# Subsystem coupling using co-simulation methods:

## *Coupling of vehicle/track-soil subsystems using an X-T approach*

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**Abstract**

The vibrations generated by the passing of a train sometimes reach important levels such that they can generate discomfort in surrounding buildings. In order to understand this phenomenon, a numerical modeling can be implemented. However, this modeling involves two mechanical parts that differ by their behavior and their mathematical representation: the vehicle and the soil. Both subsystems are linked by the track. To re-couple those subsystems during the time integration, an X-T co-simulation technique will be used such that each subsystem can be integrated using appropriate solvers that are implemented in two different software packages. Finally, the co-simulated model will be compared to an already validated two-step model.

## Introduction

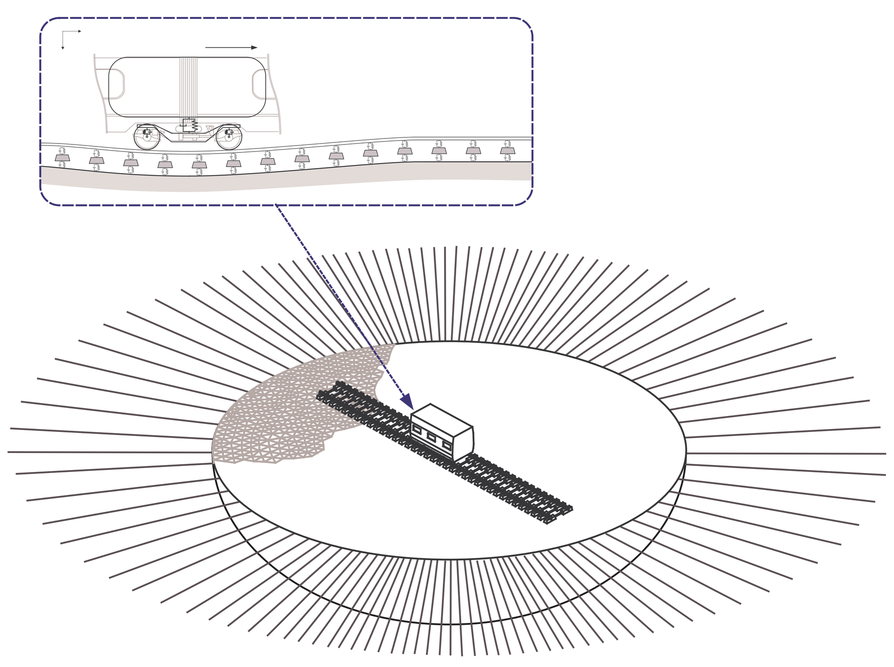

**Figure 1:** Two-step model

Originally, Kouroussis et al. [1] proved that a decoupled integration is sufficient to obtain a sufficiently accurate representation of the level of vibration in the surroundings of a track on which a train is passing. The two-step method (see Figure 1) was:

- **vehicle/track integration** with a coupled lumped mass (CLM) representation of the soil
- **soil integration** using the forces computed in the first step

However, the decoupling shows its limitation if the soil becomes too soft. Therefore, co-simulation will be used between the previously decoupled problem by re-coupling them **during** the integration process.

