

LEAP-Asia-2018 Numerical Simulation Exercise – Phase II

Type-C simulation report

Gianluca Fasano, Anna Chiaradonna, Emilio Bilotta
University of Napoli Federico II

February, 2019

Table of Contents

Introduction	3
Analysis Platform	3
Model Geometry/Mesh and Boundary Conditions.....	3
Solution Algorithm and Assumptions	4
Material Properties and Constitutive Model Parameters	5
State of Stresses and Internal Variables of the Constitutive Model in the Pre -shaking Stage	5
Results of the Dynamic Analysis.....	6
Simulation Results	6
References	6
Appendix A: Results of the simulation KyU_A_A2_1 (Model A).....	7
Appendix B: Results of the simulation RPI_A_A1_1 (Model A).....	9
Appendix C: Results of the simulation UCD_A_A2_1 (Model A).....	11
Appendix D: Results of the simulation KyU_A_B2_1 (Model B)	13
Appendix E: Results of the simulation RPI_A_B1_1 (Model B)	15

Introduction

This document presents Type-C predictions of the centrifuge experiments for the phase II of the LEAP-Asia-2018 simulation exercise. This report contains details of the numerical modeling technique to accompany the numerical simulation results.

This report discusses the main features of the numerical analysis platform used in the simulation, the model geometry and the discretization details, the boundary conditions of the numerical model, the solution algorithm employed and some assumptions used in the reported analyses. As required, it is written in sufficient details to enable a knowledgeable and experienced independent modeler to produce the same results as those submitted.

Analysis Platform

The simulations are carried out by using PLAXIS (Brinkgreve et al., 2016) as the analysis platform. PLAXIS is a 2D commercial Finite Element Method (FEM) code that includes several constitutive models. Among them, the PM4Sand model (Boulanger and Ziotopoulou 2015) has been adopted as constitutive model in the simulation exercise.

The main reason to use PLAXIS rather than other platforms where such a constitutive model is implemented, is that this numerical code, although not specifically oriented to solve boundary value problems in earthquake geotechnical engineering, is quite well widespread in the community of geotechnical practitioners. Hence it was for this team interesting to check the possible benefit of a rigorous validation of numerical simulation procedures implemented in PLAXIS through experimental data, in order to apply those procedures to a boundary value problem involving soil liquefaction.

Model Geometry/Mesh and Boundary Conditions

Figure 1 shows the mesh density and the boundary conditions. The mesh consists of 443 15-noded triangular elements. The nodes located at the base are fully constrained in x and y direction, while the nodes on the side walls are constrained laterally. The nodes on the ground surface allow full drainage from the base to the top of the scheme.

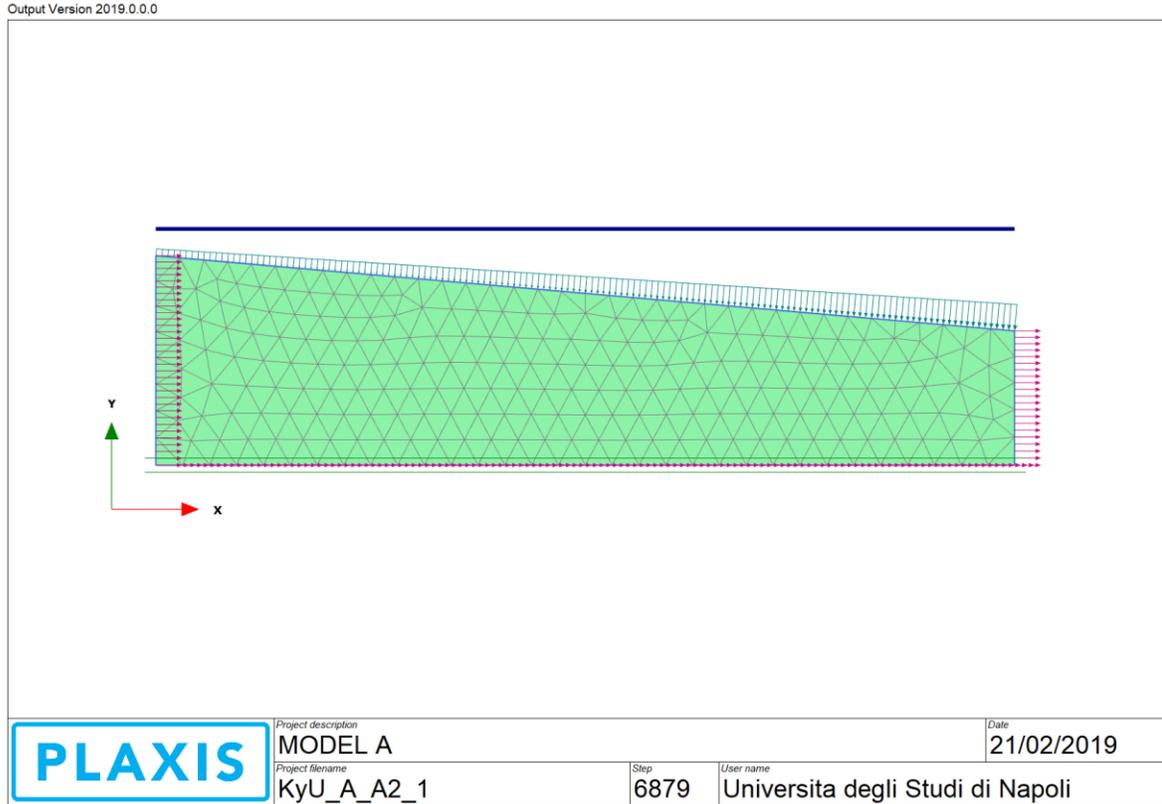


Figure 1: Sample Finite Element Model

Solution Algorithm and Assumptions

The Newmark time integration scheme is used in the simulations where the time step is constant and equal to the critical time step during the whole analysis. The proper critical time step for dynamic analyses is estimated in order to accurately model wave propagation and reduce error due to integration of time history functions. First, the material properties and the element size are taken into account to estimate the time step and then the time step is adjusted based on the time history functions used in the calculation. During each calculation step, the PLAXIS calculation kernel performs a series of iterations to reduce the out-of-balance errors in the solution. To terminate this iterative procedure when the errors are acceptable, it is necessary to establish the out-of-equilibrium errors at any stage during the iterative process automatically. Two separate error indicators are used for this purpose, based on the measure of either the global equilibrium error or the local error. The “global error” is related to the sum of the magnitudes of the out-of-balance nodal forces. The term 'out-of-balance nodal forces' refers to the difference between the external loads and the forces that are in equilibrium with the current stresses. Such a difference is made non-dimensional dividing it by the sum of the magnitudes of loads over all nodes of all elements. The “local error” is related to a norm of the difference between the equilibrium stress tensor and the constitutive stress tensor. It is made non-dimensional dividing by the maximum value of the shear stress as defined by the failure criterion. The values of both indicators must be below a tolerated error set to 0.01 for the iterative procedure to terminate. In general, the solution procedure restricts the number of

iterations that take place to 60, in order to ensure that computer time does not become too high.

