AD FALCON API Manual

Comparison of 1D Wave Propagation in an Unsaturated Soil Column (Fully-Coupled)

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fem_data_1d_unsat_dyn.txt

1.1 Problem Description

This study investigates wave propagation in a one-dimensional unsaturated elastic column using a fully-coupled hydro-mechanical formulation.
- **Column height**: 10 m
- **Boundary conditions**
- Bottom: Restrained
- Sides: Restrained
- Top: Drained and subjected to an instantaneous pressure step of 1 Pa.
- **Initial degree of saturation**: variable (see "Observed Results")
- **Poisson's ratio**: 0.02 (to mimic 1-D behaviour)

The same element mesh, time-stepping scheme, and solver tolerances as the saturated benchmark are retained.

1.2 Material Properties

1.2.1 Mechanical (UMAT)

Property	Symbol	Value
Young's modulus	E	$2\,937\,600$ kPa
Poisson's ratio	ν	0.02

1.2.2 Soil–Water Retention Curve (SWRC) – Brooks & Corey

Parameter	Symbol	Value
Air-entry suction	ψ_b	50 kPa
Pore-size distribution index	λ	1.5
Void-ratio impact factor	Ω'	0.0
Max. saturation	$S_{w,\max}$	1.0
Residual saturation	$S_{w,\min}$	0.0

1.2.3 Effective Stress – Ghorbani & Kodikara (2024)

$$\sigma' = \sigma - S_w^{\left(\frac{\beta_1}{S_w^{\beta_2}}\right)} p_w I - \left(1 - S_w^{\left(\frac{\beta_1}{S_w^{\beta_2}}\right)}\right) p_a I, (1)$$

with $\beta_1 = 1.0, \beta_2 = 0.0$ per the analytical solution proposed by Li and Schanz (2011).

1.2.4 Permeability

- **Saturated permeability**: $k_{\text{sat}} = 2.5 \times 10^{-12}\,\text{m}^2$
- **Relative-permeability model**: Brooks & Corey, $\lambda = 1.5$
- **Anisotropic vector**: $[1\ 1\ 1\ 0\ 0\ 0]$ which indicates isotropic permeabilities.

1.2.5 Phase Characteristics

Phase	Density ($\text{kg}\,\text{m}^{-3}$)	Bulk modulus (kPa)	Dynamic viscosity (Pa s)
Solid	2700	–	–
Liquid	997	$K_l = 2.25 \times 10^6$	1.0×10^{-6}
Gas	1.1	$K_g = 1.1 \times 10^2$	1.8×10^{-8}

1.3 Numerical Approach

- **Framework**: Three-phase, fully-coupled finite-element formulation (solid–water–air).
- **Time integration**: Newmark-β ($\gamma = 0.5$, $\beta = 0.25$) for dynamics. ***

1.4 Comparison with Li & Schanz (2011)

> Reference: Li, P. & Schanz, M. (2011). *Wave propagation in a 1-D partially saturated poroelastic column. Geophysical Journal International*, 184(3), 1341–1353.

Benchmarked against the semi-analytical solution for partially saturated columns. **Note**: The analytical solution shown in the plots corresponds to the first peak of the wave response as reported in Li & Schanz (2011).

