Monitoring of the E-modulus of 3D concrete made with recycled aggregates from very early ages to hardened state

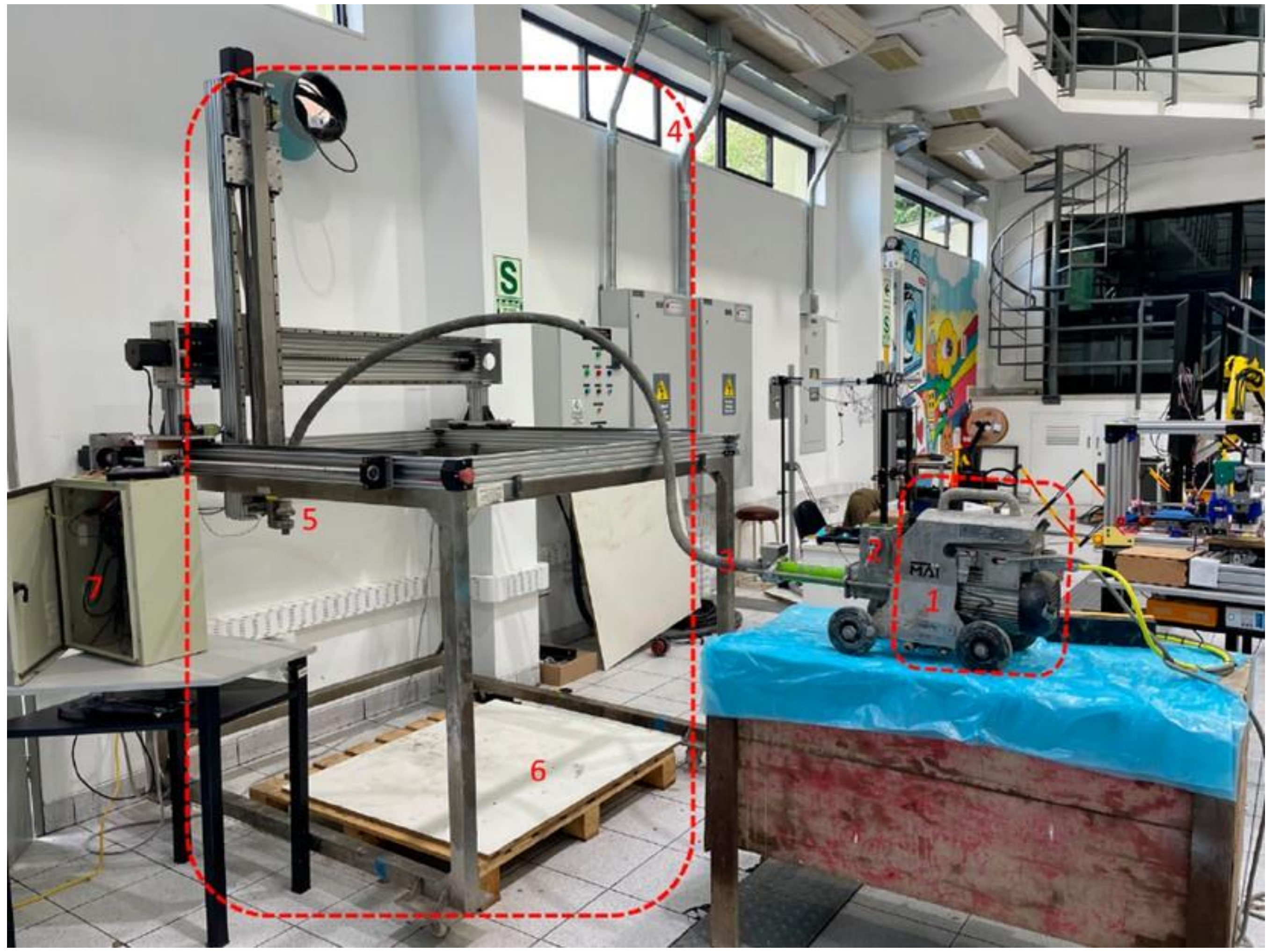
Claudia Pomahuallca Chahua, Mauricio Gonzales Paliza, Guido Silva Mondragón

Introduction

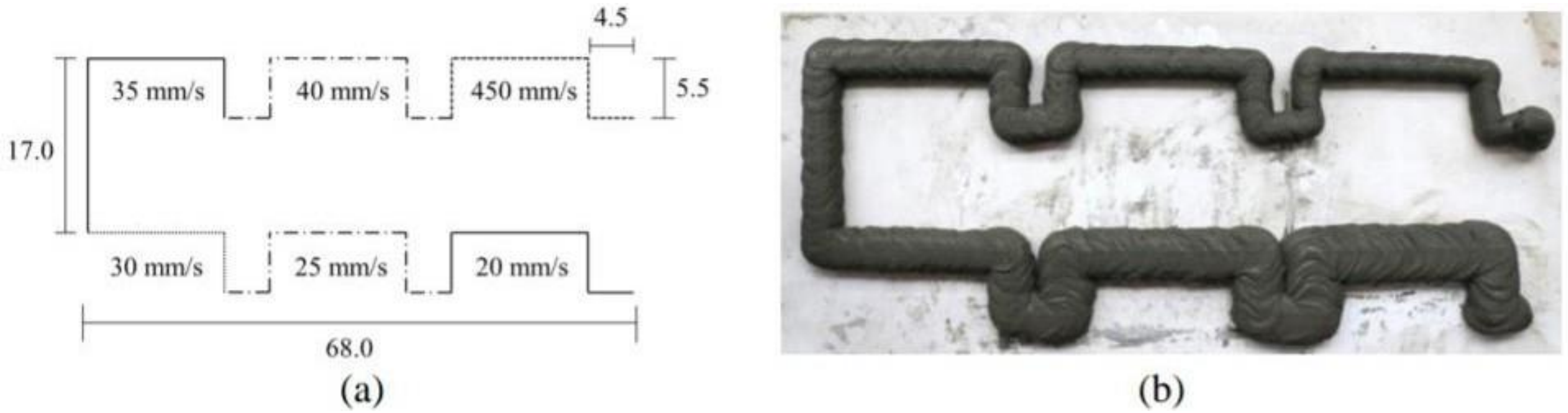
In the construction industry, 3D printing emerges as a technological innovation due to its advantages in digitalization and automation. 3D printing enables the creation of complex and customized structures in an efficient and sustainable manner, reducing construction time and waste generation. Globally, in developed countries, this technology has been growing exponentially, adopting structures such as bridges, walls, curved surfaces, houses, and even buildings.

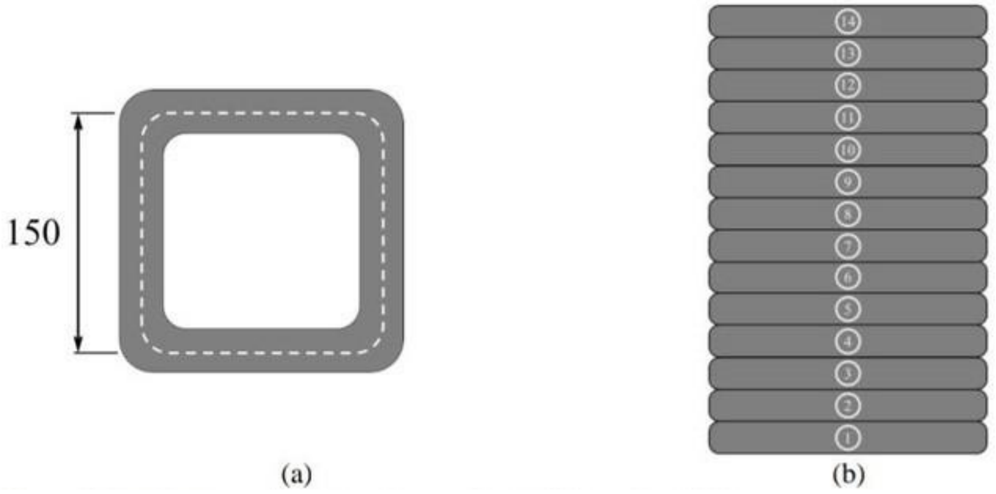
Printing process

The printing process was carried out using the Colibrí PUCP printer located at Core Facilities - FABCORE. This printer has 3 degrees of freedom (X, Y, Z) and is designed for small/medium-scale industrial operations. This type of printer is characterized by its durable structure and its ability to withstand intensive working conditions.