A full Rayleigh damping formulation has been considered in the simulation and the coefficient α_{RAY} and β_{RAY} are equal to 0.02513 and $6.366 \cdot 10^{-3}$, respectively.

The soil properties are not changed during the simulations.

Material Properties and Constitutive Model Parameters

The constitutive model used in the simulation exercise is the PM4Sand model (Boulanger and Ziotopoulou 2015). Full description of the model and calibration process can be in the *model calibration report* of the LEAP-Asia-2018 simulation exercise.

Table 1 shows the list of model parameters used in the five simulations (A and B models). The model parameters are the same obtained from the calibration Phase I, some of them are just updated to take into account for the different relative density used in the experiments.

Table 1: Parameters of the constitutive model

Initial relative density	UCD_A_A2_1	RPI_A_A1_1	KyU_A_A2_1	KyU_A_B2_1	RPI-A_B1_1
Model parameters					
Dr	0.6	0.61	0.56	0.58	0.62
G₀	803	740	690	708	750
hp₀	0.05	0.05	0.05	0.05	0.05
p_A	101.3	101.3	101.3	101.3	101.3
e_{max}	0.78	0.78	0.78	0.78	0.78
e_{min}	0.51	0.51	0.51	0.51	0.51
n_b	0.5	0.5	0.5	0.5	0.5
n_d	0.1	0.1	0.1	0.1	0.1
φ_{cv}	32	32	32	32	32
v	0.3	0.3	0.3	0.3	0.3
Q	10	10	10	10	10
R	1	1	1	1	1
PostShake	0.6	0.61	0.56	0.58	0.62

State of Stresses and Internal Variables of the Constitutive Model in the Pre-shaking Stage

All the centrifuge models are subjected to centrifugal accelerations that are increased from 1g to a designated value during the spin-up process. The soil specimen is subjected to an increasing centrifugal acceleration that affects the state of stresses and the subsequent seismic response, consequently, the initial state of stresses and internal variables of the constitutive model after the centrifuge spin-up and just before the start of shaking is a critical

aspect of the numerical simulation.

The numerical simulation report describes the state of the model before the beginning of the seismic analysis. This includes spatial distributions of all stress components (e.g., vertical, horizontal, and shear stresses) as well as the key internal variables of the constitutive model in form of contour plots.

Results of the Dynamic Analysis

The results of seismic analysis stage are also presented in the report. The reported results include:

1. Time histories of predicted vs. measured horizontal and vertical acceleration;
2. Time histories of predicted vs. measured pore water pressure;
3. Time histories of predicted vs. measured lateral displacement;

Simulation Results

The results of the Type-C simulations of Model A and Model B tests are reported in separate Excel files with the required format.

With reference to the experiments UCD_A_A2_1 and KyU_A_B2_1, the comparison between the simulated and measured time histories seems to indicate that there is an inversion in the sign of the measured accelerations (see Appendix C and D).

Excluding this, the numerical simulations provided a fairly good prediction the accelerations measured in all the tests. Underestimation of pore water pressure and lateral displacements is generally provided by the numerical analyses.

References

- Boulanger, R.W. and Ziotopoulou K. (2015). PM4Sand (Version 3): A sand plasticity model for earthquake engineering applications, Report No. UCD/CGM-15/01. Technical report, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering College of Engineering, University of California at Davis.
- Brinkgreve, R.B.J. Kumaeswamy, S. and Swolfs, W.M. (2016). PLAXIS 2016 User's manual. Retrieved from PLAXIS Website: <https://www.plaxis.com/kb-tag/manuals/>

Appendix A: Results of the simulation KyU_A_A2_1 (Model A)

