubber pads under the steel plate | Rubber layer under the slab |
|---|---|---|---|
| Direct fastening | 15 | 3.5 | --- |
| Slab Track | 15 | 3.5 | 2.08 |

*Table II Damping values of the fastenings [kNs/m]*

## 4. Simulation of train passage

Simulations of train-track-structure interaction were performed by means of the package ADTRES [5], developed in co-operation between the Department of Mechanical Engineering of Politecnico di Milano, and Italferr, which is part of the Italian Railway Authority. This model is thoroughly described in previous pubblications from the same authors [2], [5].
The conditions of simulation are as follows: an ETR500 train (Italian high speed train) running on the deck at the design speed of 130km/h; the presence of track and wheel thread irregularities

has been considered. To this end, the spatial distribution of track irregularity was generated according to ORE low level standards [9], while for wheel threads reasonable levels of irregularity were estimated from previous work [4].
A first result, shown in figure 4, regards the vertical component of the contact force between the left wheel of the leading wheelset of a passenger car and the rail. The time history of the signals is shown in the lower side of the figures, while spectra are represented in the upper side.
The dynamic component of contact forces is produced by the interaction between the track and the vehicle, where track irregularity plays an important role. As far as the behaviour of the structure is concerned, a high dynamic component of the contact force will produce important vibrations of the track, which will be partially transmitted to the deck producing noise, vibrations and dynamic over-stresses. From the vehicle's point of view, high variations of contact forces affect the safety of ride and cause vibrations in the wheelsets and in the bogies.

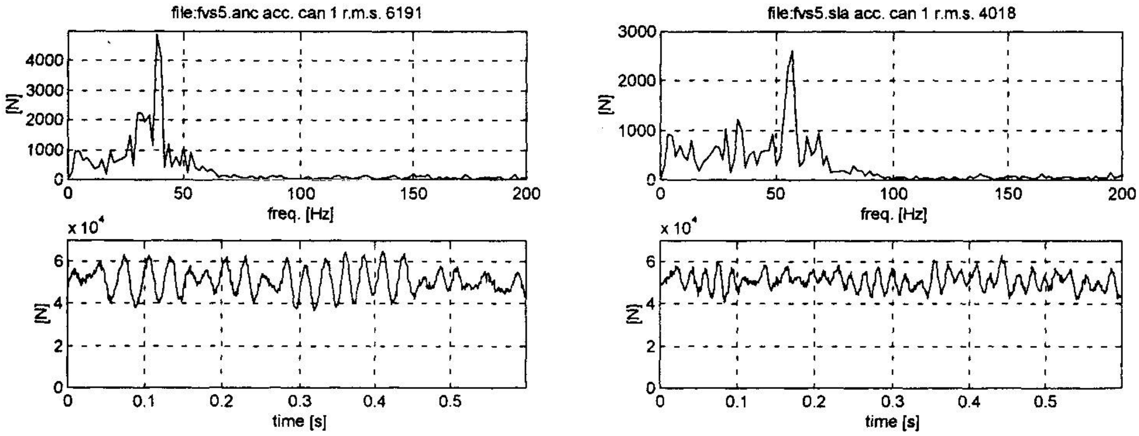


*Fig. 4 Vertical contact force between left wheel of the leading axle of a passenger car and the rails (left direct fastening track, right slab track)*

Both results show a prevailing frequency in the dynamic component of contact force (around 40Hz for D.F.T. and 60Hz for S.T.): this frequency corresponds for each kind of track to the first resonance of the wheelset coupled to the track. Slab track shows a lower level of amplitude of the dynamic component, as indicated also by the r.m.s. values.
The behaviour of the structure is affected not only by the dynamic forces between the wheels and the rails, but also by the filtering properties of the superstructure: in order to judge the vibratory behaviour of the deck Figure 5 shows the vertical accelerations of the deck under the inner rail (position "C" in figure 2); more precisely, the results obtained for D.F.T. without reinforcements are shown at left side, while those for S.T. without reinforcements are shown at right side.
These quantities are a measure of the transmitted vibrations, and are strictly related to the generation of structural noise in the deck.
The maximum level of vibration is one order of magnitude lower for the slab track, and the comparison of the two spectra shows that for frequencies above 60Hz slab track filters almost completely the vibrations coming from the rails. For the direct fastening track on the contrary, important contributions to the vibration of the deck are present at high frequencies: these components are expected to produce significant levels of noise.
The advantage introduced by slab track can be appreciated in figure 6, where the third octave band of the two signals are compared: in the frequency range above 100Hz the level of acceleration is two decades higher for D.F.T. (continuous line) than for S.T (dashed line).
More complete conclusions can be drawn from table III, where the r.m.s. values of the accelerations on the rails and in different locations on the deck are compared for the two kinds of track, considering or not the presence of reinforcements. While the accelerations at the rail reach similar values for the two superstructure solutions, the slab track produces much lower accelerations of the deck.
Moreover, as far as direct fastening is considered, the reinforcement can improve the vibrational behavior of the deck: in fact the levels of acceleration under the two rails are significantly reduced, while in point "B" are almost the same. On the contrary, for slab track the adoption of the reinforcements does not provide any significant improvement.