1.5 Observed Results

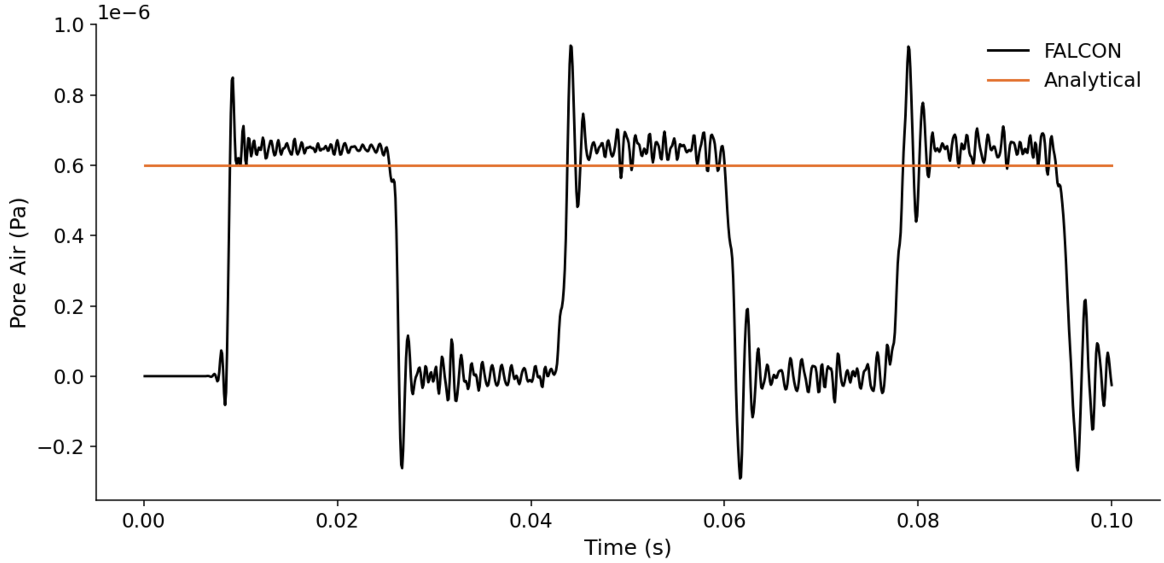

Figure 1: Gas Pressure Sw0.5

Case	Initial S_w	Remark
A	0.50	Toward dry side
B	0.90	Near-saturated
C	1.00	Fully saturated