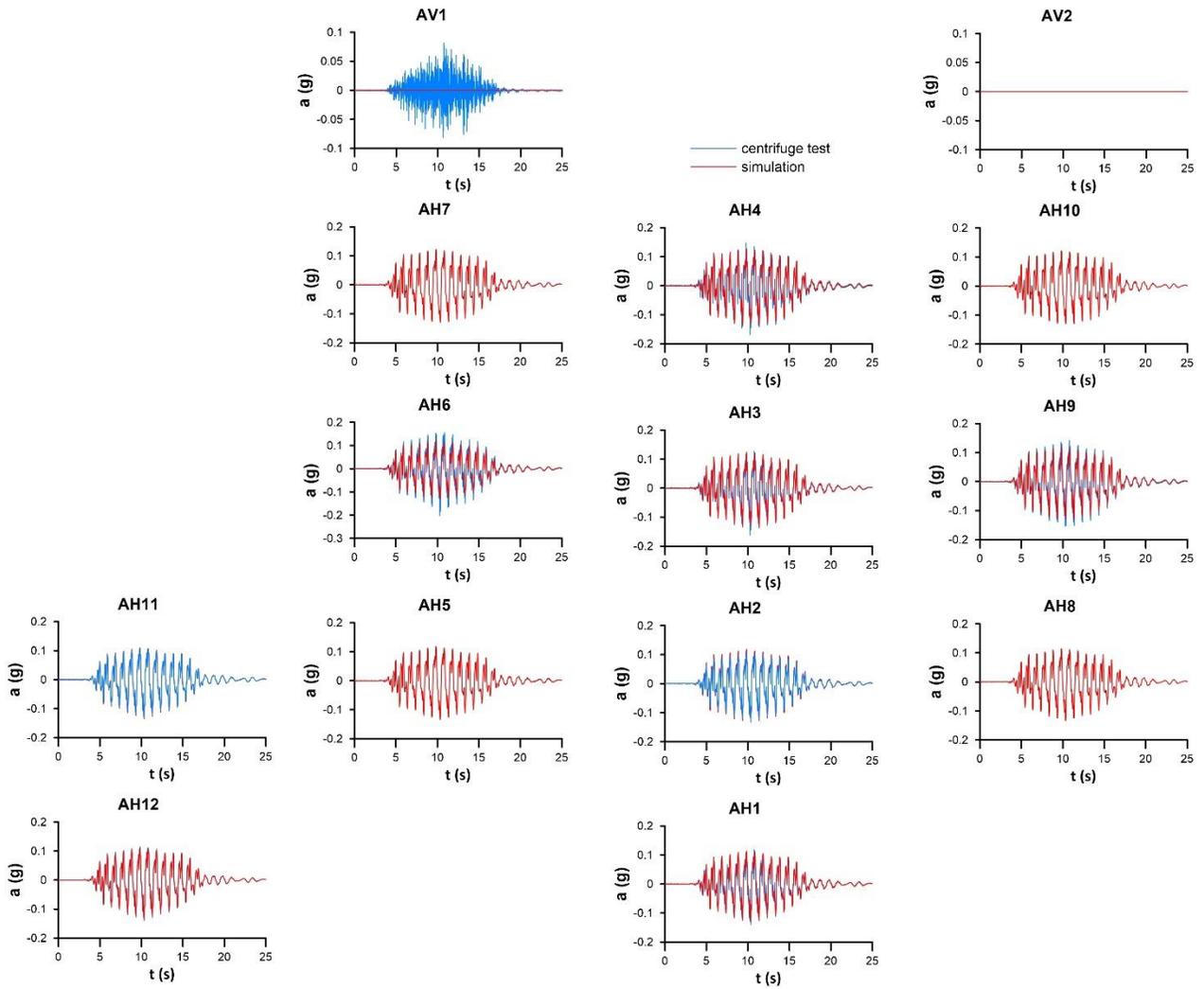


Figure 2: Predicted vs. measured acceleration time histories

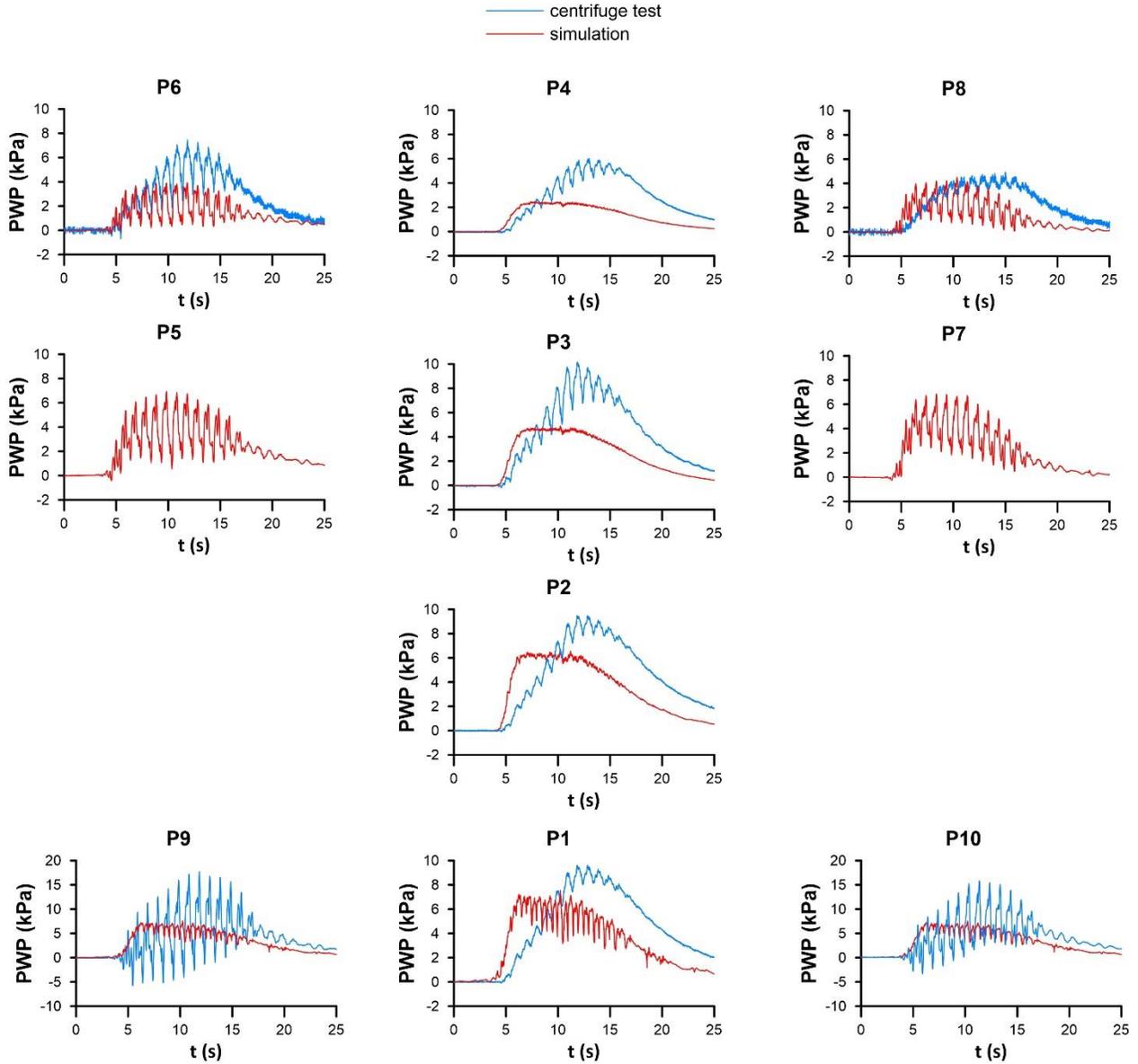


Figure 3: Predicted vs. measured pore pressure time histories

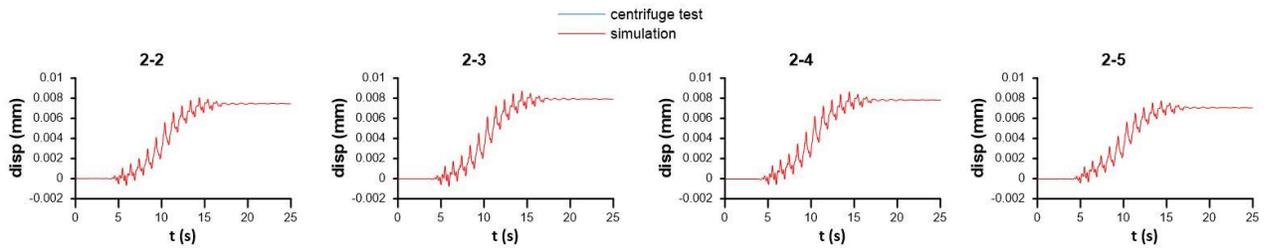


Figure 4: Predicted vs. measured lateral displacement time histories

Appendix B: Results of the simulation RPI_A_A1_1 (Model A)