## 1 Subsystem choice and coupling method

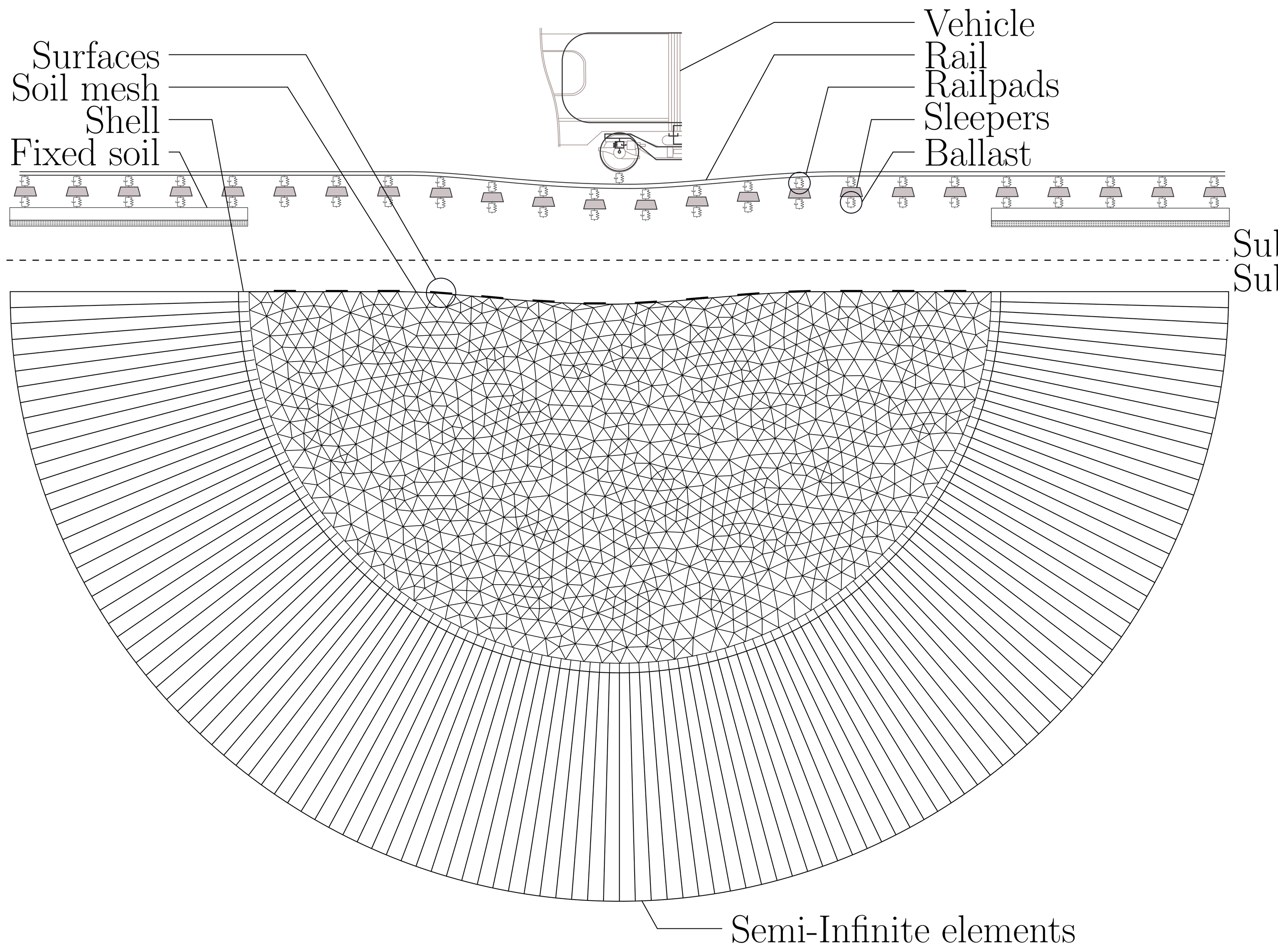


**Figure 2:** Subsystems representation

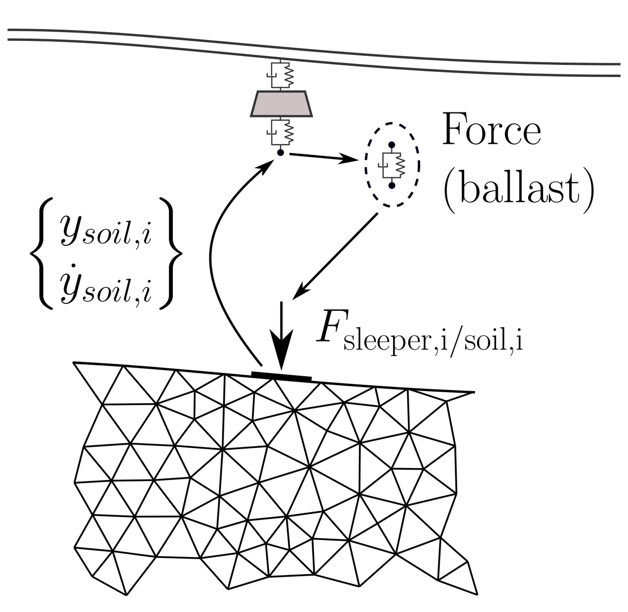


**Figure 3:** X-T Flexible coupling method

The entire model described in Figure 2 is composed of two interacting subsystems:

- **Subsystem 1:** [EasyDyn] vehicle (wheel set) and the track (rail/railpads/sleepers)
- **Subsystem 2:** [ABAQUS] 3D soil (meshed soil kernel/semi-infinite shell)

The coupling **X-T method** that consists of an exchange of a displacement/speed and force is illustrated in Figure 3. This coupling is performed through the **ballast** which is modeled as a flexible element (spring-damper system).