1.6 Figures for $S_w = 0.5$ and $S_w = 0.9$

Figure 1 – Gas Pressure $p^g(y = 0)$ **for** $S_w = 0.5$

Figure 2 – Pore Water Pressure $p^w(y = 0)$ **for** $S_w = 0.5$

Figure 3 – Displacement $u(y = 10\,\text{m})$ **for** $S_w = 0.5$

Figure 4 – Gas Pressure $p^g(y = 0)$ **for** $S_w = 0.9$

Figure 5 – Pore Water Pressure $p^w(y = 0)$ **for** $S_w = 0.9$

Figure 6 – Displacement $u(y = 10\,\text{m})$ **for** $S_w = 0.9$

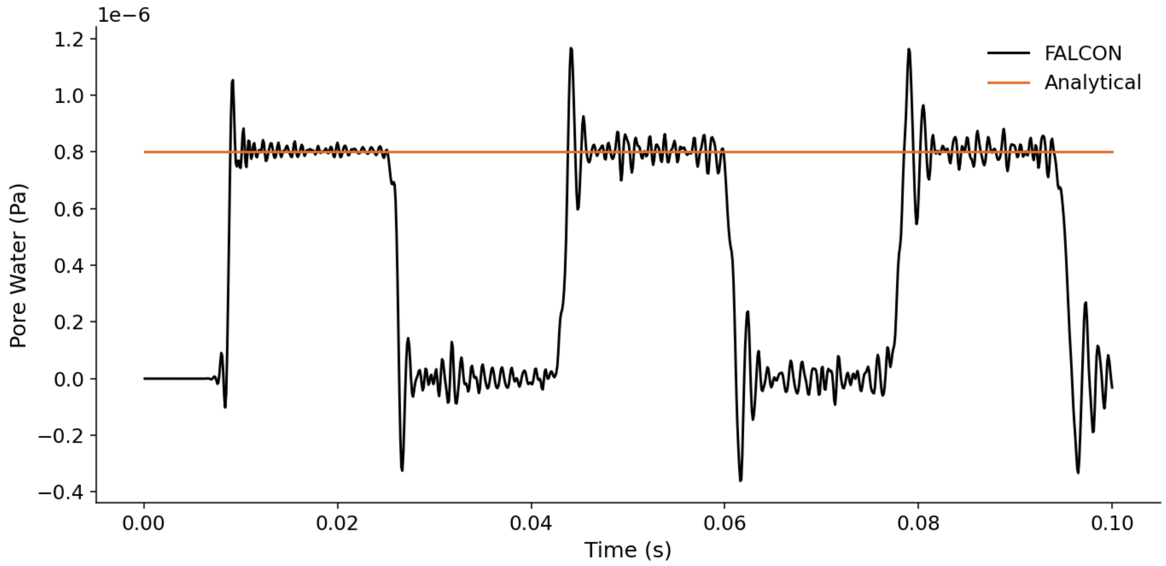

Figure 2: Pore Water Pressure Sw0.5