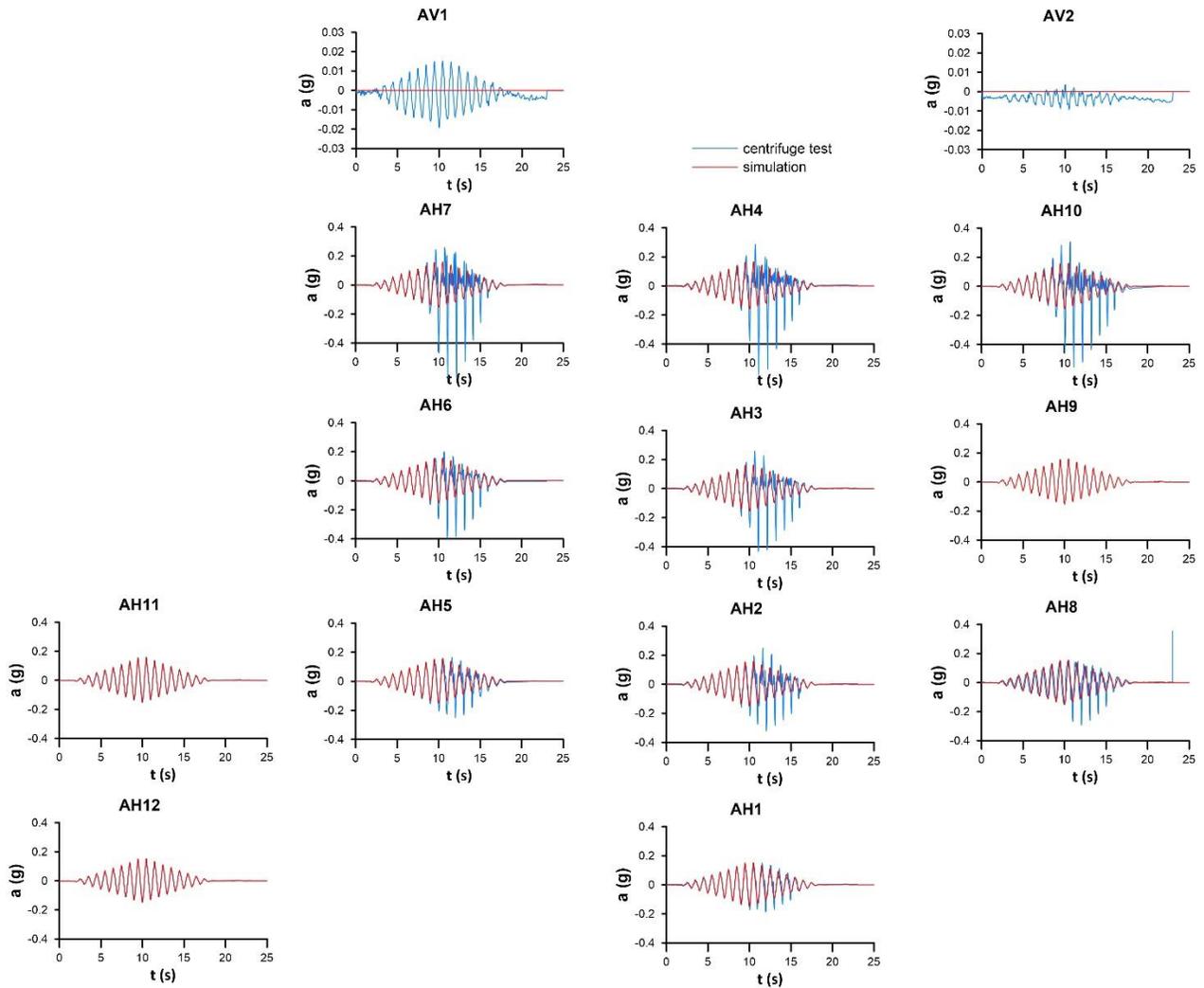


Figure 5: Predicted vs. measured acceleration time histories

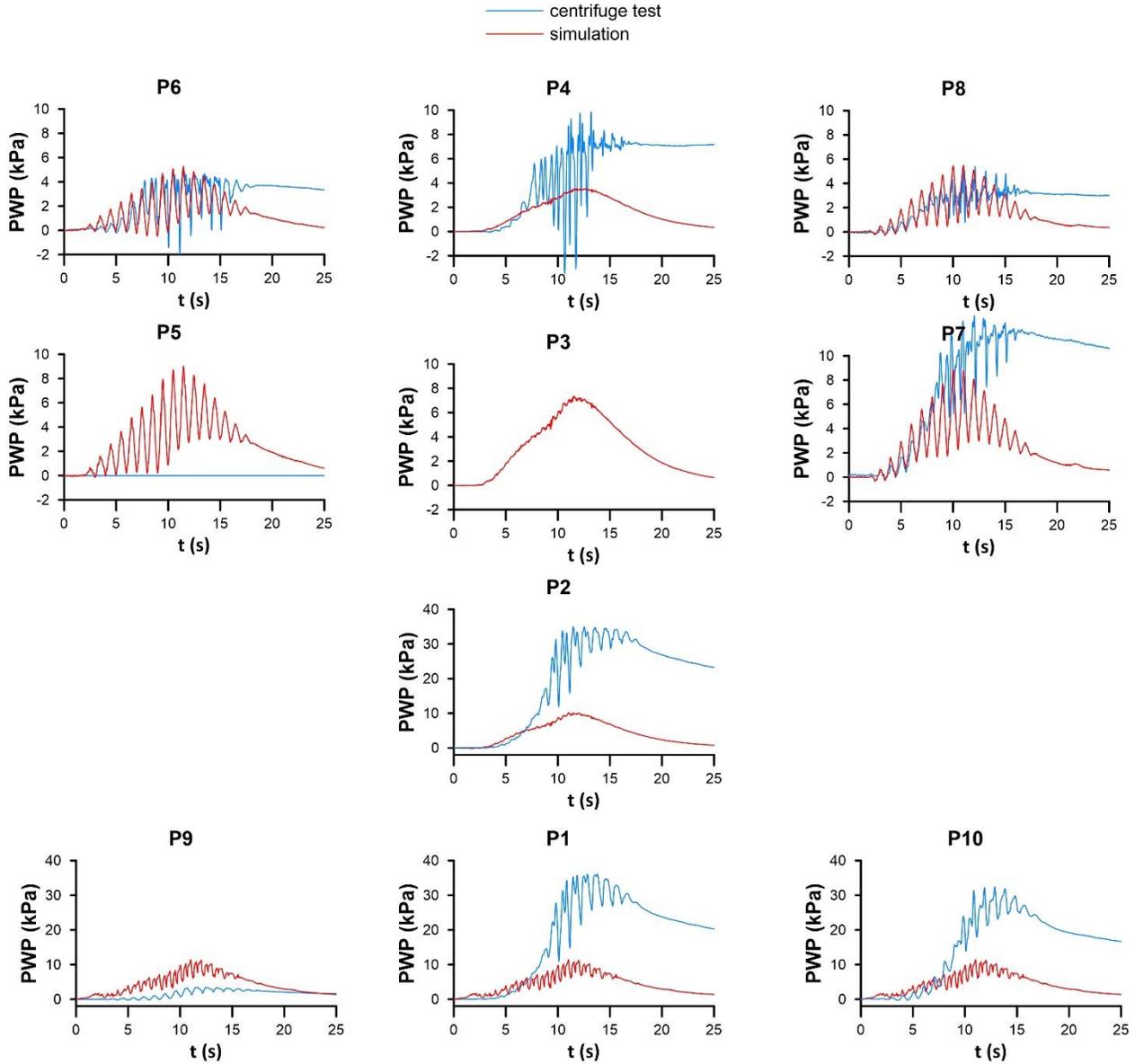


Figure 6: Predicted vs. measured pore pressure time histories

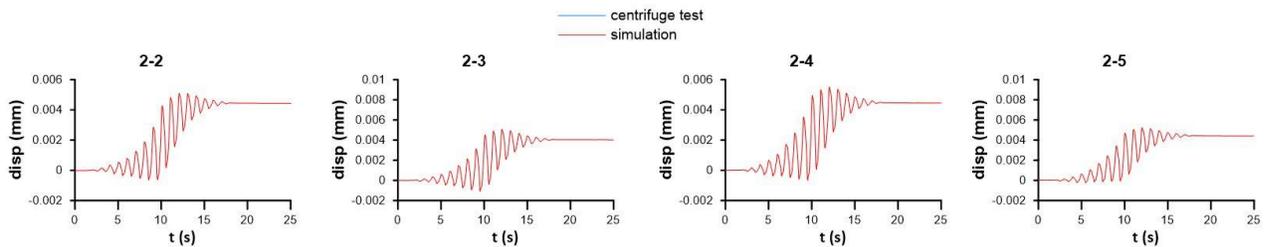


Figure 7: Predicted vs. measured lateral displacement time histories

Appendix C: Results of the simulation UCD_A_A2_1 (Model A)