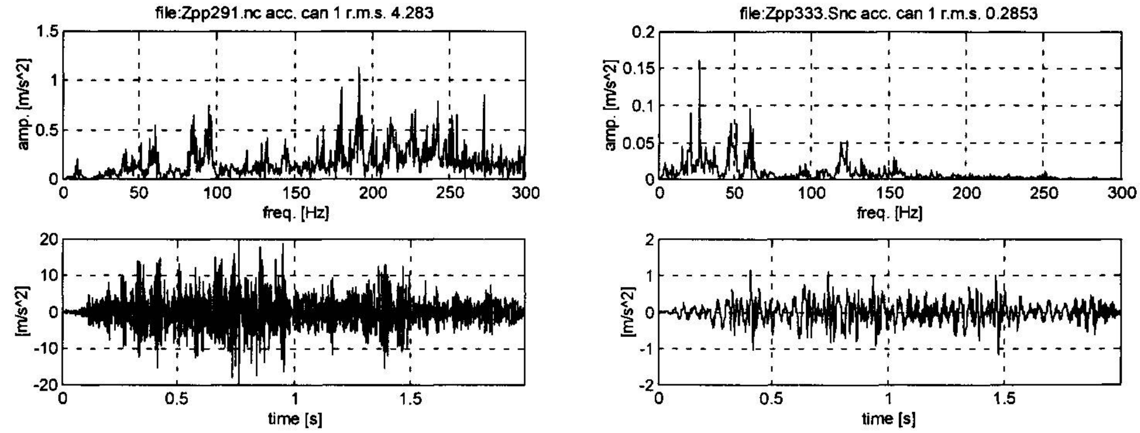


*Fig. 5 Vertical acceleration of the upper side of the deck in point "C" (left direct fastening track, right slab track)*

| | Direct fastening No reinforcement | Direct fastening with reinforcement | Slab track No reinforcement | Slab track With reinforcement |
|---|---|---|---|---|
| Rail | 8.88 | 9.43 | 8.43 | 8.44 |
| Deck pos. A | 4.65 | 2.31 | 0.21 | 0.14 |
| Deck pos. B | 3.90 | 3.69 | 0.24 | 0.27 |
| Deck pos. C | 4.20 | 3.29 | 0.28 | 0.26 |

*Tab. III r.m.s. values of acceleration in different locations of the structure ([m/s$^2$])*

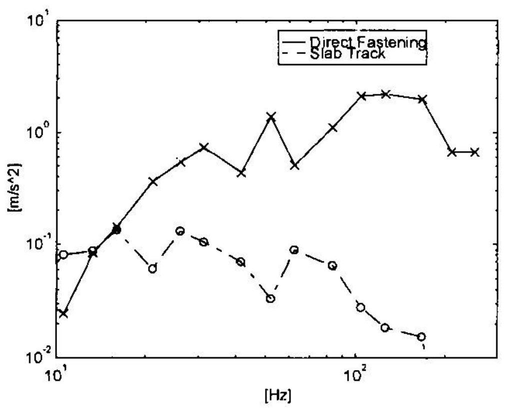


*Fig. 6 Third octave band representation of vertical accelerations of the deck.*

Besides the levels of vibration of the deck, it is important to evaluate the over-stresses induced in the deck by the passage of the train: in fact these quantities affect the fatigue resistance of the structure. As an example, Figure 7 shows for D.F.T. (left) the time history of the vertical force transmitted to the deck by a single rubber pad (continuous line) and the history of the same force when static train loads are applied (dashed line). The figure shows the passage of the front bogie of a passenger car (total weight 420kN approximately): a strong amplification (about 25%) of the first peak of force corresponds to the passage of the first wheelset.

Similar results are shown for slab track in the same figure (right), in this case the force transmitted by a portion of the elastic layer placed under the track has been reported. In order to make this result comparable to those for D.F.T., a portion with length equal to one sleeper has been considered. Figure 7 shows that the use of slab track can keep dynamic effects on the structure at very low levels.