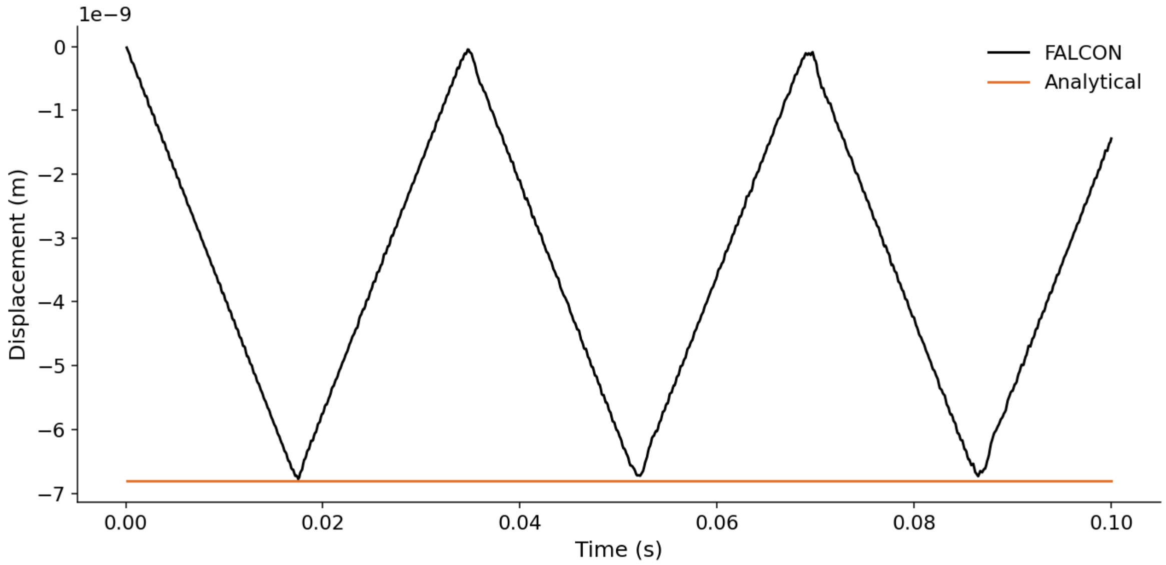

Figure 3: Displacement Sw0.5

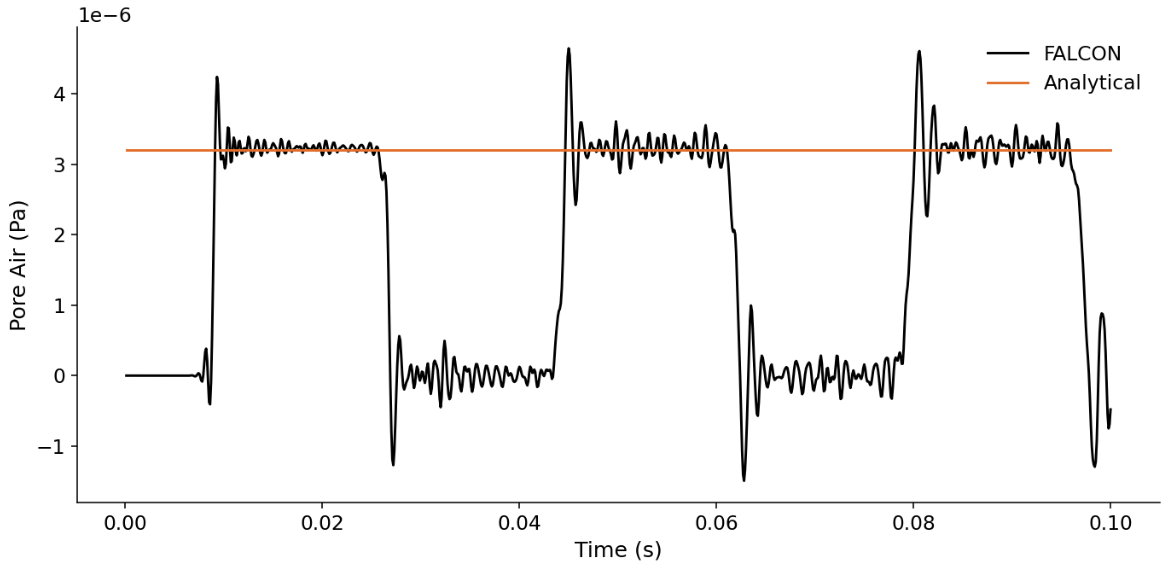

Figure 4: Gas Pressure Sw0.9

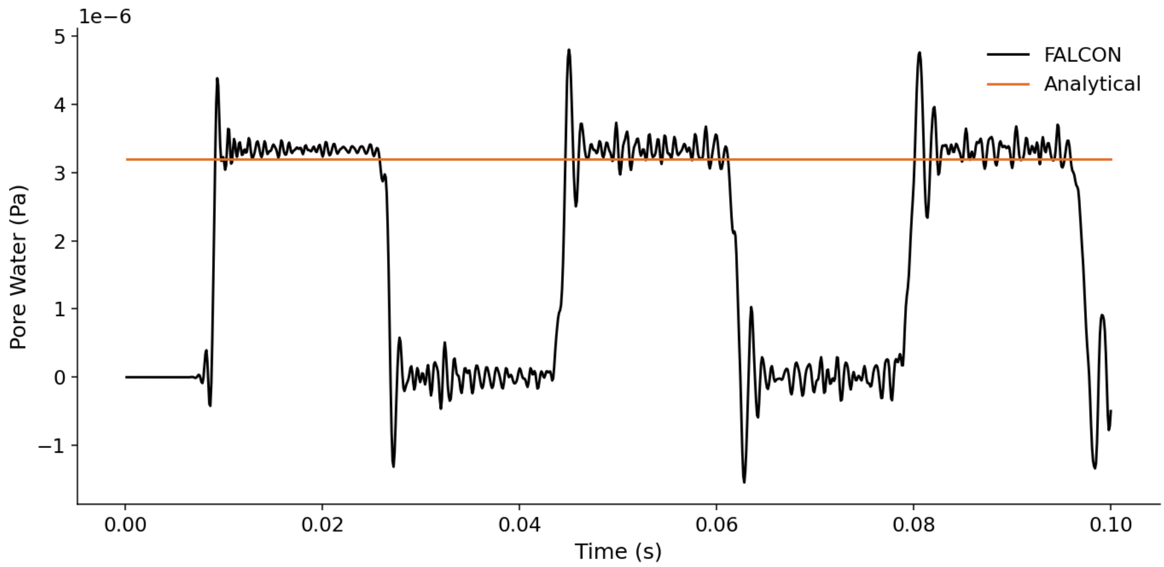

Figure 5: Pore Water Pressure Sw0.9

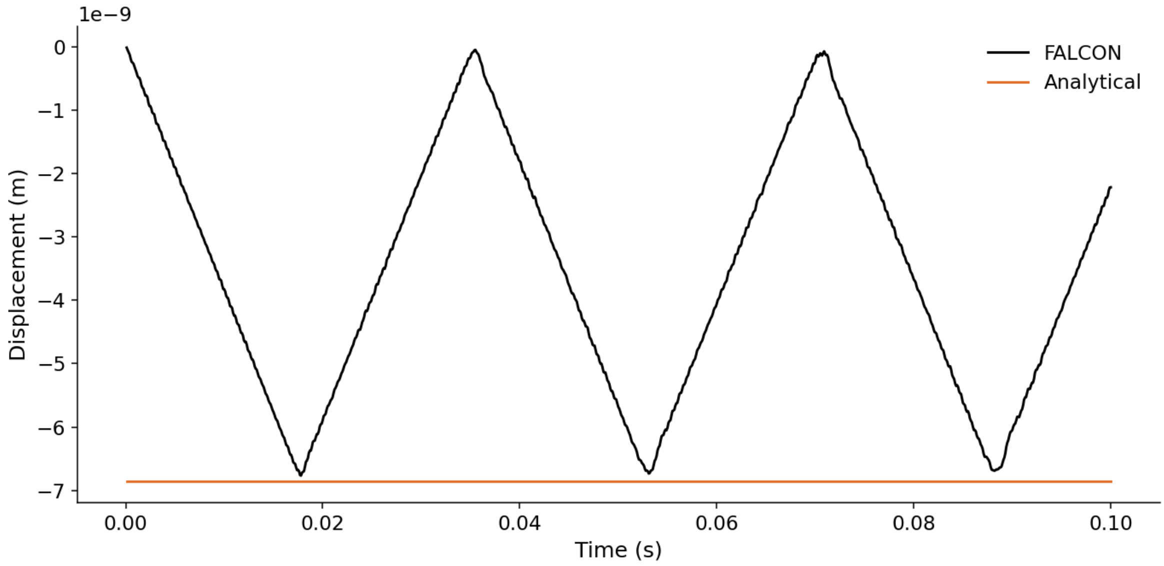

Figure 6: Displacement Sw0.9

1.7 Figures for Full Saturation $S_w = 1.0$

Figure 7 – Pore Water Pressure $p^w(y = 0)$ for $S_w = 1.0$

Figure 8 – Displacement $u(y = 10\,\mathrm{m})$ for $S_w = 1.0$

1.8 New Analysis: Fully Coupled vs. Coupled Solution

In this new analysis, we directly compare the dynamic response of the soil column when using a fully-coupled model with the degree of saturation fixed at 1.0 against the previous coupled approach that incorporates only water and soil. A distinct advantage of using the effective-stress formulation is its ability to recover Terzaghi's effective stress in fully saturated conditions, and we also demonstrate that the overall system of equations converges to the same solution as the fully coupled dynamic model. Specifically, we examine:

Figure 9 – Comparison of Pore Water Pressure $p^w(y = 0)$

Figure 10 – Comparison of Displacement $u(y = 10\,\mathrm{m})$

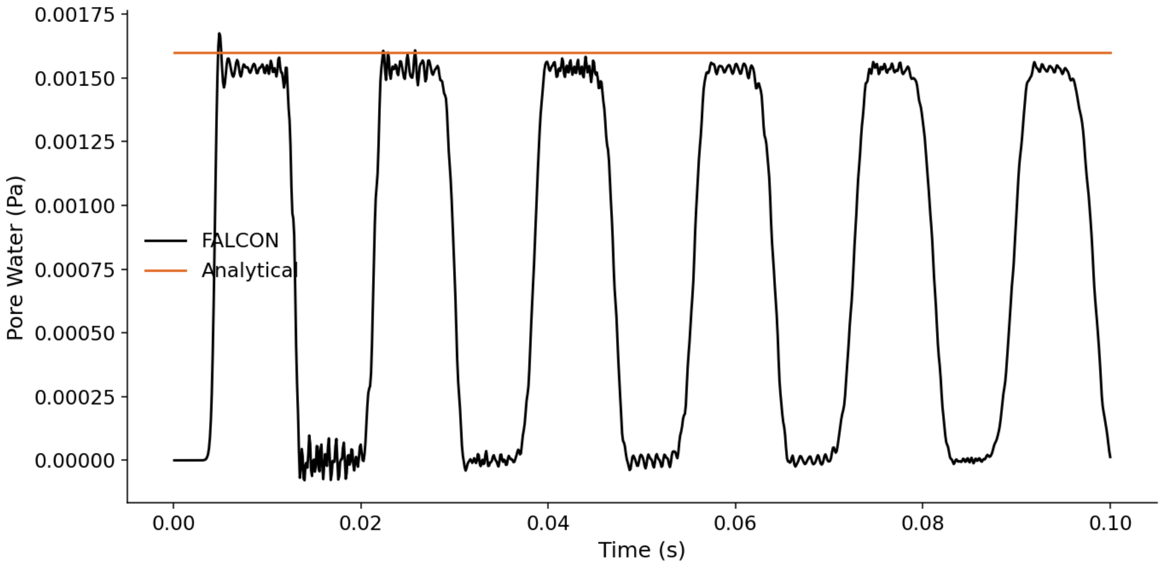

Figure 7: Pore Water Pressure Sw1.0