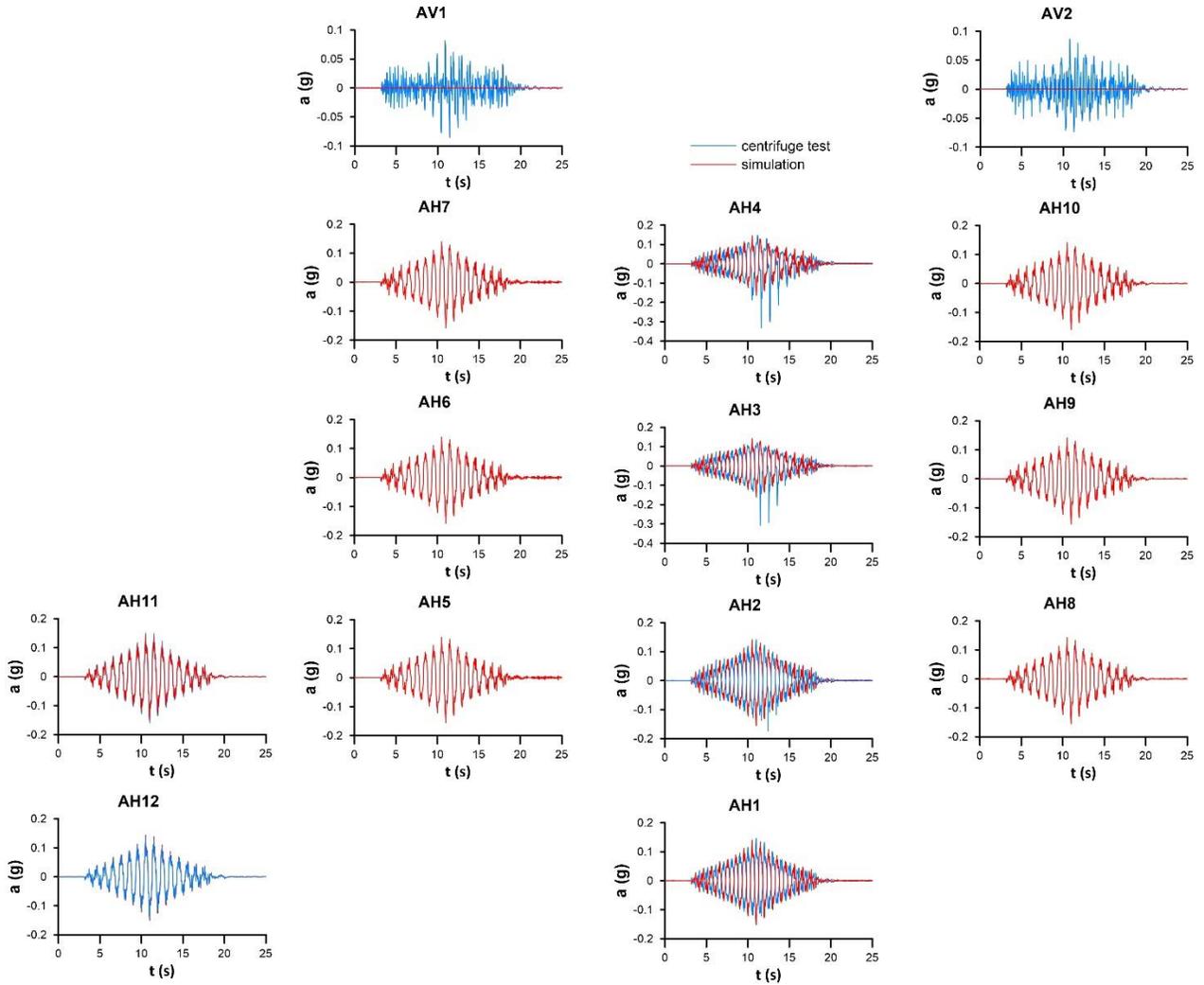


Figure 8: Predicted vs. measured acceleration time histories

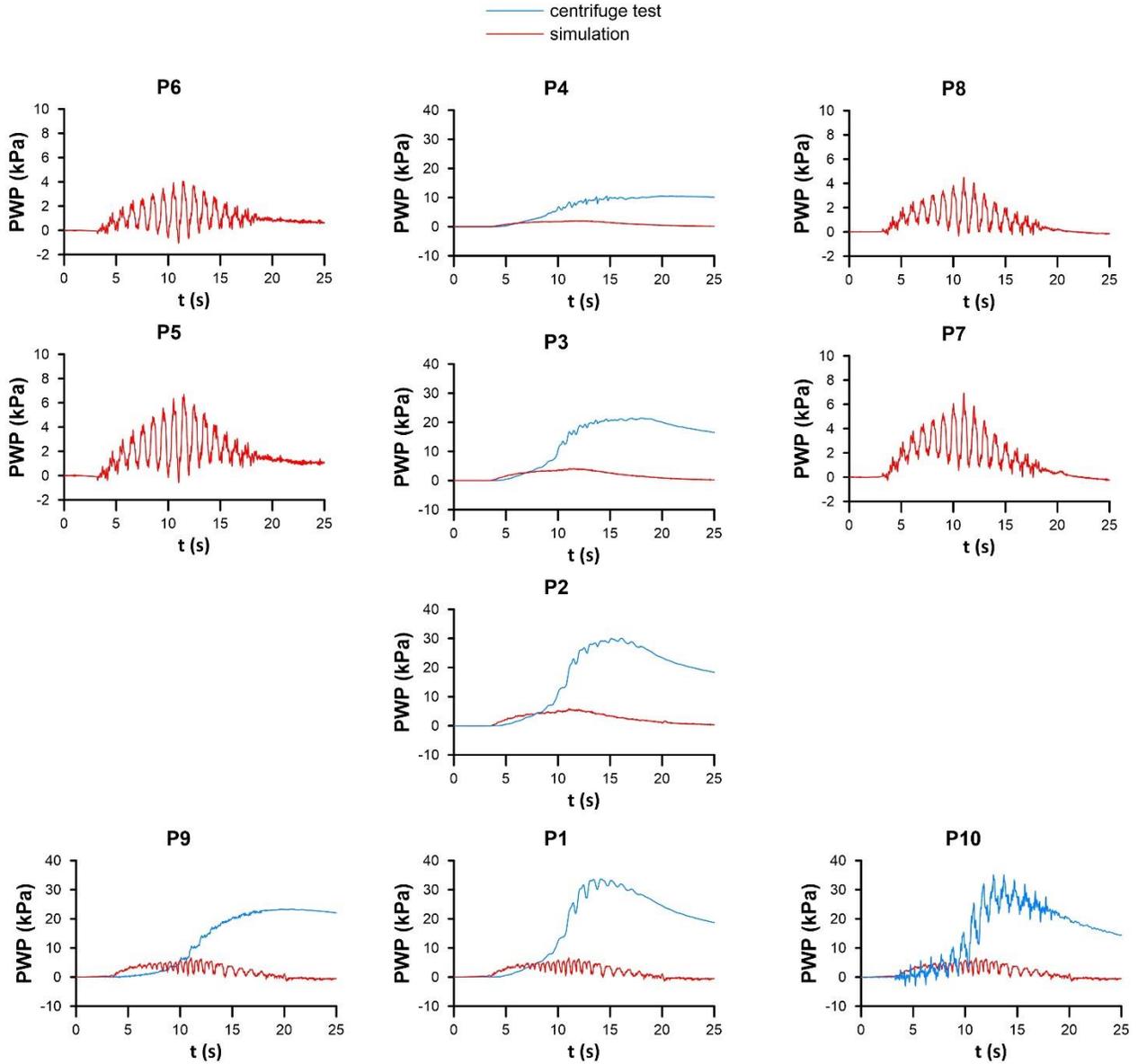


Figure 9: Predicted vs. measured pore pressure time histories

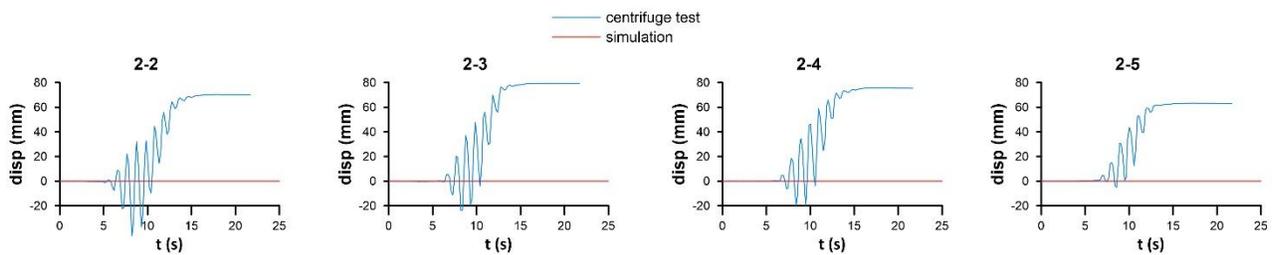


Figure 10: Predicted vs. measured lateral displacement time histories

Appendix D: Results of the simulation KyU_A_B2_1 (Model B)