## 2 Investigated co-simulation methods

The co-simulation approaches investigated (see Figure 4) differ by the way both subsystems are integrated and also how the data are exchanged between them:

- **Gauss-Seidel (GS):** purely sequential integration
- **Jacobi (J):** parallel integration

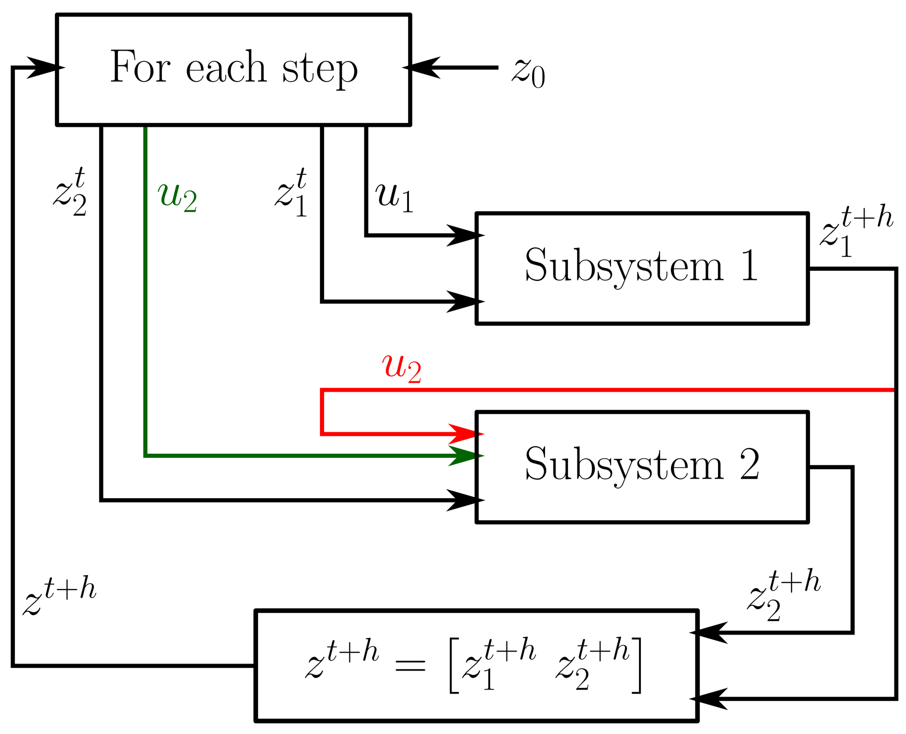


**Figure 4:** Gauss-Seidel scheme (red) - Jacobi scheme (green)

## 3 Results

The results obtained using the co-simulated model are compared with the two-step decoupled model in Figures 5 and 6. $E$ represents the soil elasticity while the exponent of GS and J denotes $log_{10}(H)$ with $H$ the macrotimestep (data exchange timestep).