Colibrí Printer; (1): Pump, (2): Feeding system, (3): Hose, (4): Colibrí Printer, (5): Material output,
(6): Printing base, (7): Control and command subsystem





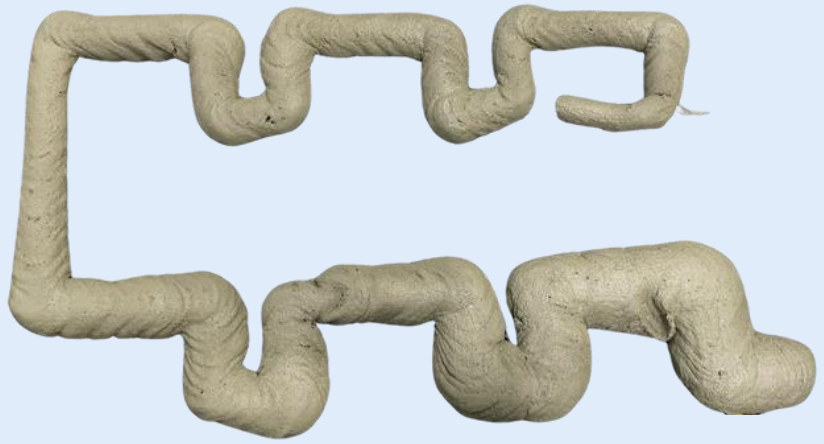
Printing parameters

Fluidity

Fluidity is a crucial property, as it determines the rheology of fresh cementitious materials.

Extrudability

Extrudability is the ability of a material to be continuously deposited or extruded through a nozzle.

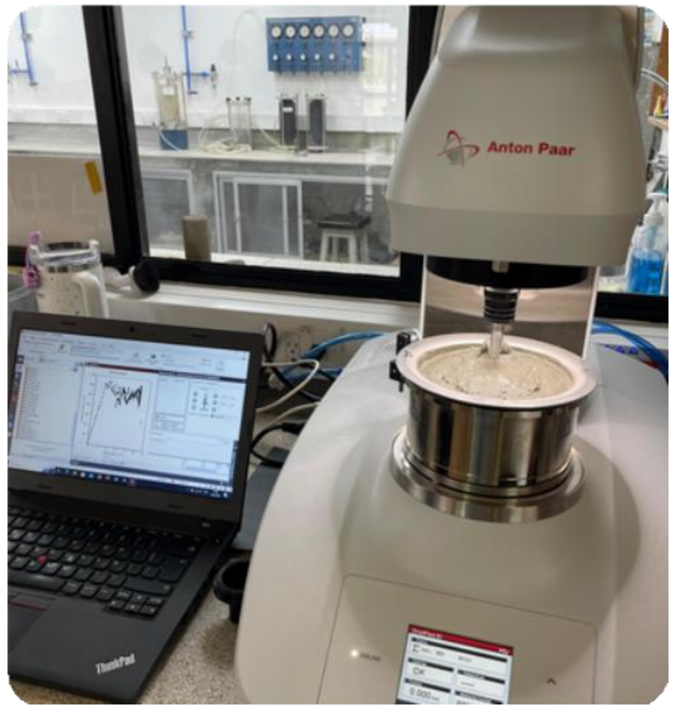


Buildability

Buildability is the capacity of a layer to support the weight of the subsequent layer without collapsing during the printing of the subsequent layer.