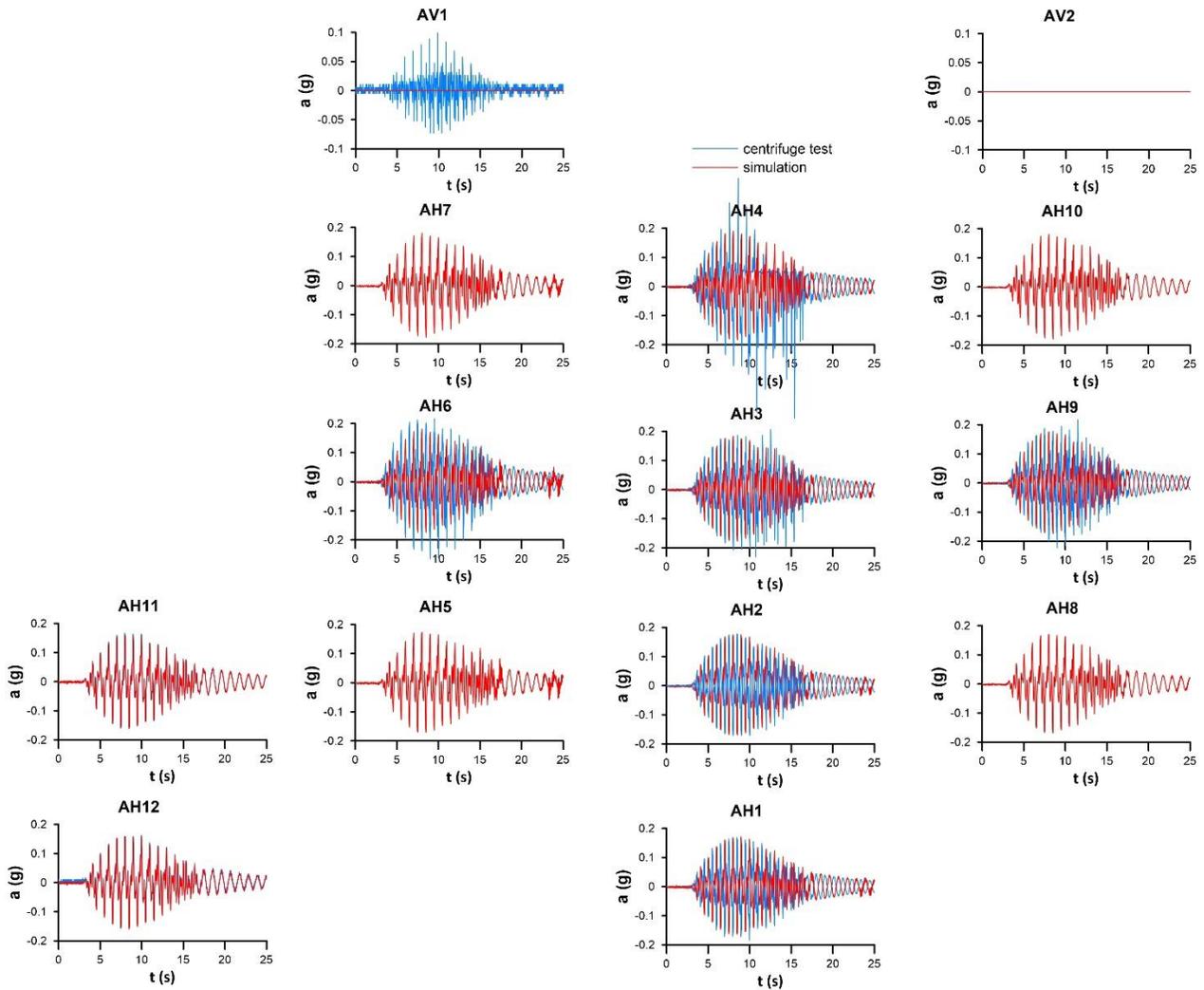


Figure 11: Predicted vs. measured acceleration time histories

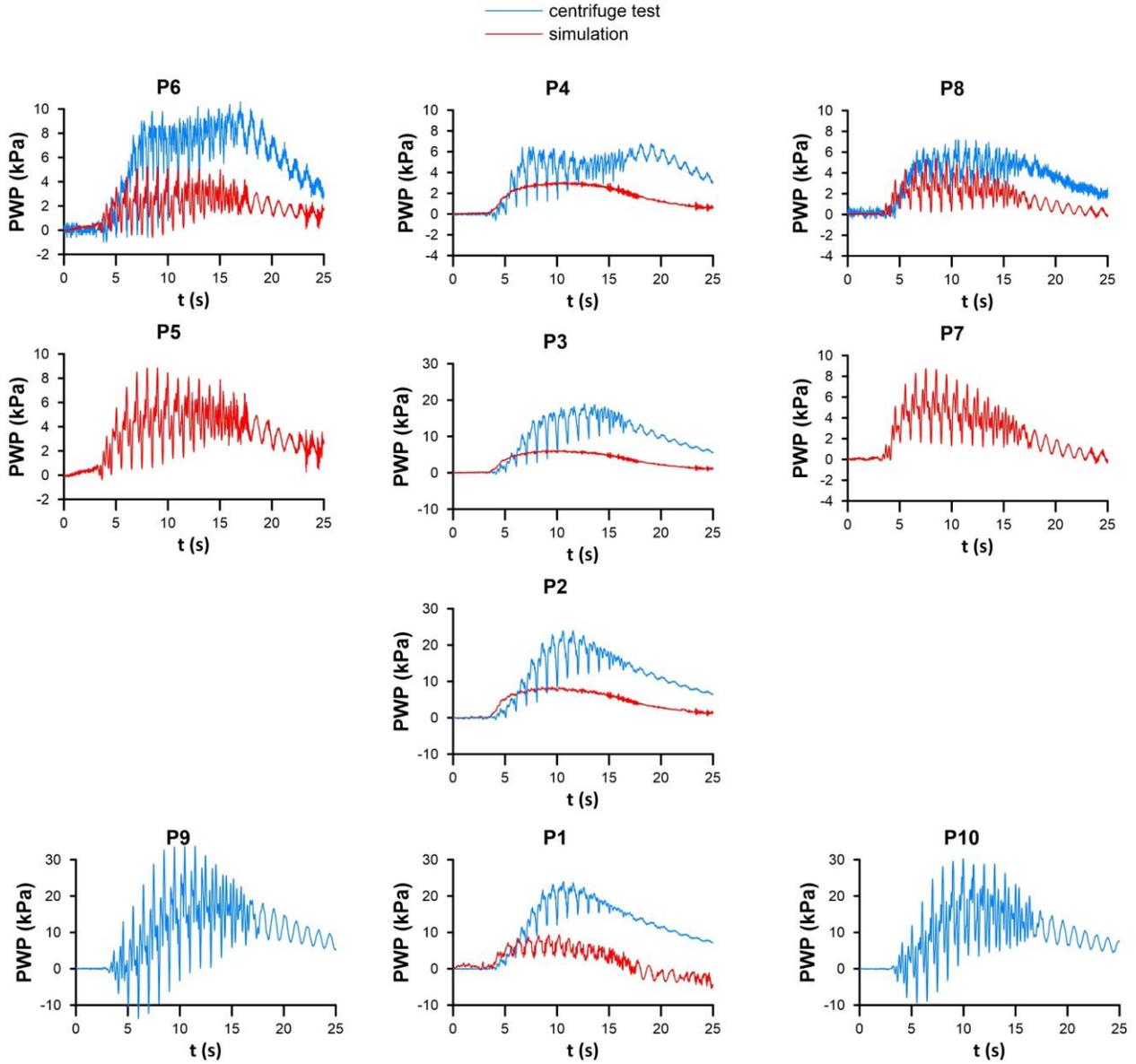


Figure 12: Predicted vs. measured pore pressure time histories