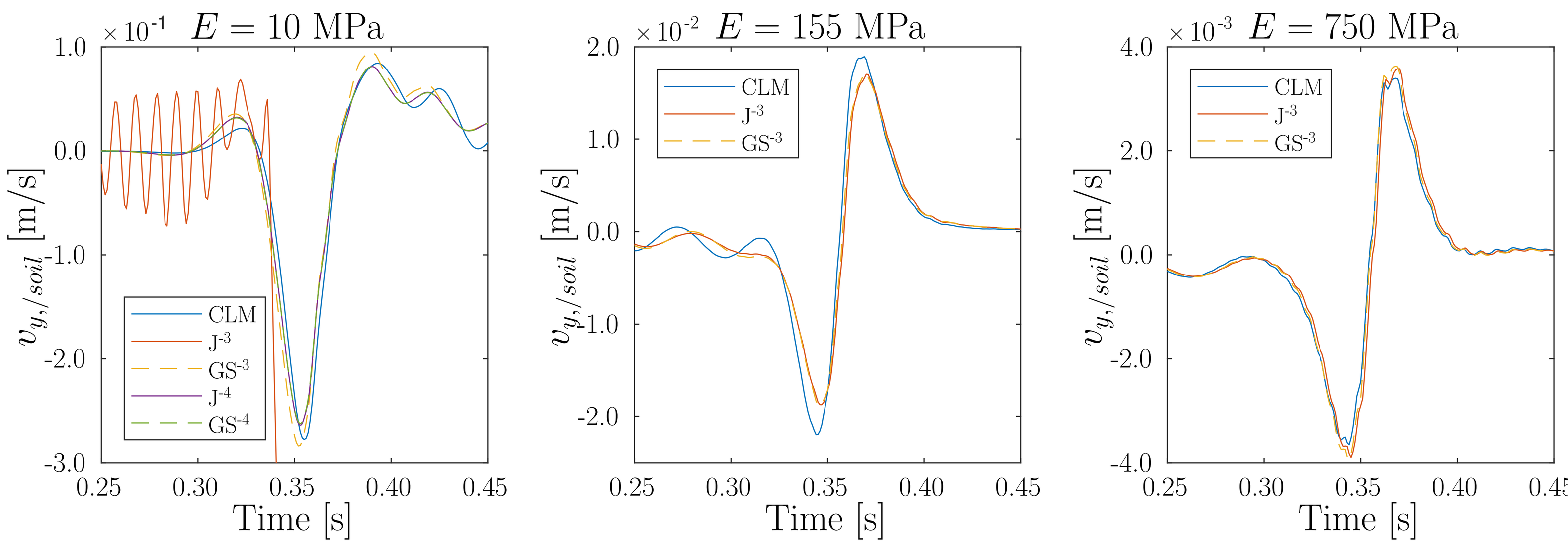


**Figure 5:** Time history of the vertical velocity of the middle sleeper print on soil

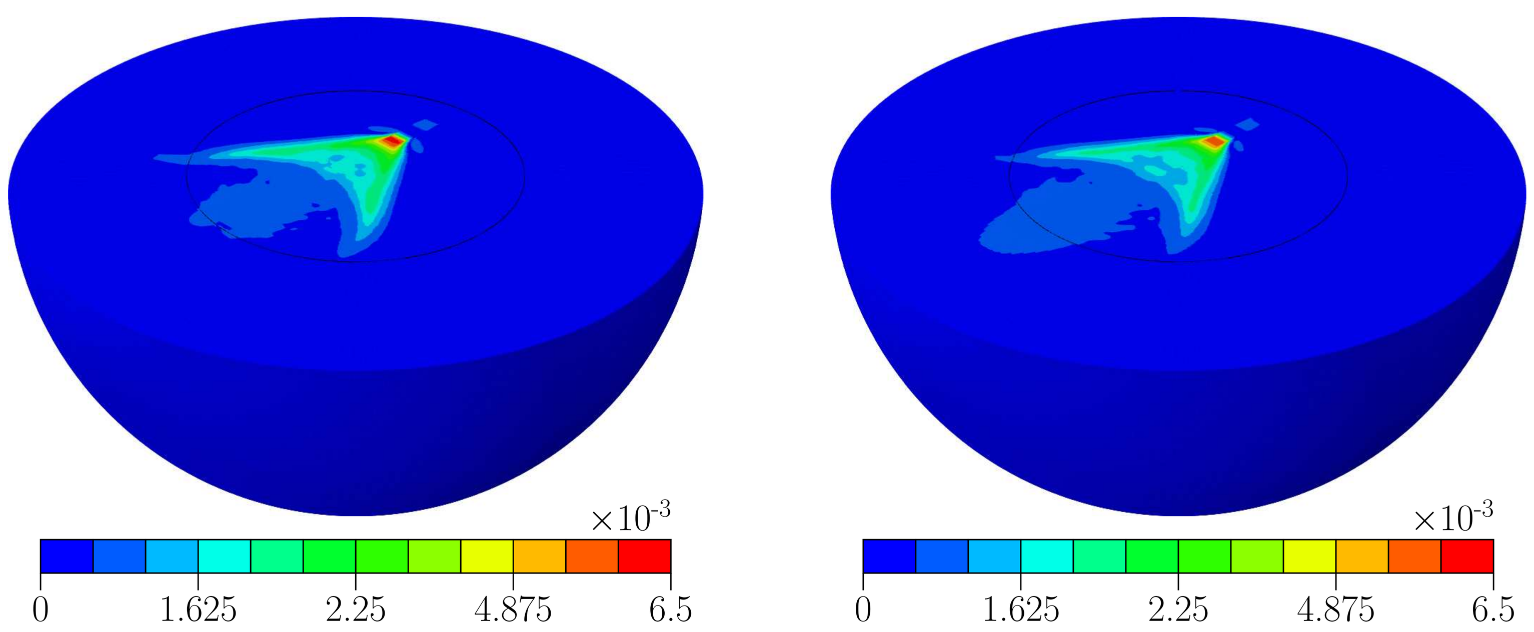


**Figure 6:** Comparison of Gauss-Seidel (left) and two-step (right) models in terms of soil displacement magnitude

## 4 Conclusions

- **Convergence** to the same solution is obtained due to the zero-stable characteristics of the numerical schemes [2]).
- **Gauss-Seidel** provides more accurate and more stable results than **Jacobi** for a same macrotimestep.
- The stiffer the soil, **the closer the results** are between the co-simulated and the two-step models.

## References

[1] G. Kouroussis and O. Verlinden. Prediction of railway induced ground vibration through multibody and finite element modelling. *Mechanical Sciences*, 4(1):167–183, 2013.

[2] B. Olivier, O. Verlinden, and G. Kouroussis. Stability and error analysis of applied-force co-simulation methods using mixed one-step integration schemes. In *IUTAM Symposium on co-simulation and solver coupling*, Darmstadt (Germany), 2017.

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