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An alternative to floating slabs in tunnels

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1.INTRODUCTION

CDM is a Belgian company with 60 years experience specialising in noise and vibration isolation in the building, industrial and rail markets. We are one of about 30 partners involved in the EU funded Urban Track Project which is due for completion in 2010.

This paper summarises our work in the development of a rail fixing which will deliver similar vibration isolation as a floating slab track.

2. OBJECTIVE

There are many examples of metro tunnels where trains cause vibration and structure-borne noise nuisance to the occupants of nearby buildings. Some of these tunnels are not big enough to accommodate floating slab track and in some instances operators cannot afford the installation time. Our aim, therefore, was to develop a rail fixing capable of providing similar vibration isolation performance as a floating slab track, so the 'Elastiplus' product was born.

3. ELASTIPLUS DEVELOPMENT

A. Floating Slab Working Principles

In order to develop an alternative to floating slabs we have to first understand the working principle of them. Floating slab track vibration isolation is 3rd level intervention, based on the principle of a concrete slab supported on an elastic medium which can be pads, strips or mats. The noise and vibration performance of this system can be approximated by the mass spring system, where the concrete slab, rail fixation, rail and rolling stock all represent the mass and the resilient mat acts as the spring. The resonant frequency of such a system is calculated as follows:

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \text{ (Hz)}$$

$$\begin{aligned} \text{with} \quad & k = \text{dynamic stiffness of resilient mat (N / mm)} \\ & m = \text{mass} \end{aligned}$$

Since a floating slab is 3rd level isolation the suspended mass *m* is very high which results in a system with a low resonance frequency around 20Hz. From the insertion loss given in figure 1 we can clearly see that a track infrastructure system with a resonance frequency of around 20Hz will have a high attenuation performance in the critical frequency range of 30 – 120 Hz.

Figure 1: Insertion loss for a floating slab track

B. Pre-compression Technique

To develop an alternative system to a floating slab a low resonance frequency is required which can be achieved by either increasing the mass of the system or by using resilient material with a lower dynamic stiffness.

Direct rail fixation is 2nd level isolation which means it is not possible to alter the suspended mass ie. baseplate, rail and rolling stock. A low resonance frequency can only be achieved by decreasing the dynamic stiffness of the resilient material, therefore decreasing the static stiffness (by ~ 5kN/mm) which will increase rail deflection enormously. On the other hand, rail deflection is limited to 4mm to ensure track stability and thus puts a limit on lowering the dynamic stiffness of the resilient material for classical direct fixations. Classical direct rail fixations are limited by track stability, however the Elastiplus fixation precompresses the resilient material in order to deal with this limitation (the working principle of Elastiplus is given in figure 2). The imposed pre-compression gives additional deflection at maximum load of less than 4mm. To benefit from the low dynamical stiffness of the resilient mat and prevent transmission of structure borne noise from the base plate through the springs and into the tunnel invert, it is very important that the compression springs release as quickly as possible during wheel passage.