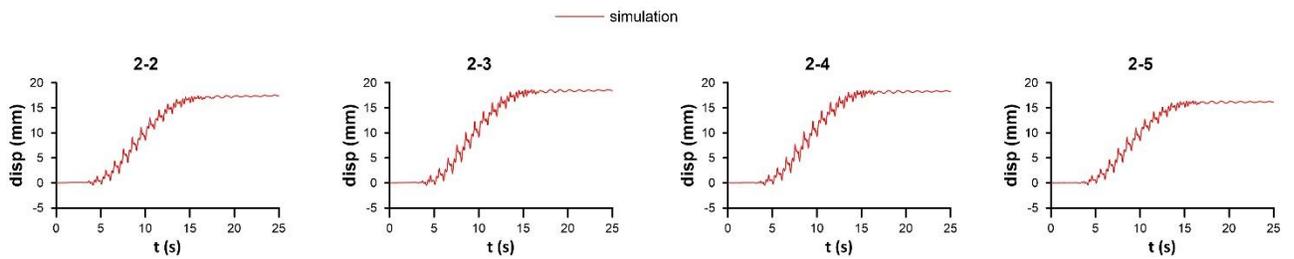


Figure 13: Predicted vs. measured lateral displacement time histories

Appendix E: Results of the simulation RPI_A_B1_1 (Model B)

