PREDICTION OF GROUND-BORNE VIBRATIONS INDUCED BY RAILWAY TRAFFIC BASED ON MACHINE LEARNING TECHNIQUES

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ABSTRACT

Over the latter years, there was a demand for the development of advanced numerical techniques for the prediction of ground-borne vibrations induced by railway traffic which can provide the desired level of accuracy, despite of structural complexity of the entire system. Despite the suitability of these models in dealing with such phenomena, their applicability to cases where it is intended to have a general assessment of the potential impacts of a new/updated railway project is difficult to achieve. In such cases, the development of expedited prediction methods is desired, allowing the delimitation of cases that require a deeper analysis, using advanced numerical models, and of those that can be immediately discarded, with all the benefits of cost and time associated. Thus, it is the intention to develop an innovative prediction tool, powered by an efficient and intelligent calculation engine based on surrogate modelling, that allows an efficient assessment of ground-borne vibrations at the free-field surface due to railway operation.

Keywords — railway traffic; ground-borne vibrations; numerical modeling; surrogate model.

1. INTRODUCCIÓN

The management of densely populated urban areas, their mobility and the need to combat climate change are major challenges for the society, which justify the wide expansion of railway projects in modern cities. Although the benefits (economic, social and environmental) inherent to rail transport are evident, their exploration leads to environmental concerns, motivated by the generation and propagation of vibrations and noise that affect the comfort and life quality of the inhabitants in railway surroundings. Over latter years there was a demand for the developing of advanced numerical techniques from the vibration source (vehicle–track interaction) up to the receiver (building). Generically, these models take into account the following patterns associated with the physical problem: i) the movement of the train on the track constitutes the source of vibrations; ii) the energy is spread in the ground; iii) the vibration field reaches nearby buildings giving rise to vibrations and noise [1-8].

Despite the suitability of these models in dealing with such phenomena, predicting vibration levels demands high-standard numerical models, which require huge computational cost. This condition is enhanced when it is intended to have a general assessment of the potential impacts of new/updated railway projects. In such cases, the development of expedited prediction methods is desired, allowing the delimitation of cases that require a deeper analysis, using advanced numerical models, and of those that can be immediately discarded, with all the benefits of cost and time associated.

Thus, it is the intention to develop a prediction tool, powered by an efficient and intelligent calculation engine based on surrogate modelling, that allows an efficient assessment of ground-borne vibrations at the free-field surface due to railway operation.

2. NUMERICAL APPROACH

The prediction tool of the track-(tunnel)-ground system response is designed in two layers: i) semi-analytical/numerical modelling the subsystems of the railway infrastructure; and ii) development of a surrogate model to have a 'quick-to-compute' engine.

In what concerns to the first layer, a large database will be created based on massive simulations that aim to represent the most typical situations that can be faced in railway

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infrastructure projects. In this perspective, advanced numerical models already developed by the authors will be employed [9-11].

For the second layer, and instead of performing the physical modelling of the system (which requires a huge computational effort), the so-called surrogate models will be created to easily obtain results through a relatively simple and 'quick to-compute' emulator of results. Figure 1 presents a general overview of the prediction tool.

3. PRELIMINARY RESULTS

Advanced numerical models previously developed by the research group and experimentally validated are used in this task for the simulation of the track-ground system. Based on that, it was possible to compute the free-field response for different scenarios. The parametric studies performed attend to different characteristics of rolling stock, railway infrastructure, and geotechnical conditions. A total of 648 parametric studies were considered for the generation of the database. The modelling parameters considered for each case are presented in Figure 2.

From the advanced numerical method used, it was possible to compute the free-field response. Figure 2a and b) presents, as an example, the vertical vibration velocity for a point above the tunnel and at the surface (time domain and frequency content) for Profile 1 defined in Figure 2. Figure 3c presents the maximum value of the Running RMS (in dB) for different distances to the centre of the tunnel.

To fulfill the objectives initially stated, machine learning algorithms, namely Artificial Neural Networks (ANN) and Support Vector Machine (SVM) techniques, are applied to this type of problem. The expected outputs correspond to the evaluation of the maximum vibrations levels expected at the ground surface and the frequency content. Considering the validation scenario defined in Figure 4a, the results obtained by the different techniques are compared with numerical results (observed). It is possible to observe a positive correlation in the results, either in the time and frequency domain.