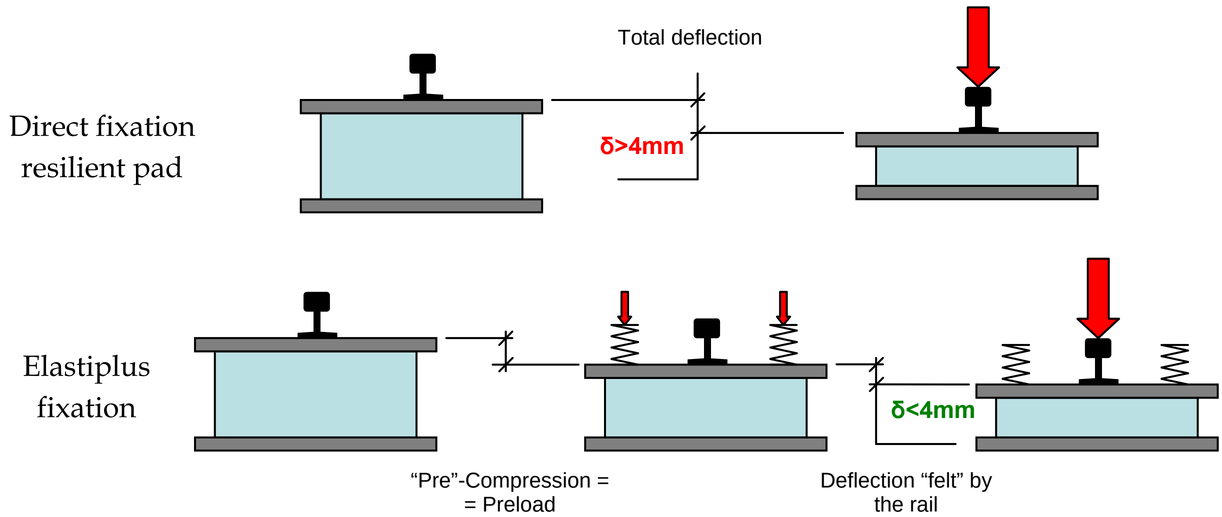
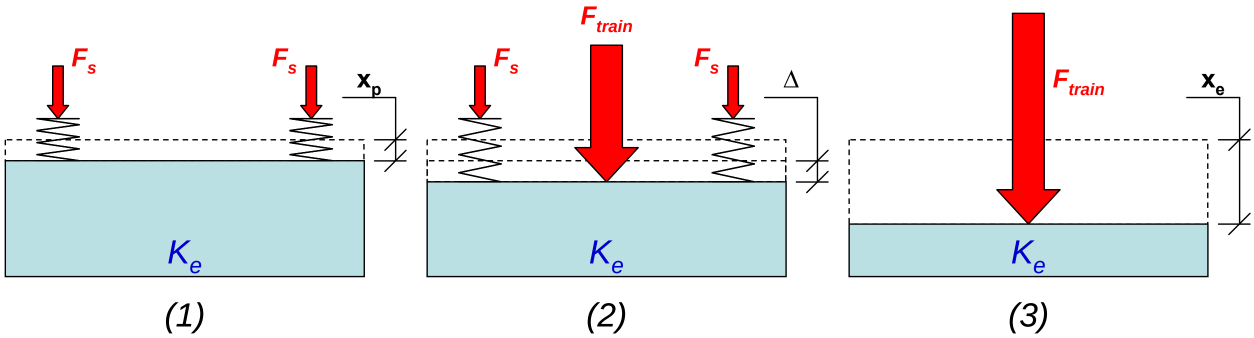


Figure 2: Working principle of the Elastiplus fixation

C. Mathematical Description of System

A mathematical description of the system can be given as follows:



- Situation 1: Precompression (in factory) of the fixation

$$2F_s = F_{precompression}$$

$$2K \cdot x_{s0} = Ke_{(xe)} \cdot x_e = Ke_{(xp)} \cdot x_p$$

$$x_{s0} = \frac{Ke_{(xp)} \cdot x_p}{2K_s} \qquad \text{(Equation 1)}$$

- Situation 2: Loading of the fixation (train passage)

$$2F_s \downarrow + F_{train} \uparrow = F_{precompression} \uparrow$$

$$\boxed{2K_s(x_{s0} - \Delta) + F_{train}^{\Delta} = Ke_{(xp+\Delta)} \cdot (x_p + \Delta)}$$

$$\begin{aligned} F_{train}^{\Delta} &= Ke_{(xp+\Delta)} \cdot (x_p + \Delta) - 2K_s(x_{s0} - \Delta) \\ &= \left(Ke_{(xp+\Delta)} - Ke_{(xp)}\right) \cdot x_p + \left(Ke_{(xp+\Delta)} + 2K_s\right)\Delta \\ &\approx \left(Ke_{(xp)} + 2K_s\right)\Delta \end{aligned} \qquad \text{(Equation 2)}$$

This is true until $\Delta = x_{s0} \Rightarrow F_s = K_s\left(x_{s0} - \Delta\right) = 0$

In this point:

$$\begin{aligned} F_{train} &= Ke_{(xp+xs0)} \cdot (x_p + x_{s0}) \\ &= Ke_{\left(xp+\frac{K\exp\cdot xp}{2Ks}\right)} \cdot \left(x_p + \frac{Ke_{xp} \cdot x_p}{2K_s}\right) \\ &= Ke_{\left(xp(1+\frac{K\exp}{2Ks})\right)} \cdot x_p\left(1 + \frac{Ke_{xp}}{2K_s}\right) \\ &\approx F_{precompression} \end{aligned} \qquad \text{(Equation 3)}$$

$$F_{train} > F_{precompression}$$

- Situation 3: Loading of the fixation, pre-compression springs releases.

$$F_{train} = Ke_{xe} \cdot x_e \qquad \text{(Equation 4)}$$

D. Graphical Description of System

The Elastiplus performance can be easily understood trough the diagram shown in figure 3.