Testing performed

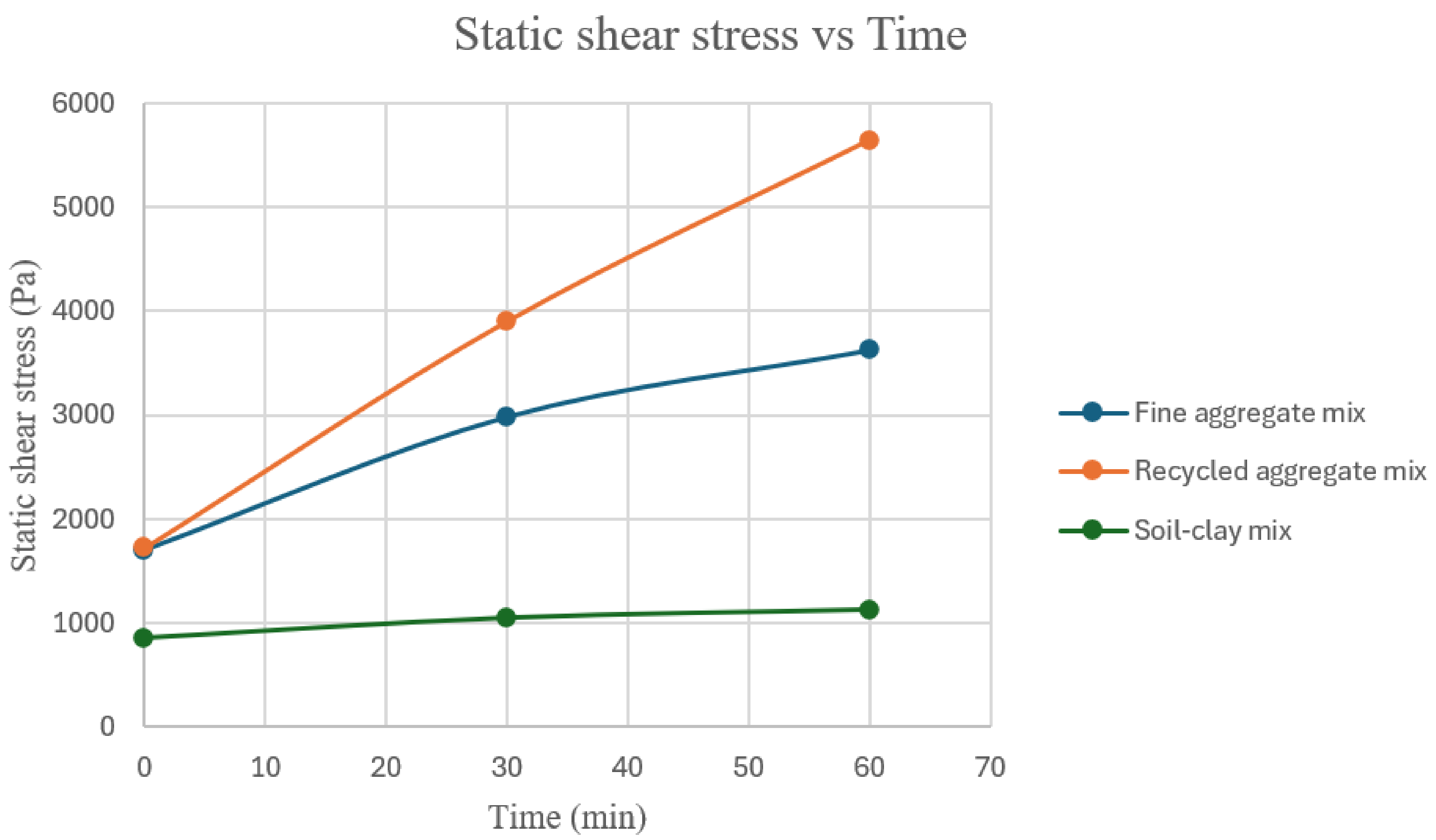
Rheological tests



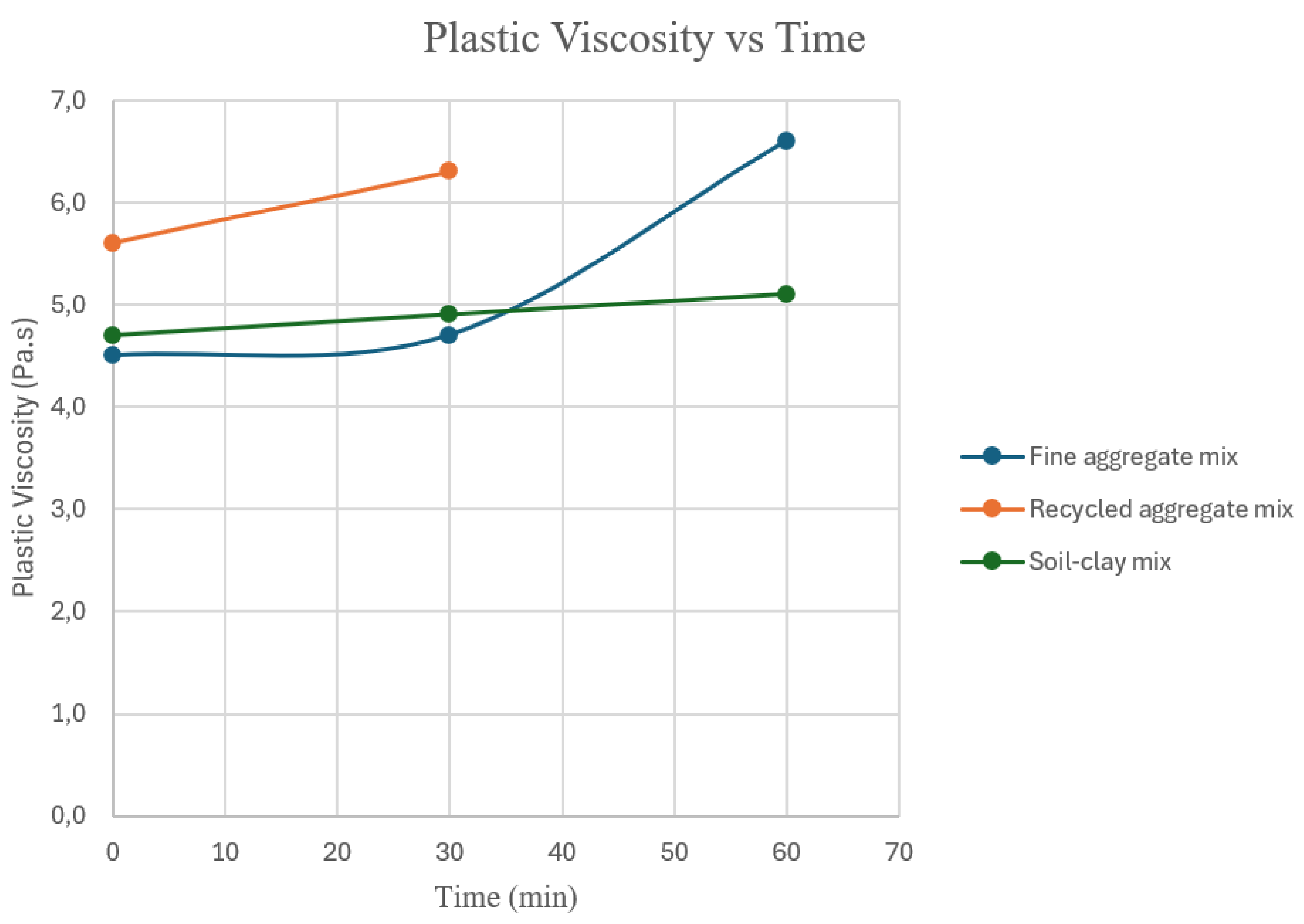
Penetrometer (ASTM C33)