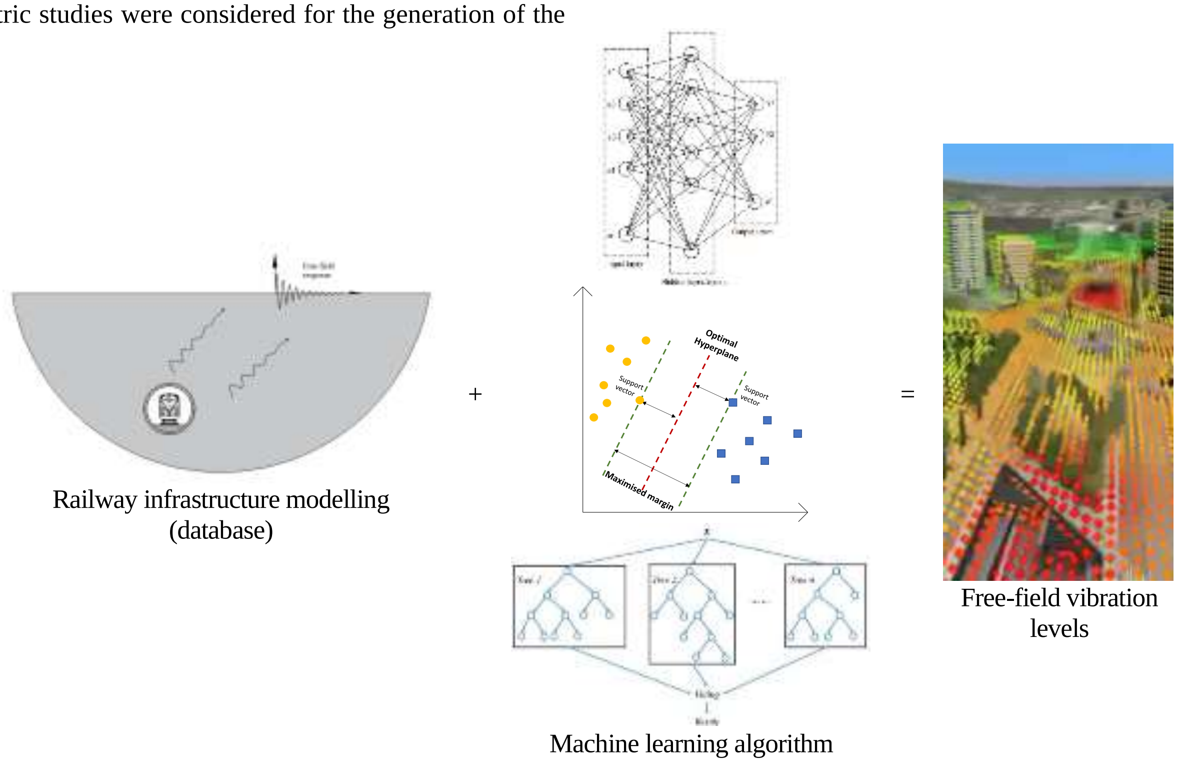
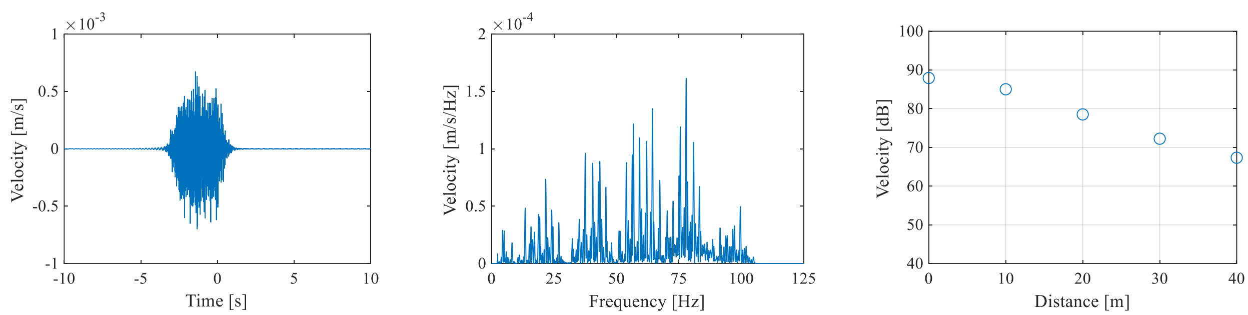


Figure 1. General overview of the surrogate model.