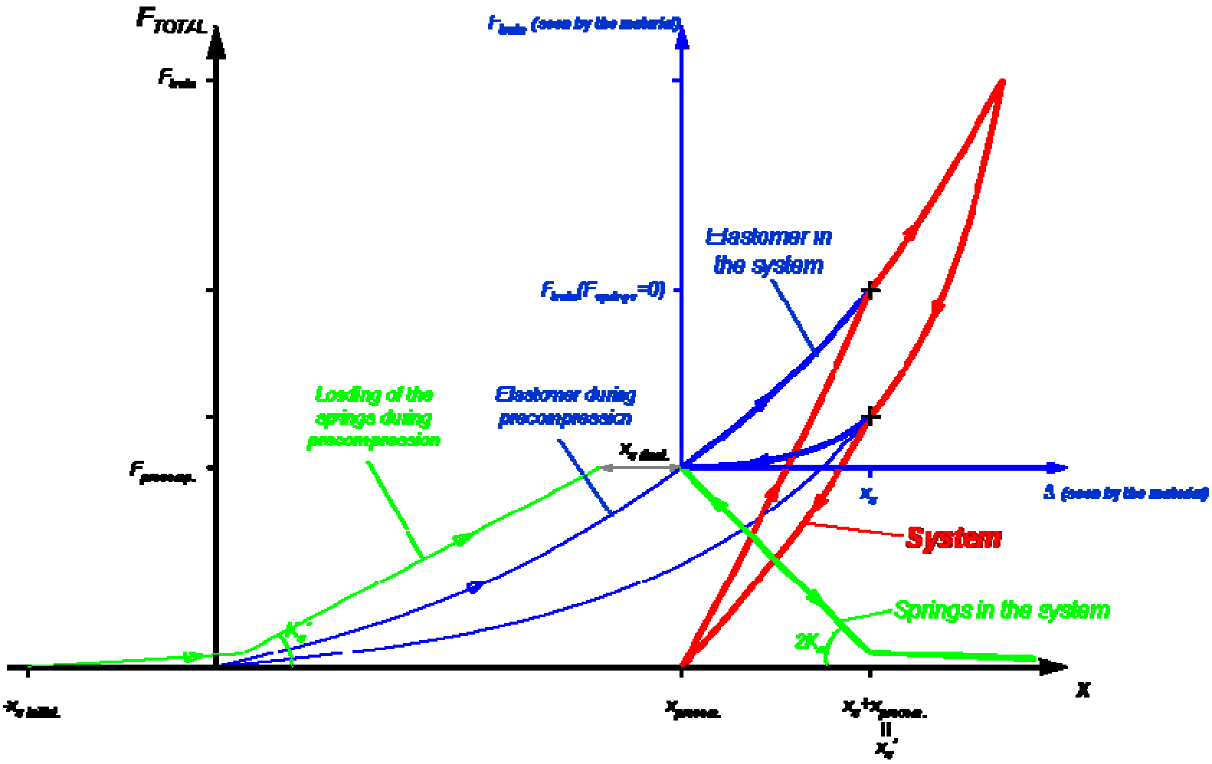


Figure 3: Graphical Elastiplus working concept

The thinner lines represent each of the elements before the pre-compression is reached; the thicker lines represent the separate elements in the system (elastomer in blue; springs in green and the full system in red).

The spring forces the elastomer to stay pre-compressed and as the train approaches the fixation, the spring loses contact with the elastomer as it bears the full load of the train. After the passage the pre-compression springs limit the recovery of the elastomer again.

E. Insertion Loss for Elastiplus System

A calculation of the insertion loss was made for an Elastiplus fixation with a static stiffness of 5kN/mm and compared with the insertion loss obtained by a floating slab track. From the results, depicted in figure 1, we can conclude that the Elastiplus fixation has similar N&V performances as a floating slab track. Therefore we can state that an alternative for floating slab track has been found.