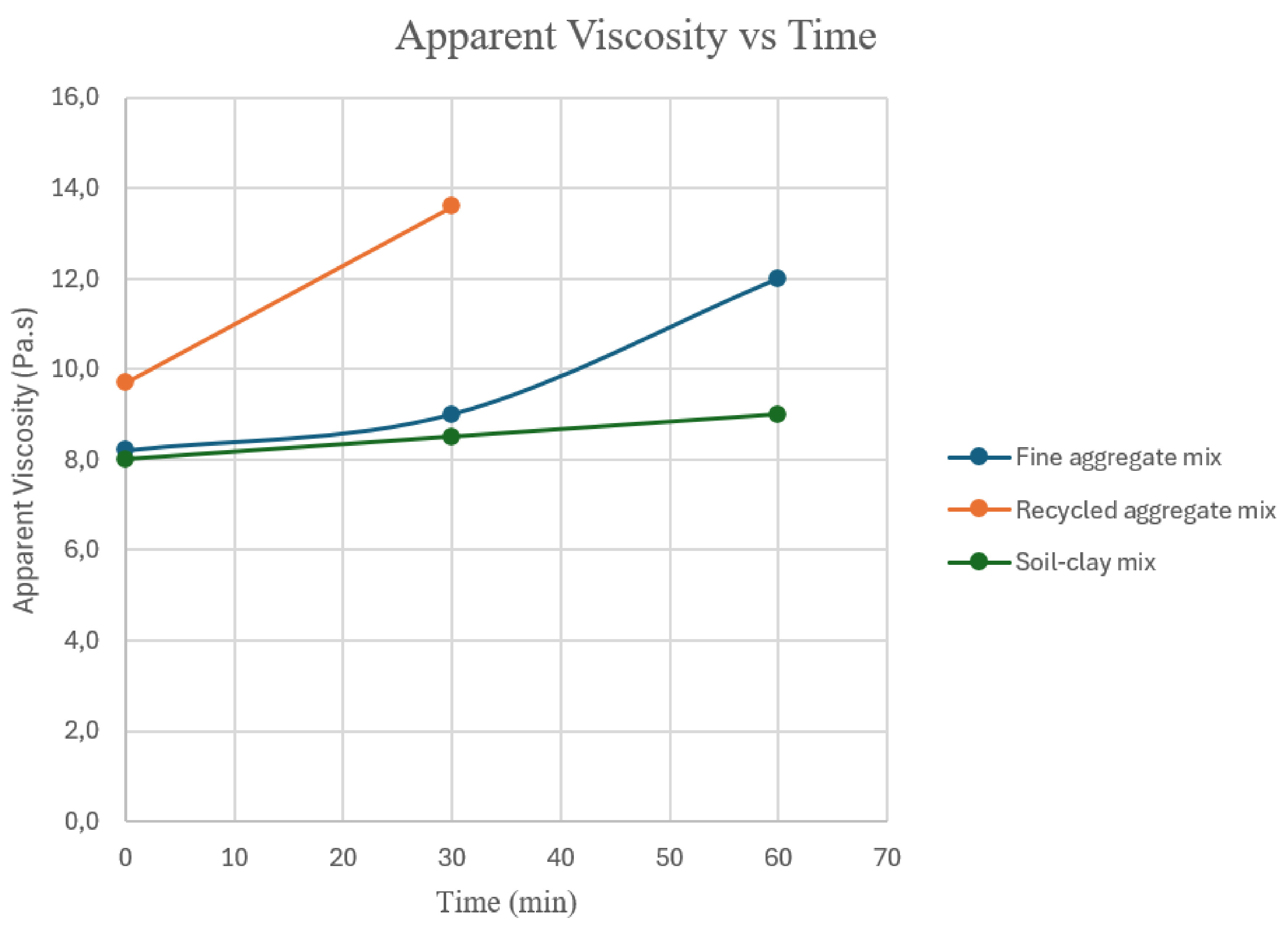
EMM ARM

Rheological tests

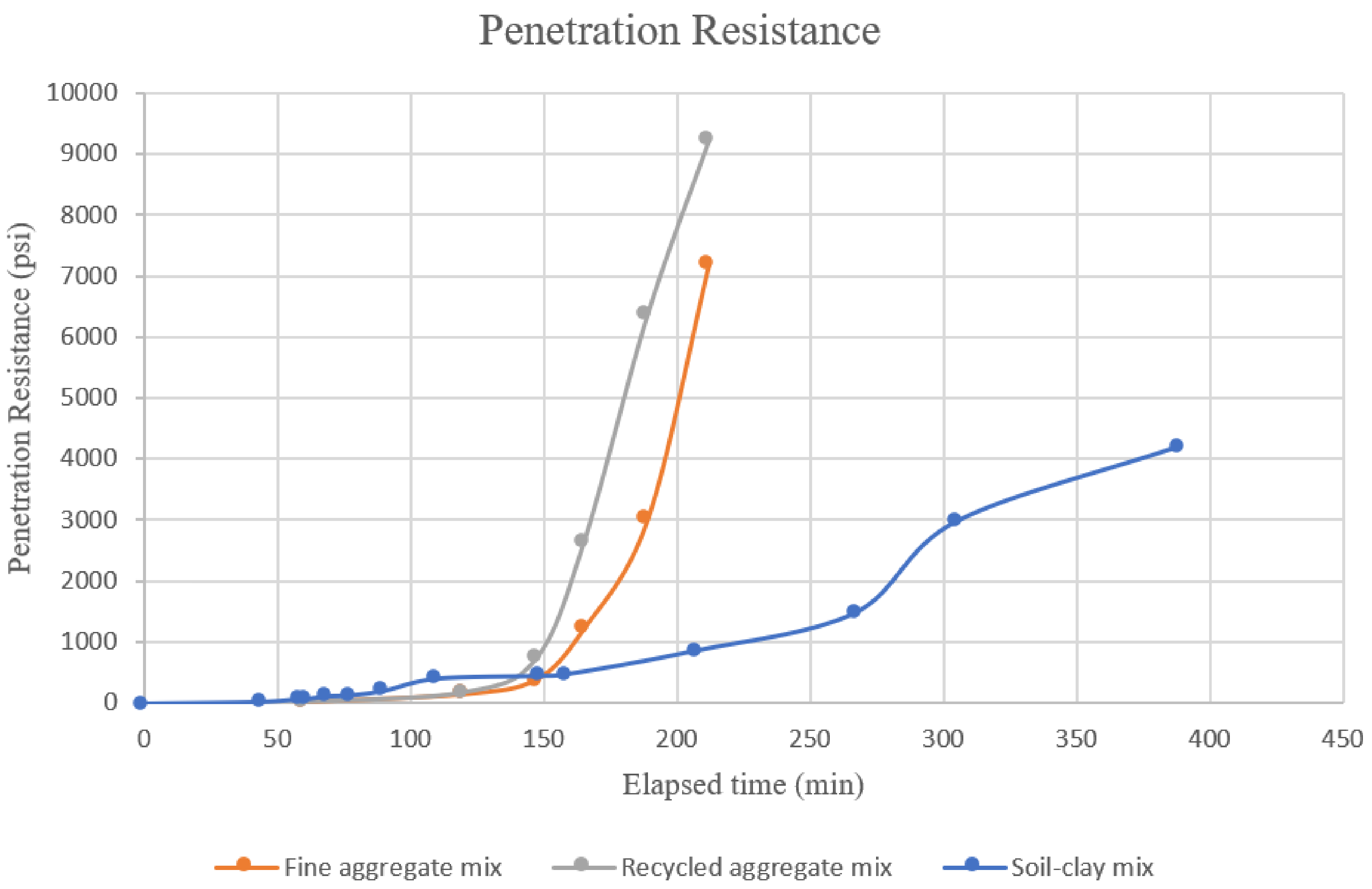


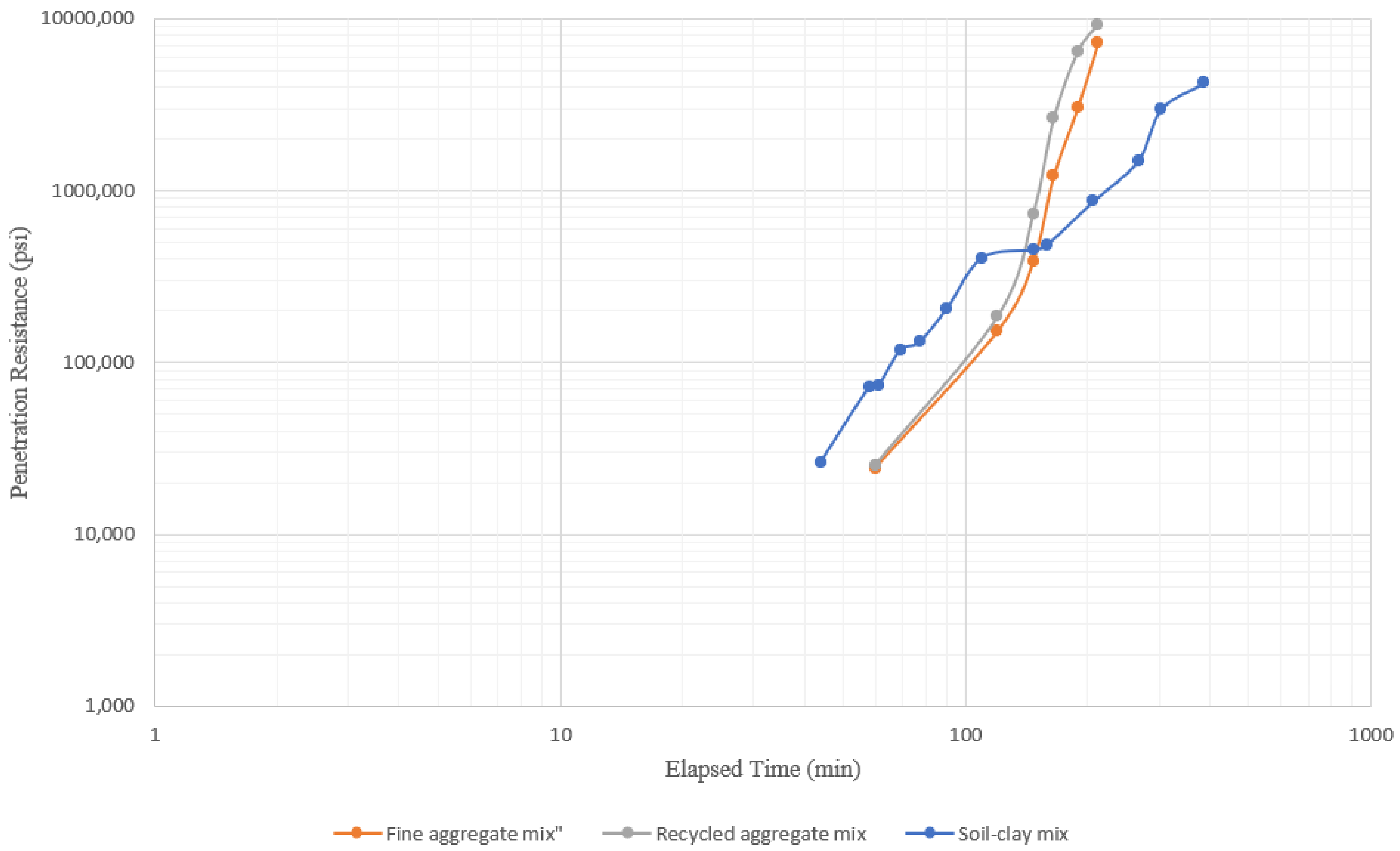
Rheological tests