A common way to represent the influence of dynamic effects on the stresses is to define suitable impact factor parameters as the ratio between the dynamic stress induced by the train and the corresponding value produced by the static application of train axle loads on the structure. These quantitites can be defined for different stress components and for different locations in the structure: Table IV reports the values of impact factors for the vertical force transmitted by the superstructure to the deck and for the stress in longitudinal direction in a point of the upper side of the deck placed under the inner rail.

The impact factors obtained with the slab track are very low (around 3%), while much higher values are obtained for D.F.T: in this latter case, a small reduction of the impact factors corresponds to the introduction of the reinforcements on the deck.

Figure 7 also shows that the static value of the force transmitted to the deck is lower for S.T. than for D.F.T.: this is due to the fact that the flexural stiffness of the slab allows the re-distribution of the axle loads on a wider portion of the deck than for D.F.T. All these circumstances show that the adoption of slab track can significantly improve the fatigue resistance of the deck.

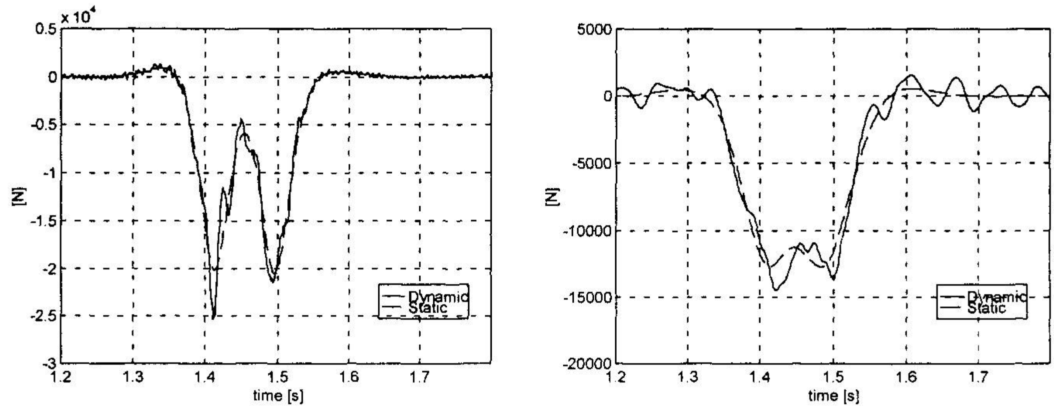


*Fig. 7 Vertical force transmitted to the deck (left direct fastening track, right slab track)*

| | Direct fastening No reinforcement | Direct fastening with reinforcement | Slab track No reinforcement | Slab track With reinforcement |
|---|---|---|---|---|
| Vertical force on the deck | 1.25 | 1.24 | 1.14 | 1.14 |
| Longitudinal stress in the deck | 1.14 | 1.12 | 1.03 | 1.03 |

*Tab. IV Values of local impact factors*

## 5. Concluding remarks

A comparison of two alternative superstructure typologies proposed for the railway box of Messina bridge has been presented. Direct fastening track is simple, light and economic, but even if its stiffness and damping values are correctly tuned, its performances with respect to the transmission of vibrations and noise cannot considered completely satisfactory. Slab track instead, though introducing a significant increase of weight (about 1 t/m), shows a very attractive dynamic behaviour, producing very low levels of vibration of the deck, low dynamic over-stresses, and good quality of ride of the vehicle.

## References

[1] Diana G., Cheli F., Bruni S., Collina A., *Super long suspension bridges, railway runnability* 15th IABSE Congress, Copenhagen, Denmark, June 16-20 1996

[2] Diana G., Cheli F., Bruni S., Collina A., *Interaction between railroad superstructure and railway vehicles* 13th IAVSD Symp., Chengdu, P. R. China, August 23-27 1993

[3] Diana G., Cheli F., Bruni S., Collina A., *Train-track interaction: a comparison between a numerical model and full scale experiments*, IV to appear on Heavy haul transit, part of Int. Jour. Of Vehicle Design

[4] Diana G et al., *A.D.Tre.S., a software for railway runnability analysis* WCRR '97 Congr., Florence, Italy, 16-19 November 1997

[5] Eisenmann, J., *Vibration and structure borne sound by underground railways* Symp. on Vibro-acoustic and env. impact of underground railways, Bergamo, Italy, 2-3 June 1994

[6] Grassie S. L., *Resilient railpads: their dynamic behaviour in the laboratory and on track* Proc. Inst. Mech. Eng.rs, Part F, 1989, Vol. 203, 25-35

[7] ORE, Question B176, Utrecht, Belgium, July 1992.

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