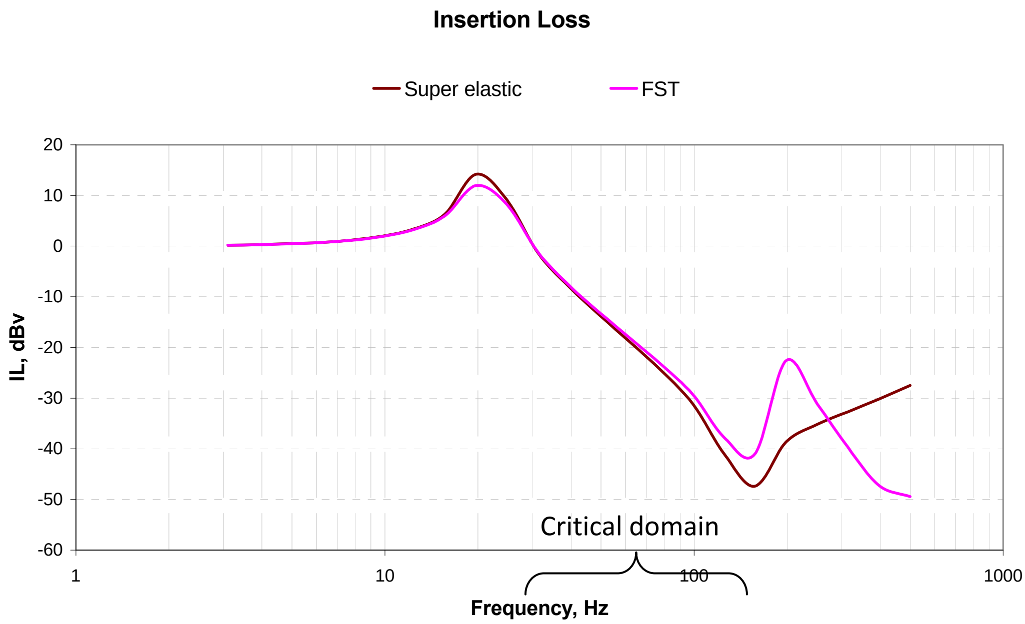


Figure 4: Comparison of insertion loss for a floating slab track and Elastiplus fixation

F: Development of Prototypes

The prototypes of 'Elastiplus' were made to meet the requirements of metro Barcelona where in-situ testing is due later in 2009. Below are 2 of the prototypes made.

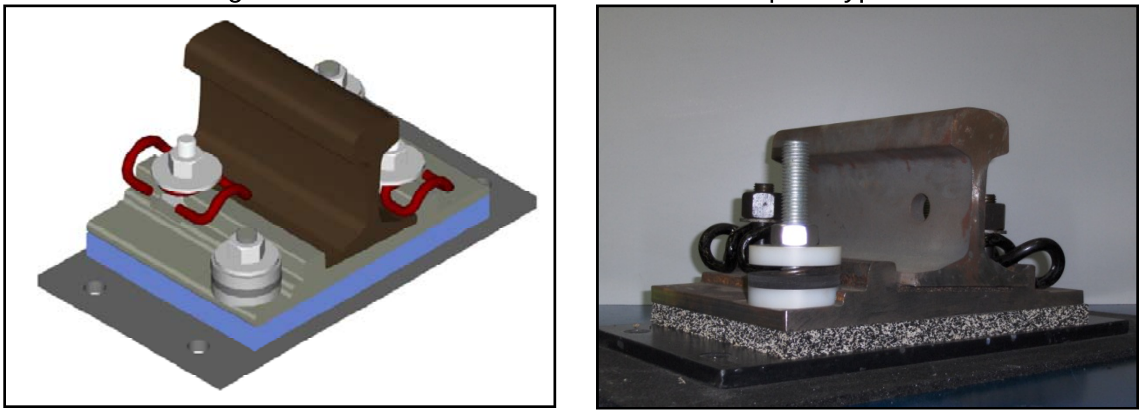


Figure 5: Initial Elastiplus Prototype

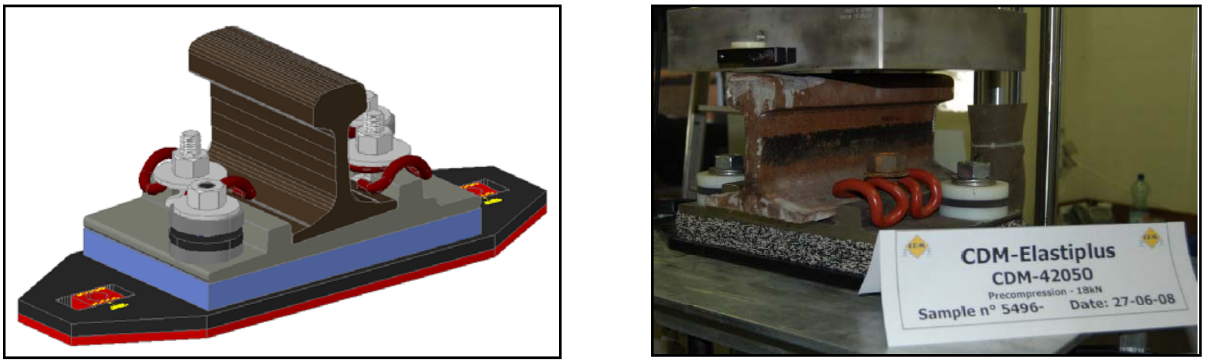


Figure 6: Final Elastiplus Prototype

4. LIFE CYCLE COST

To comply with Urban Track objectives an LCC calculation must be made in order to check if the target of 25% reduction in LCC has been reached.