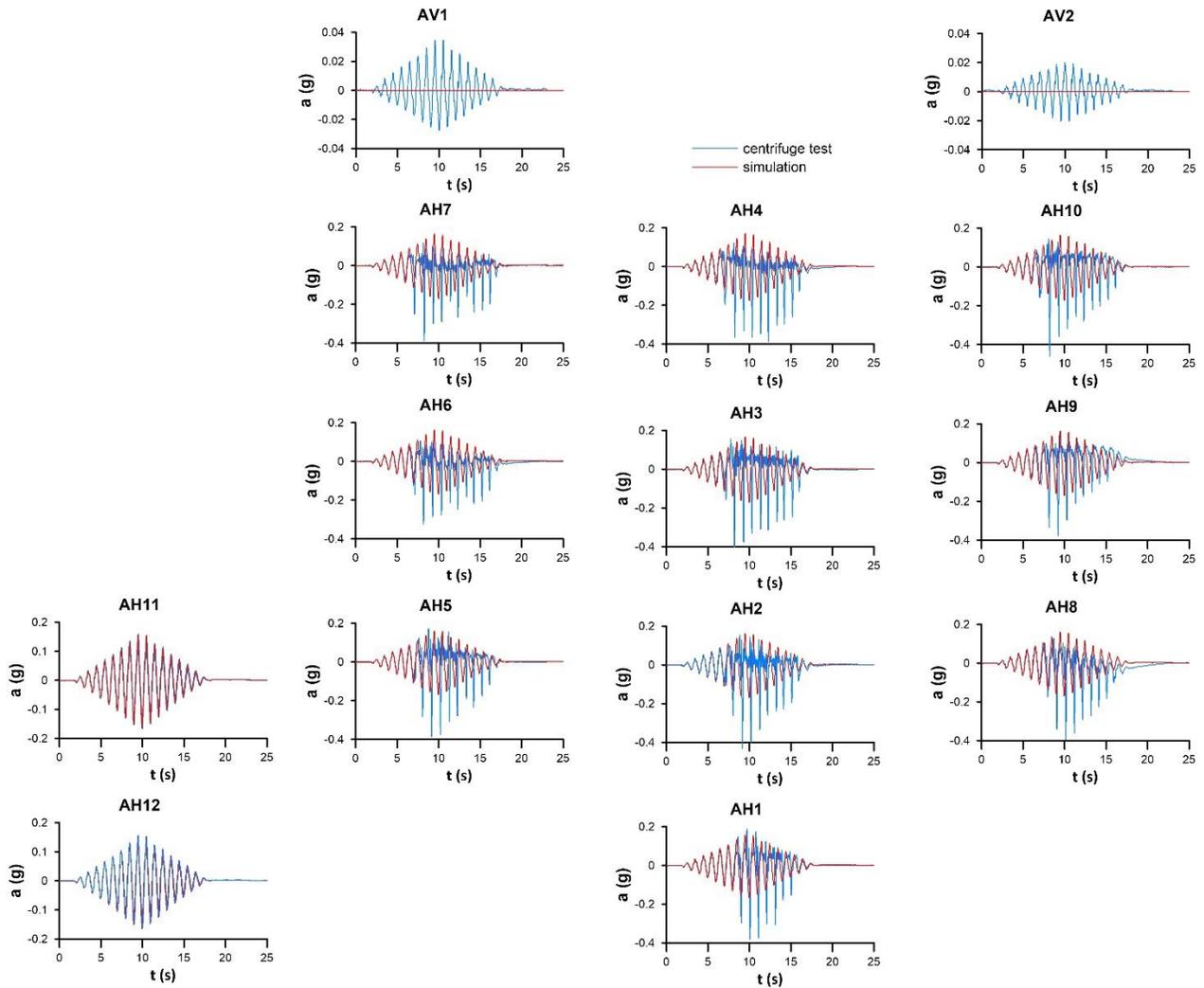


Figure 14: Predicted vs. measured acceleration time histories

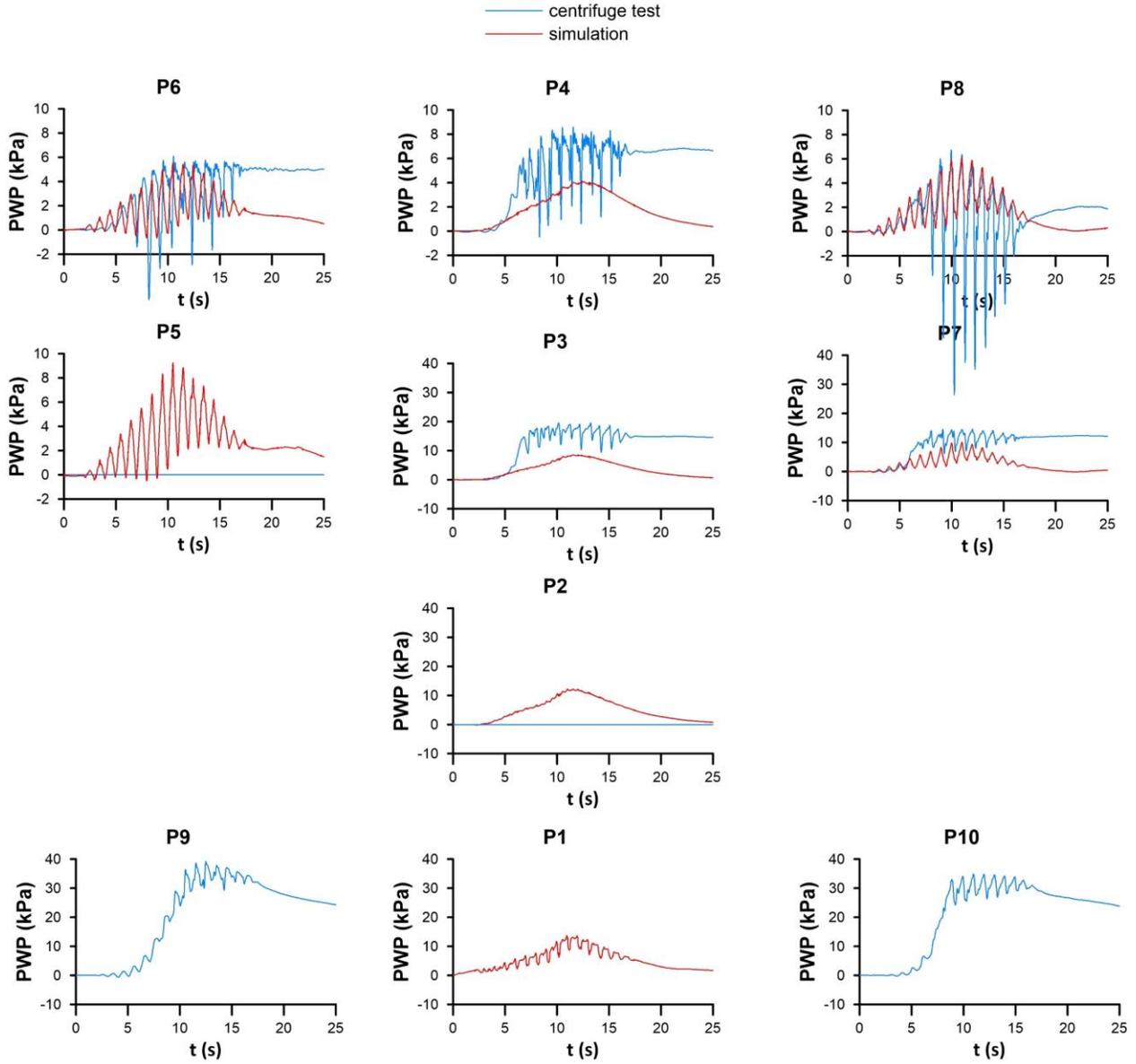


Figure 15: Predicted vs. measured pore pressure time histories

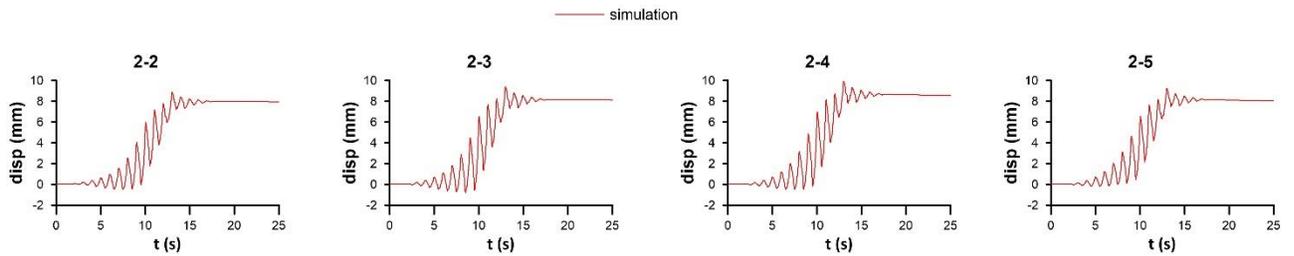


Figure 16: Predicted vs. measured lateral displacement time histories