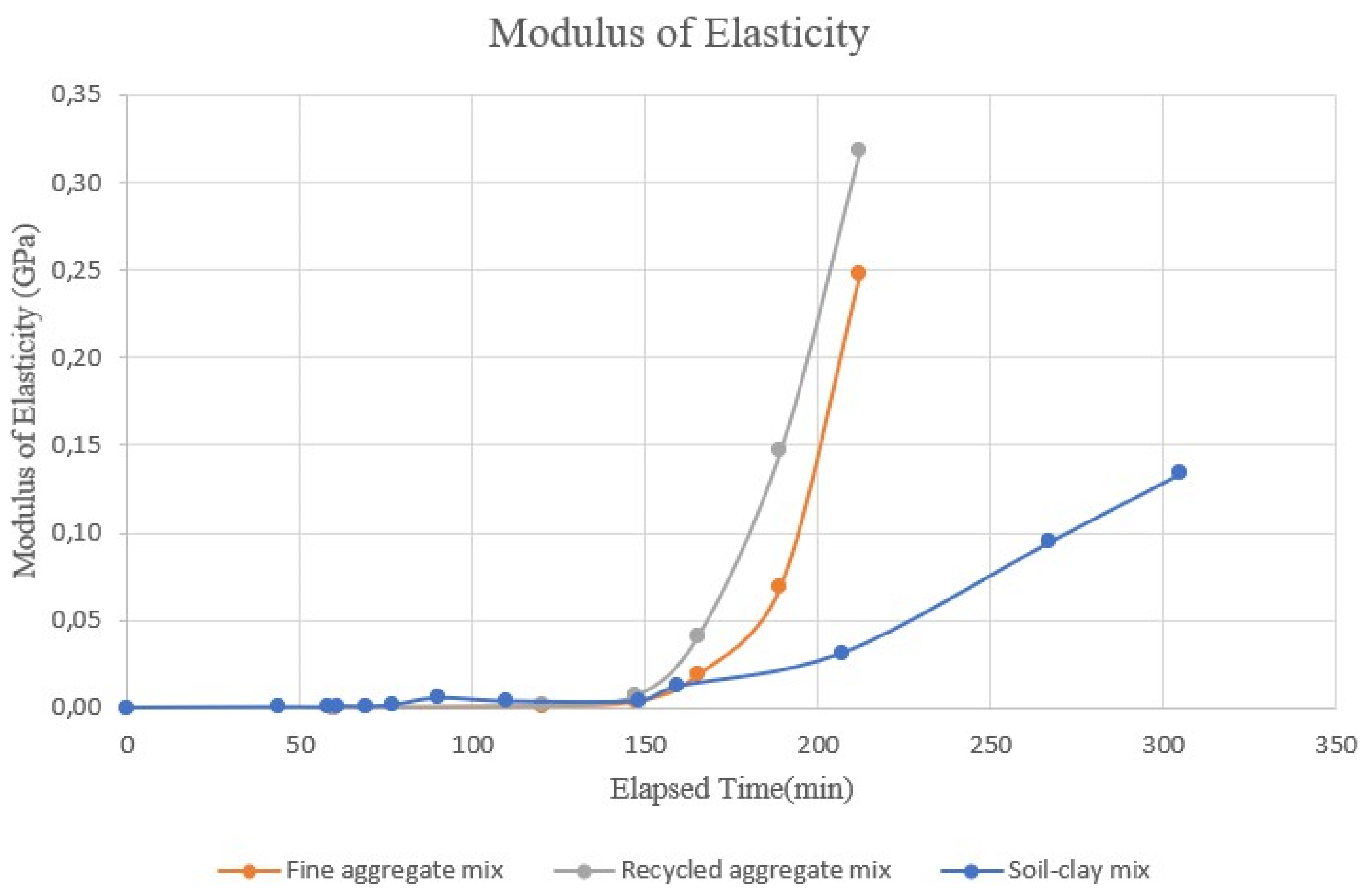


Penetrometer (ASTM C33)





Penetrometer (ASTM C33)



EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)