The reference is a new floating slab track using direct rail fixations compared with a new regular slab track having Super Elastic rail fixations. To get a comparison of LCC in % between the two track systems and their infrastructure, the LCC analysis must cover all the cost elements of both systems. The most important parameters adopted in the LCC calculation are:

- Configuration of line : 100 m of straight single track at grade
- Cost of engineer = 50 €/h, technician = 40 €/h, skilled labor = 30 €/h.
- Floating slab thickness = 0,45 m
- Floating slab width = 2,5 m
- Foundation thickness = 0,2 m
- Slab track thickness = 0,375 m
- Slab track width = 2,5 m
- Cost of concrete : 85 €/m^3
- Cost of resilient mat : 32 €/m^2
- Cost of excavation of 1m3 ground volume : 10 €/m^3
- Cost of direct fixation for use on floating slab : 60 €
- Cost of super elastic fixation : 180 €
- Distance between fixations : 0,9 m
- Rail cost : 120 Euro/m of rail
- Cost of rail grinding : 5 €/m of track
- Rail grinding frequency : once per year
- Rail replacement frequency: once per 20 years
- Cost of removal and disposal : 100 €/m of track
- Life cycle of tracks is 30 years
- Installation of floating slab track takes two times more time than regular slab track with the super elastic fixation
- Socio economic cost are estimated 100 €/m per hour track installation

Figure 7 and the values in Figure 8, show the differences between both compared systems.

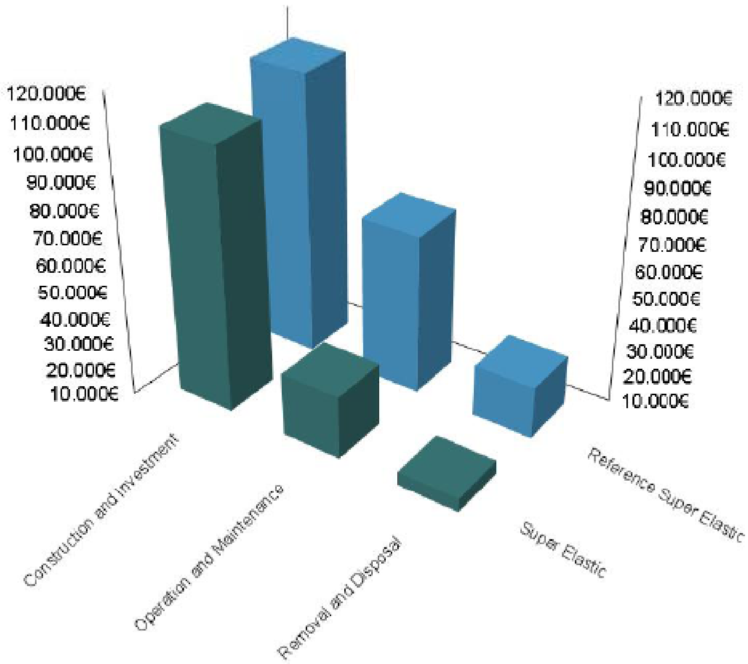


Figure 7: Graphic of total LCC over period under consideration vs. Life Cycle phases

		Phase			Total
		Construction & Investment	Operation & Maintenance	Removal & Disposal	
Candidates	Reference: 100lmst in FST+Direct fixation	115.087 €	69.603 €	29.234 €	213.924 €
	Elastiplus installed in 100lmst	107.374 €	33.698 €	15.043 €	156.115 €
Reduction		7%	52%	49%	27%

Figure 8: Figures for total LCC over period under consideration vs. Life Cycle phases

We can clearly demonstrate that the target has been reached and conclude the main differences between the systems are:

a) At the installation phase the floating slab installation requires a bigger excavation, more concrete for the foundation and slab, installation of a resilient layer – all of which takes a significant amount of time
b) At the removal phase the amount of concrete to be decommissioned, removed and disposed off is significantly reduced using the Elastiplus system
c) The socio economic benefits of the Elastiplus outweigh the direct fixation system due to less disturbance to local occupants because of shorter installation time

A final and more accurate LCC calculation will be made once the system has been installed in workpackage WP 3.8.

5. CONCLUSIONS

The Elastiplus rail fixing is capable of delivering very similar vibration isolation performance to a floating slab track and the system will be tested in metro Barcelona later in 2009 to verify its performance.

If successful a new isolation system will have been developed that allows high levels of vibration isolation to be installed in tunnels where floating slab tracks do not fit, it will also allow retrofitting in much shorter periods of time than a floating slab track.

The system offers significant Life Cycle Cost reductions when compared to a floating slab track.