Profile ID	Train		Track										
	Type	Speed [km/h]	Unevenness class (FRA)	Rail		Railpad		Slab				Mat	
				EI [N.m^2]	Mass [kg/m]	K [kN/mm]	C [kNs/mm]	Thickness [m]	b [m]	E [GPa]	ρ [kg/m^3]	K [N/m^2]	C [Ns/m^2]
1	EuroTrain	100	6	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	1,00E+20	5,50E+04
2	EuroTrain	100	6	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	1,00E+20	5,50E+04
3	EuroTrain	100	6	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	1,00E+20	5,50E+04
…	…	…	…	…	…	…	…	…	…	…	…	…	…
645	TramTrain	60	4	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	4,00E+07	5,50E+04
646	TramTrain	60	4	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	4,00E+07	5,50E+04
647	TramTrain	60	4	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	4,00E+07	5,50E+04
648	TramTrain	60	4	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	4,00E+07	5,50E+04

Profile ID	Tunnel							Ground			
	Tunnel depth [m]	Tunnel radius [m]	Tunnel wall					Properties			
			Thickness [m]	E [Mpa]	ν [-]	ξ [-]	ρ [kg/m^3]	Cs [m/s]	ν [-]	ξ [-]	ρ [kg/m^3]
1	9	3	0,3	3,00E+04	0,2	0,01	2500	150	0,35	0,05	1900
2	9	3	0,3	3,00E+04	0,2	0,01	2500	150	0,35	0,03	1900
3	9	3	0,3	3,00E+04	0,2	0,01	2500	300	0,35	0,04	1900
…	…	…	…	…	…	…	…	…	…	…	…
645	21	3	0,3	3,00E+04	0,2	0,01	2500	300	0,35	0,04	1900
646	21	3	0,3	3,00E+04	0,2	0,01	2500	300	0,35	0,02	1900
647	21	3	0,3	3,00E+04	0,2	0,01	2500	800	0,35	0,03	1900
648	21	3	0,3	3,00E+04	0,2	0,01	2500	800	0,35	0,02	1900

Figure 2. Defined mechanical and geometrical properties of the train-track-tunnel-ground system.



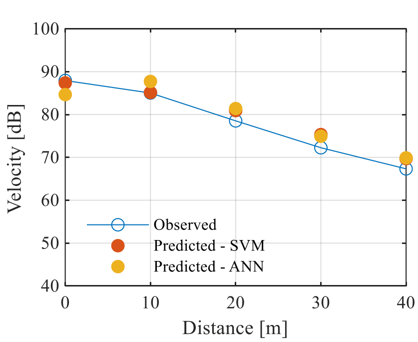
a) b) c)

Figure 3. Defined mechanical and geometrical properties of the train-track-tunnel-ground system.

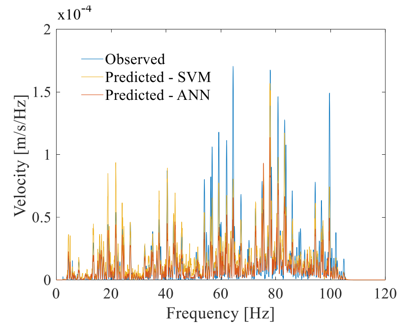
Profile ID	Train		Track										
	Type	Speed [km/h]	Unevenness class (FRA)	Rail		Railpad		Slab				Mat	
				EI [N.m^2]	Mass [kg/m]	K [kN/mm]	C [kNs/mm]	Thickness [m]	b [m]	E [GPa]	ρ [kg/m^3]	K [N/m^2]	C [Ns/m^2]
1	EuroTrain	100	6	6,14E+06	60,34	1,01E+09	2,25E+04	0,3	2,75	30,00	2500	1,00E+20	5,50E+04

Profile ID	Tunnel							Ground			
	Tunnel depth [m]	Tunnel radius [m]	Tunnel wall					Properties			
			Thickness [m]	E [Mpa]	ν [-]	ξ [-]	ρ [kg/m^3]	Cs [m/s]	ν [-]	ξ [-]	ρ [kg/m^3]
1	9	3	0,3	3,00E+04	0,2	0,01	2500	200	0,35	0,04	1900

a)



b)



c)

Figure 4. Surrogate model results: a) validation example properties; b) Maximum running RMS versus distance to tunnel axis; c) frequency content of a point above the tunnel and at the surface.

4. CONCLUSIONS

From the results achieved, it is possible to conclude that the presented methodology is able to be used in the prediction of the dynamic response of the track-ground-building system, allowing a computationally efficient assessment of free-field vibrations due to railway operation. In order to make the prediction tool able to be used by technicians that, although have basic knowledge about the topic, are not experts on railway noise and vibrations, it is intended the development of a user-friendly framework of wider practical application. The integration of the prediction tool with GIS (Geographical Information Systems) can also be useful for the visualization of problematic regions, allowing focus on those problematic areas, either through additional and more complex numerical studies or the design of mitigation measures.

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