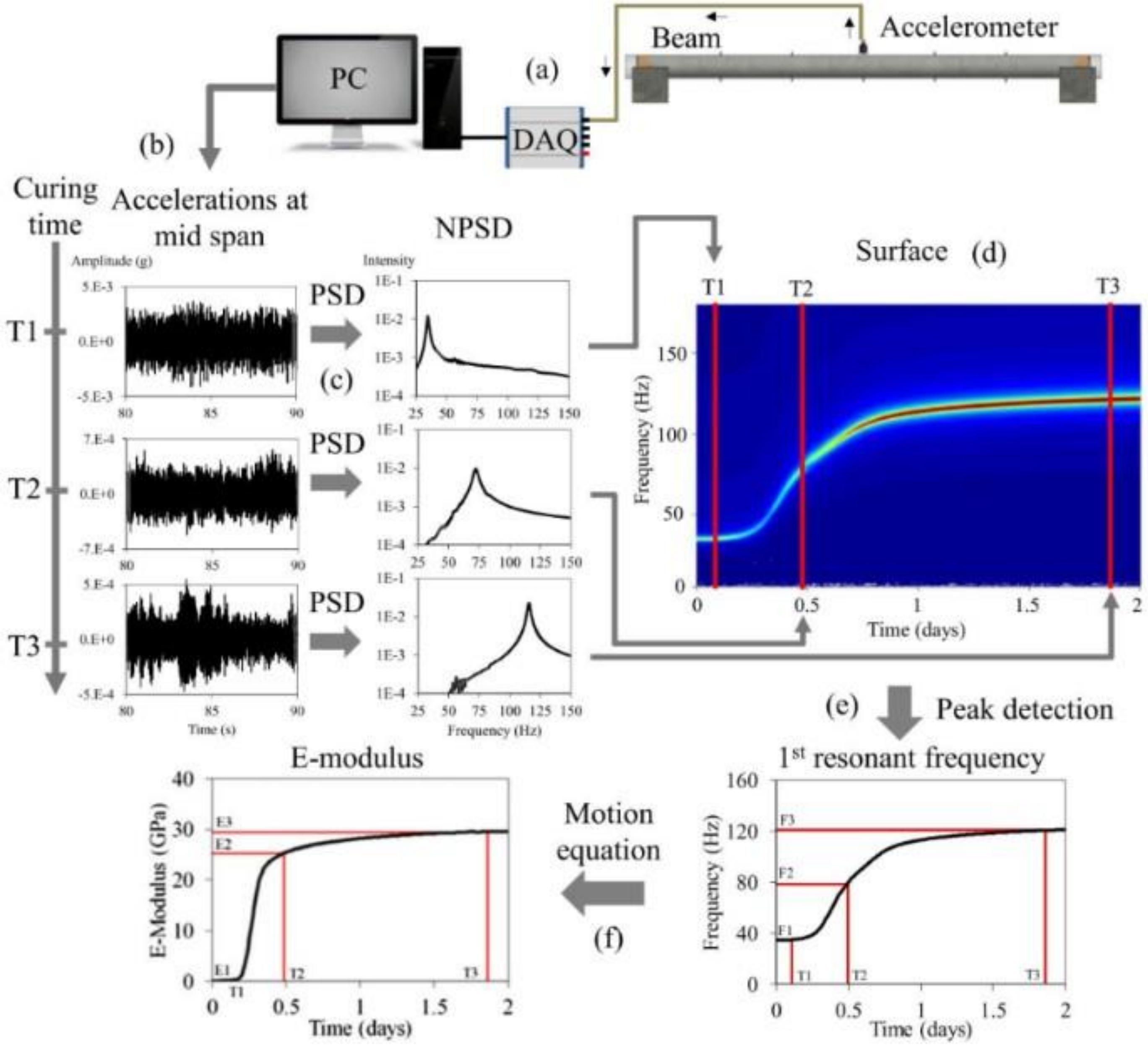
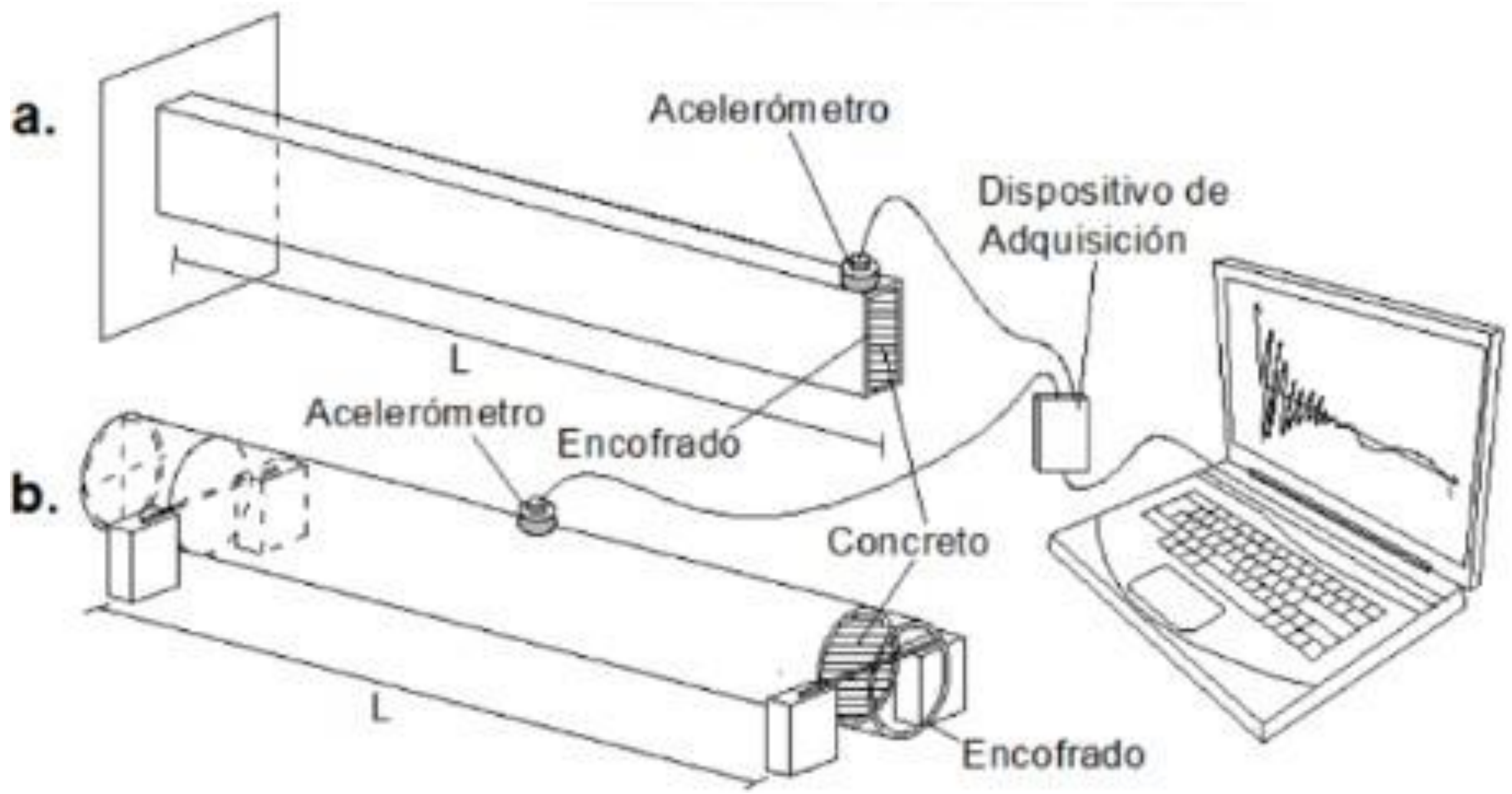


Figure 2. Schematic of the EMM-ARM test procedure (Granja and Azenha, 2017).

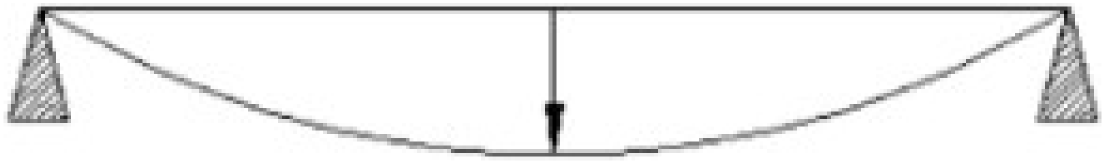
EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)



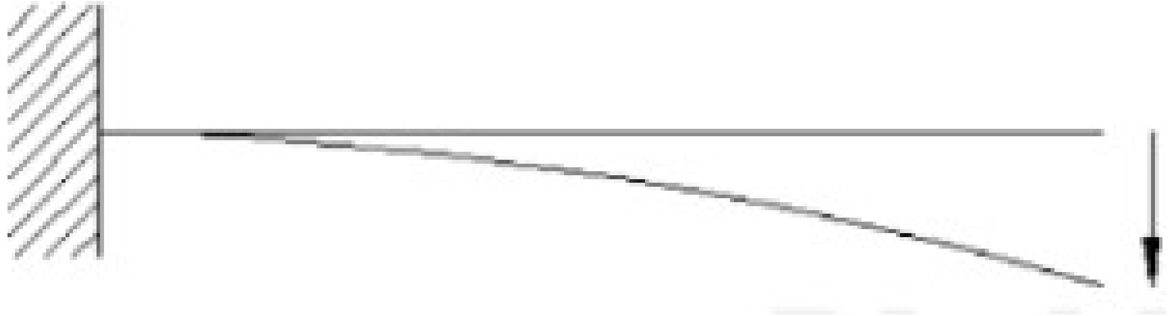
$$E_{ARM} = \frac{EI - E_e I_e}{I_{ARM}}$$

Figure 3. Schematic of the EMM-ARM test procedure (Gonzales, 2016).

EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)



$$EI = \left(f\,\frac{2L^2}{\pi}\right)^2 m_1$$



$$\begin{aligned} &a^3(cosh(aL)\cos(aL) + 1) \\ &+ \frac{\omega^2 m_1}{EI}(\cos(aL)\sinh(aL) - \cosh(aL)\sin(aL)) = 0 \end{aligned}$$