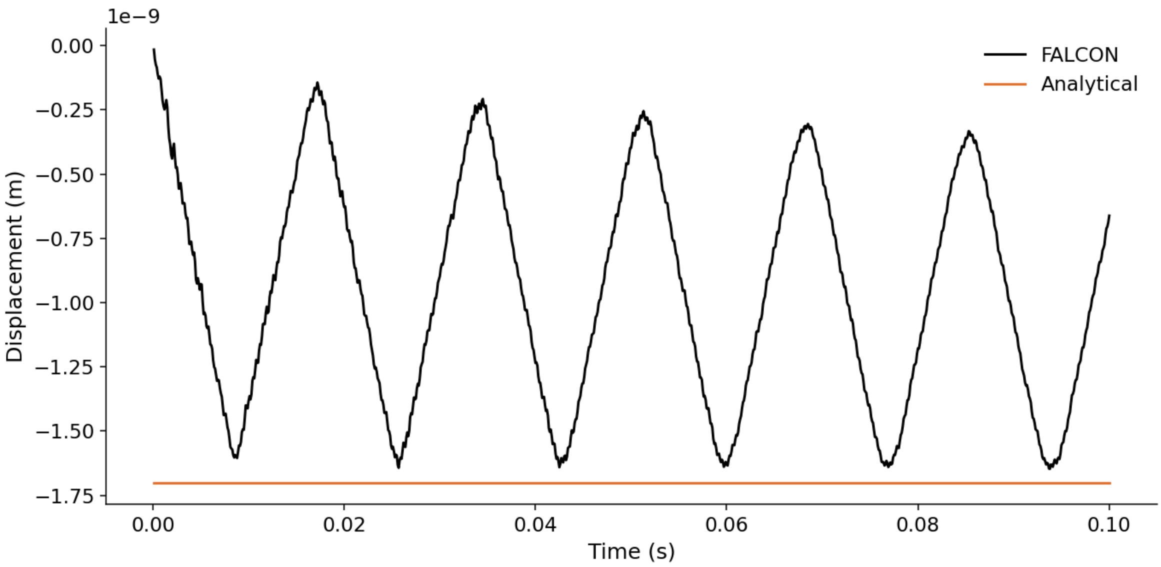

Figure 8: Displacement Sw1.0

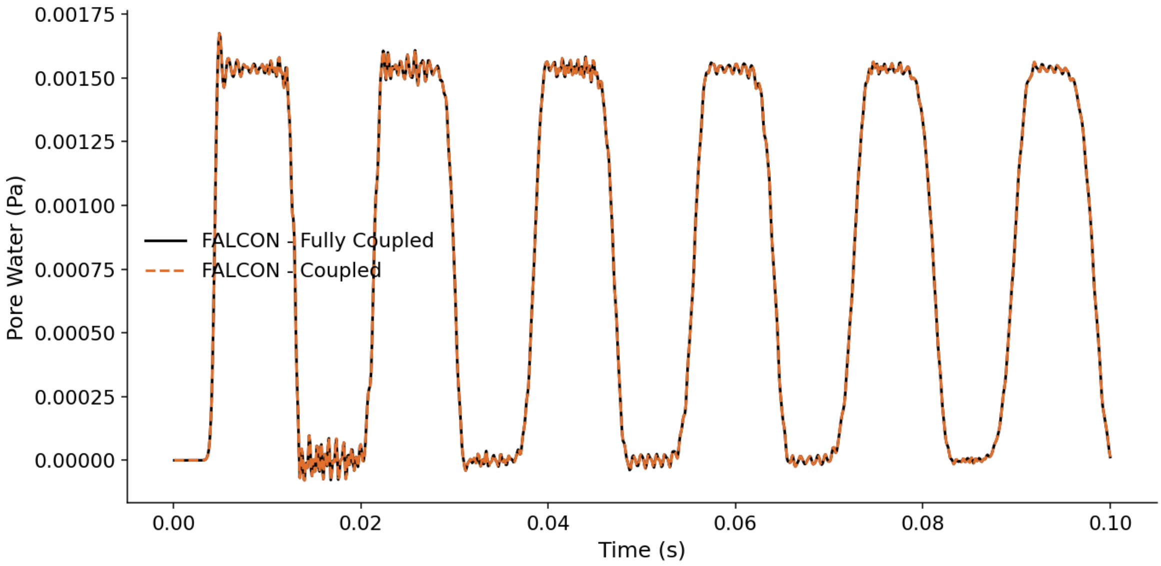

Figure 9: Comparison Pore Water

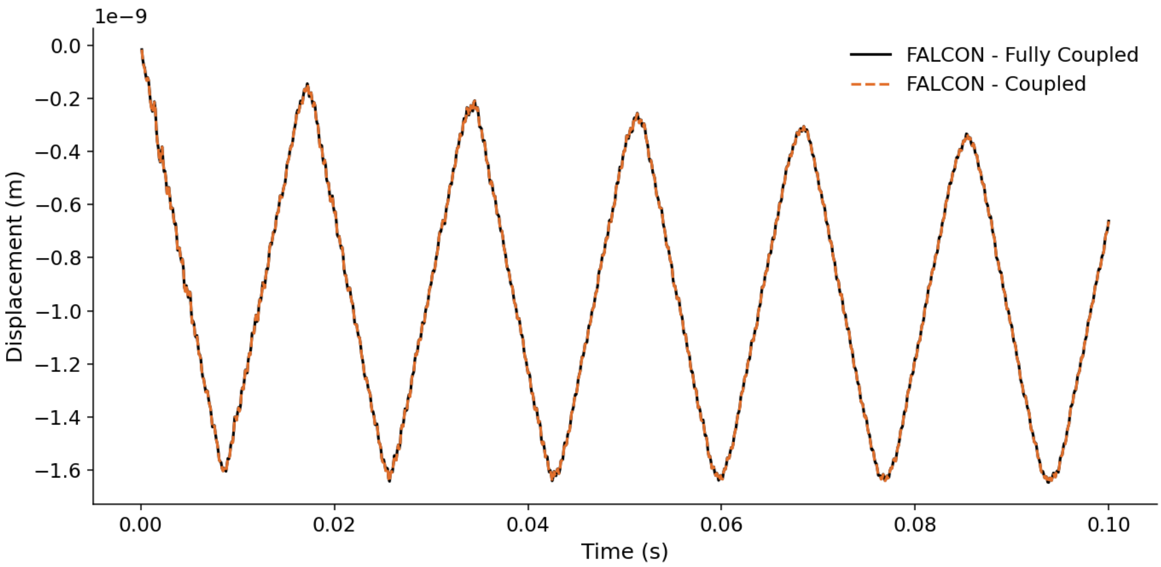

Figure 10: Comparison Displacement