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Comparison of X–T and X–X co-simulation techniques applied on railway dynamics

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The displacement of heavy vehicles is usually an important factor in the generation of ground-borne vibrations. In the case of railway dynamics the vibrations propagating through the soil may disturb the surrounding environment leading to disturbance or discomfort and even to structural damaging in the buildings surrounding the track. The estimation of the ground-borne vibrations is therefore of high interest either when building a new track or when constructing a building nearby a railway track. In order to assess efficiently the level of vibrations generated by a moving train, a numerical model can be built including a sufficiently comprehensive model of the soil. Since the soil and vehicle are two fundamentally different subsystems, a co-simulation technique coupling two software especially dedicated to each subsystem (one for the vehicle and one for the soil dynamics) is investigated in this paper.

Similar co-simulation studies were already performed in the literature [1, 2] but they usually focus on the vehicle and track dynamics without taking into account a sufficiently accurate model of the soil (for vibration assessment). The model studied in this work, detailed in [3], includes a three-dimensional finite element modeling of the soil (425.000 DOFs, in a finite element software) co-simulating with a two-dimensional vehicle/track model (504 DOFs in a multibody dedicated in-house software). In reality, the whole problem is obviously completely

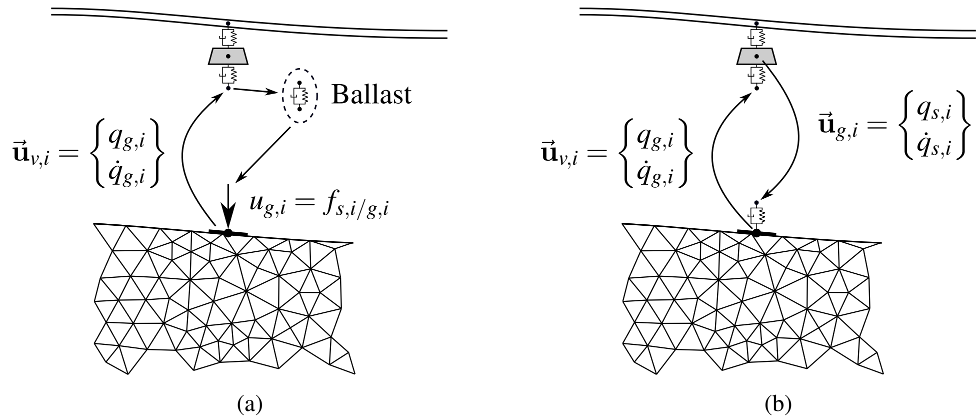

Figure 1: A ballast split for co-simulated vehicle/track/soil model. Focus on coupling element i for X–T (displacement/force) coupling type in Fig. 1a and X–X coupling type (displacement/displacement) in Fig. 1b. Figure 1a from [3].

coupled. However, in order to use the dedicated software for the soil and vehicle subsystems, a choice has to be made regarding the split location and therefore the location of the track (rail-railpads-sleepers-ballast) in these subsystems. Unlike the approaches in [1, 2] that split the system at the wheel/rail contact level, the choice was made to split the system at the ballast level, so that the track is completely included in the vehicle subsystem. As depicted in Fig. 1, two different types of applied-force co-simulation, defining the nature of the exchanged variables between the subsystems, are investigated when splitting the system at the ballast level [4]:

- A displacement/force type (called X–T) depicted in Fig. 1a: the inputs $\vec{\mathbf{u}}_{v,i}$ of the vehicle subsystem are the displacement $q_{g,i}$ and velocity $\dot{q}_{g,i}$ of the soil node i connected to the sleeper i through the ballast (considered as spring-damper elements). The inputs of the soil $u_{g,i}$ are then the forces $f_{s,i/g,i}$ exerted through the ballast on the soil.

- A displacement/displacement type (called X–X) depicted in Fig. 1b: the inputs $\vec{\mathbf{u}}_{v,i}$ of the vehicle subsystem remain unchanged in comparison with the previous X–T type. However, the inputs of the soil $\vec{\mathbf{u}}_{g,i}$ are the displacement $q_{s,i}$ and velocity $\dot{q}_{s,i}$ of the sleepers. In this case, the ballast is included in both subsystems and the force exerted is therefore recomputed in both subsystems as well.

Two different co-simulation approaches, that define the way both subsystems exchange their coupling variables and the order in which they are integrated, are used [5]: a completely parallel method called Jacobi, and a sequential method called Gauß-Seidel that firstly integrates the vehicle subsystem and then the soil subsystem over a macrotimestep. The implementation of those co-simulation methods is non-iterative, explicit and it does not include any extrapolation in the present case. The results obtained for two different homogeneous and elastic soils (E=10 MPa for soft and E=155 MPa for medium) are given through the peak particle velocity in Fig. 2. Generally speaking, the X–X type is always more stable but less accurate than the X–T type. In any case, Jacobi provides less stable and less accurate results than Gauß-Seidel.

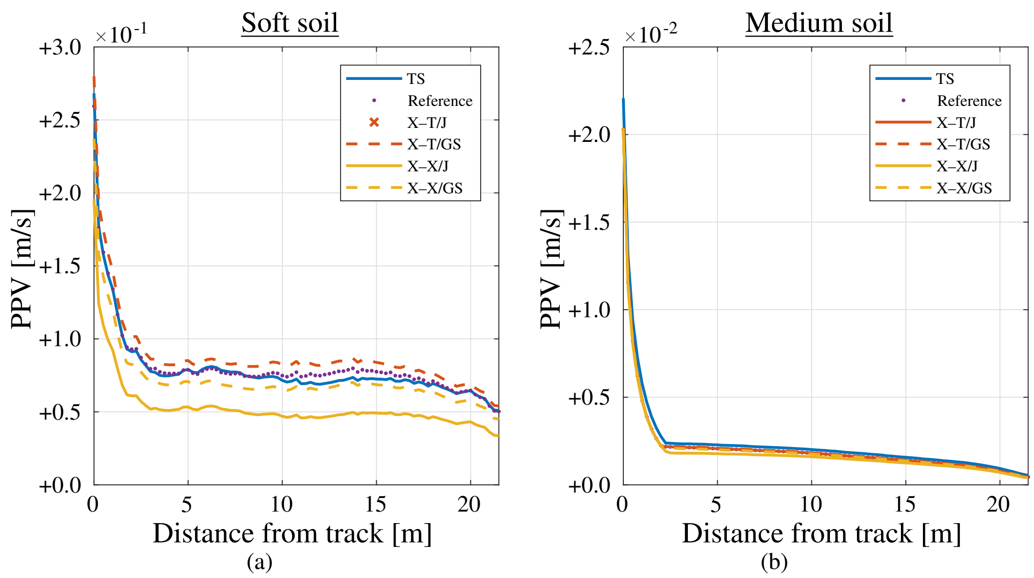

Figure 2: Peak Particle Velocity (PPV) of the soil surface nodes located on a line perpendicular to the track. Results in Fig. 2a are for the soft soil and in Fig. 2b for the medium soil. In both, the reference two-step (TS) model is compared with X–T (red) and X–X (yellow) types for Jacobi (J ——) and Gauß-Seidel (GS - - -) coupling approaches. A cross (×) denotes an unstable integration. Macrotimestep tuned to $H = 10^{-3}$ s and Reference is Gauß-Seidel X–T with $H = 10^{-4}$ s.

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