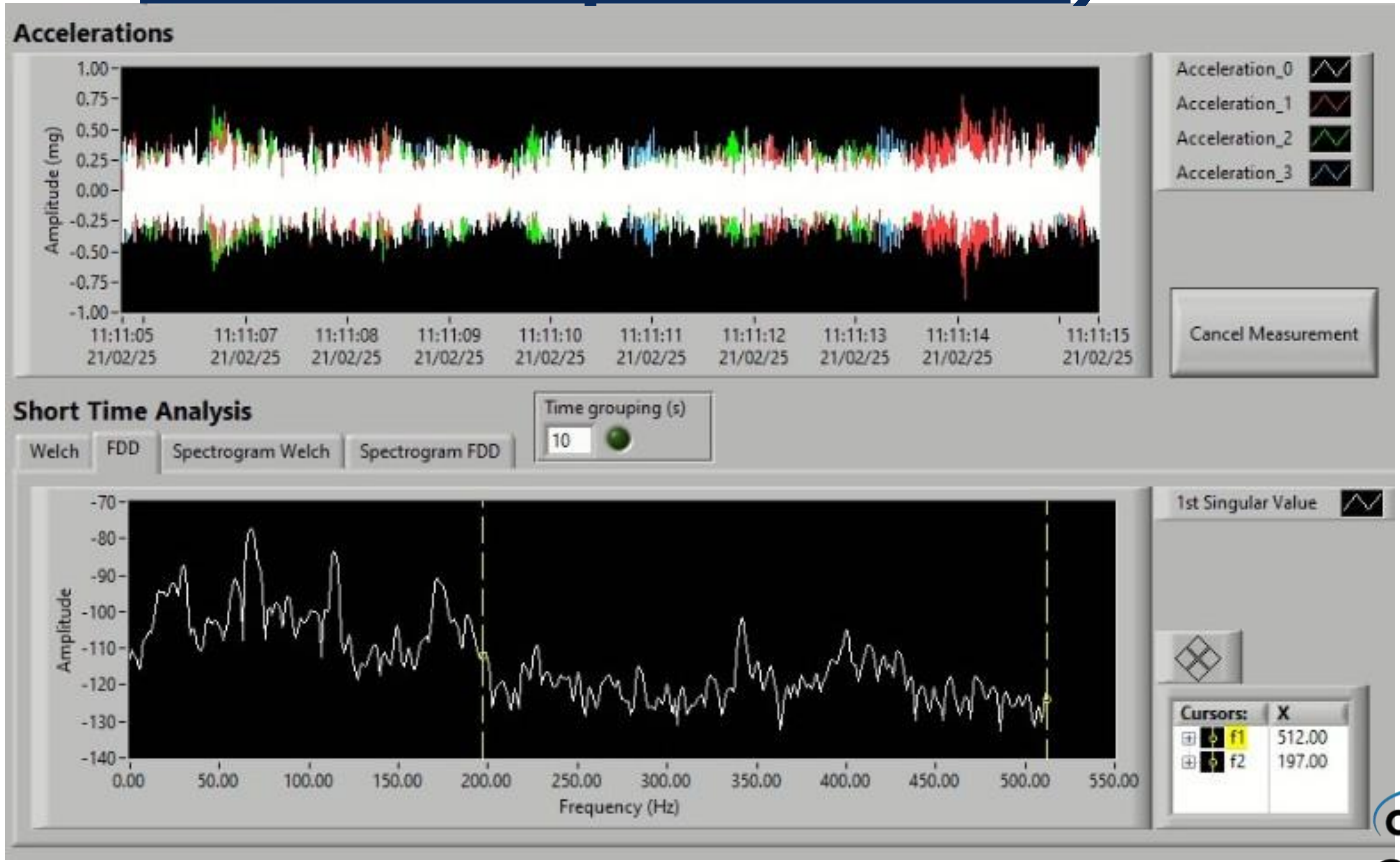
$$a = \sqrt[4]{\frac{\omega^2 \cdot \overline{m}}{\overline{EI}}},$$

Figure 4. Equations of the EMM-ARM test procedure (Granja and Azenha, 2017).

EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)

ACI CONCRETE CONVENTION

EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)



EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)

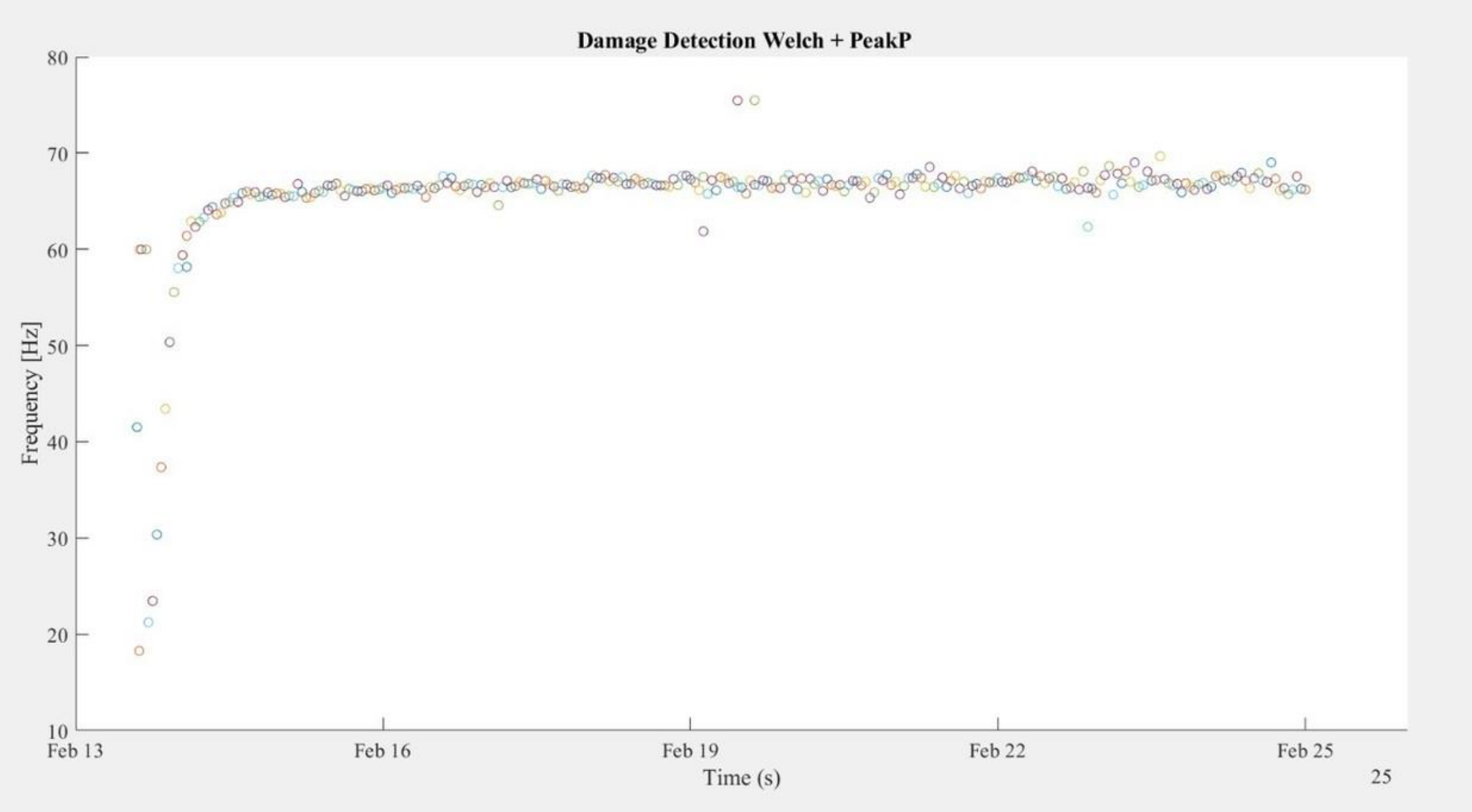


Figure 3. Frequency vs Time: Mix with Conventional aggregate

EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)

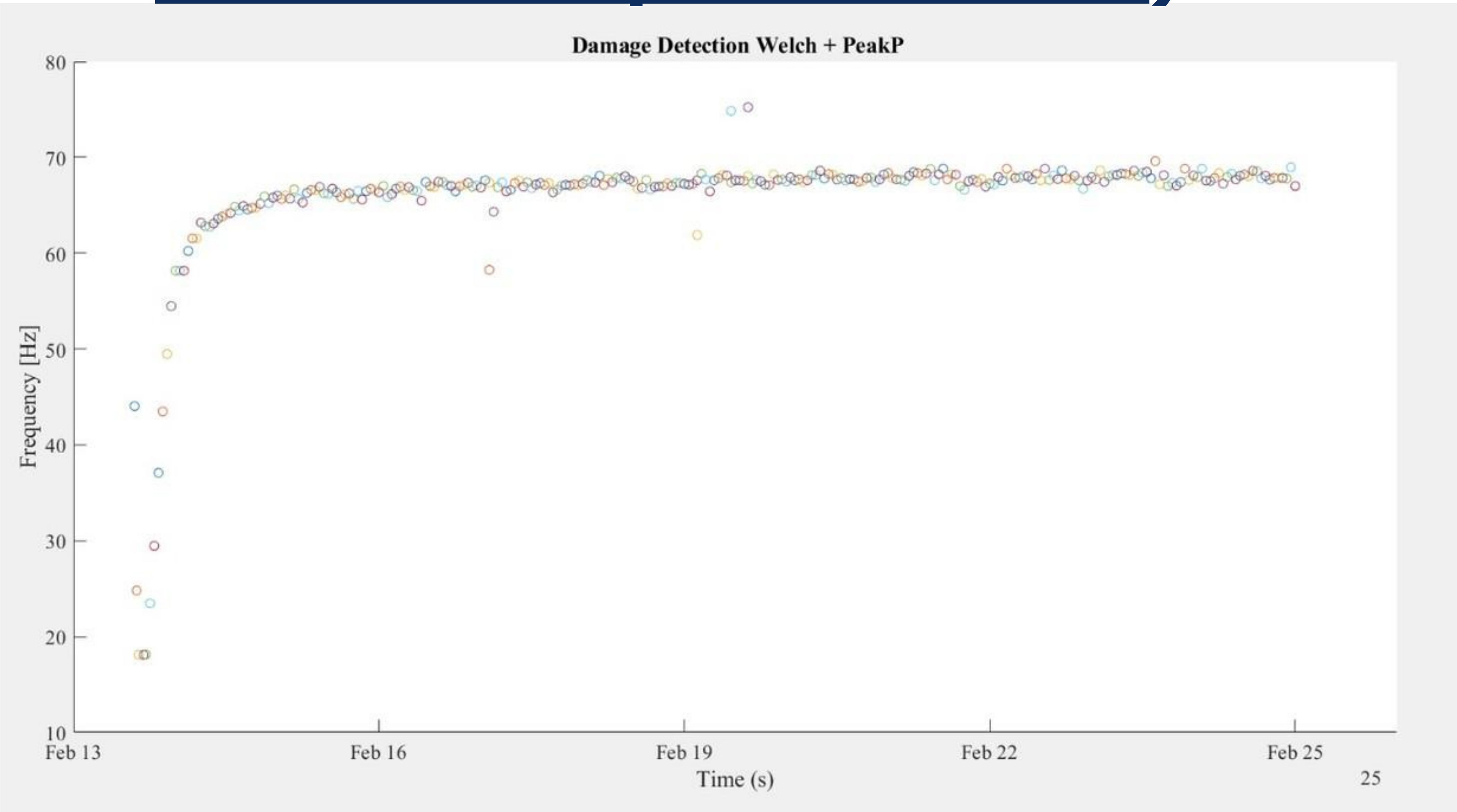


Figure 4. Frequency vs Time: Mix with 100% recycled aggregate.

EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method)

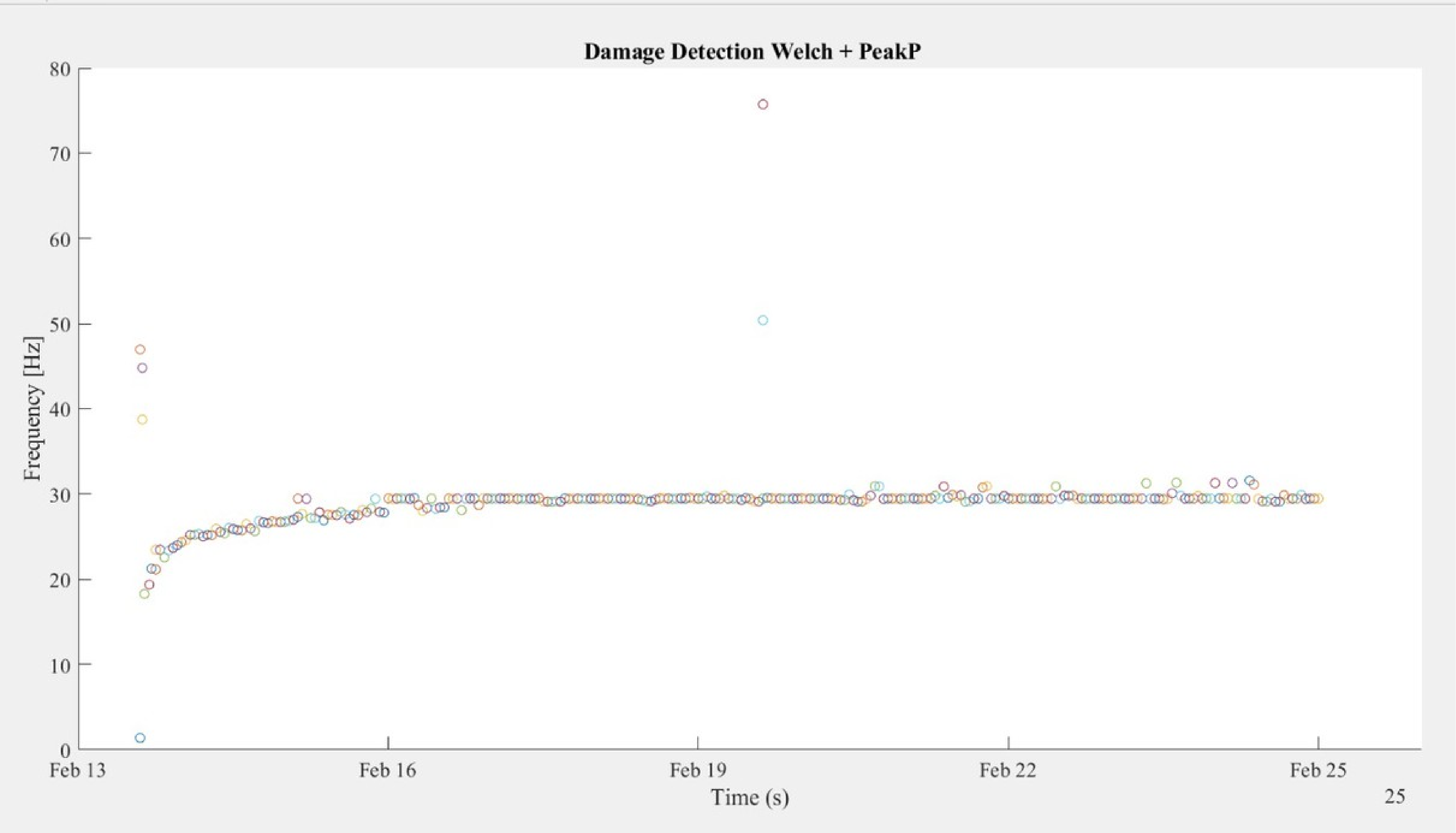


Figure 5. Frequency vs Time: Mix composed of soil and clay.

Conclusion

In conclusion, the results obtained through the three evaluation methods (rheological tests, penetrometer, and EMM-ARM) demonstrated that the elastic modulus of the mix with recycled aggregate is superior to that of the control mix and significantly higher than that of the soil-clay mix. This monitoring allowed us to analyze the material's behavior in its early setting hours and to project its structural performance over time.

Thank you!

Claudia Yesenia Pomahuallca Chahua

Research Assistant at Pontifical Catholic University of Peru

claudia.pomahuallca@pucp.edu.pe

Claudia Yesenia