Geotechnical Aspects of Re-Engineered Estuarine Shorelines in Response to High Energy Waves

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Background and Objectives

A current study investigating mitigation of adverse effects of high-energy waves on estuarine shorelines along the Tolomato River relies on porous break walls for wave energy dissipation (Figure 1). The success in reversing the adverse effects on the living shoreline hinges on the break wall's stability and ability to dissipate wave energy. The degree to which the walls are stable is dependent on the soil conditions on the shoreline and the wall properties. Loading on the porous walls and their efficiency at energy dissipation are a function of its porosity. An energy analysis suggests that porosity should be low (less than 0.25) to optimize dissipation. However, low porosity walls under wave loading experience more lateral displacement than walls with higher porosity. Based on the results, for these types of break walls to be effective at reducing the wave energy that the oyster gabions and salt march experience, steps to account for the porosity should be included in installation guidelines.

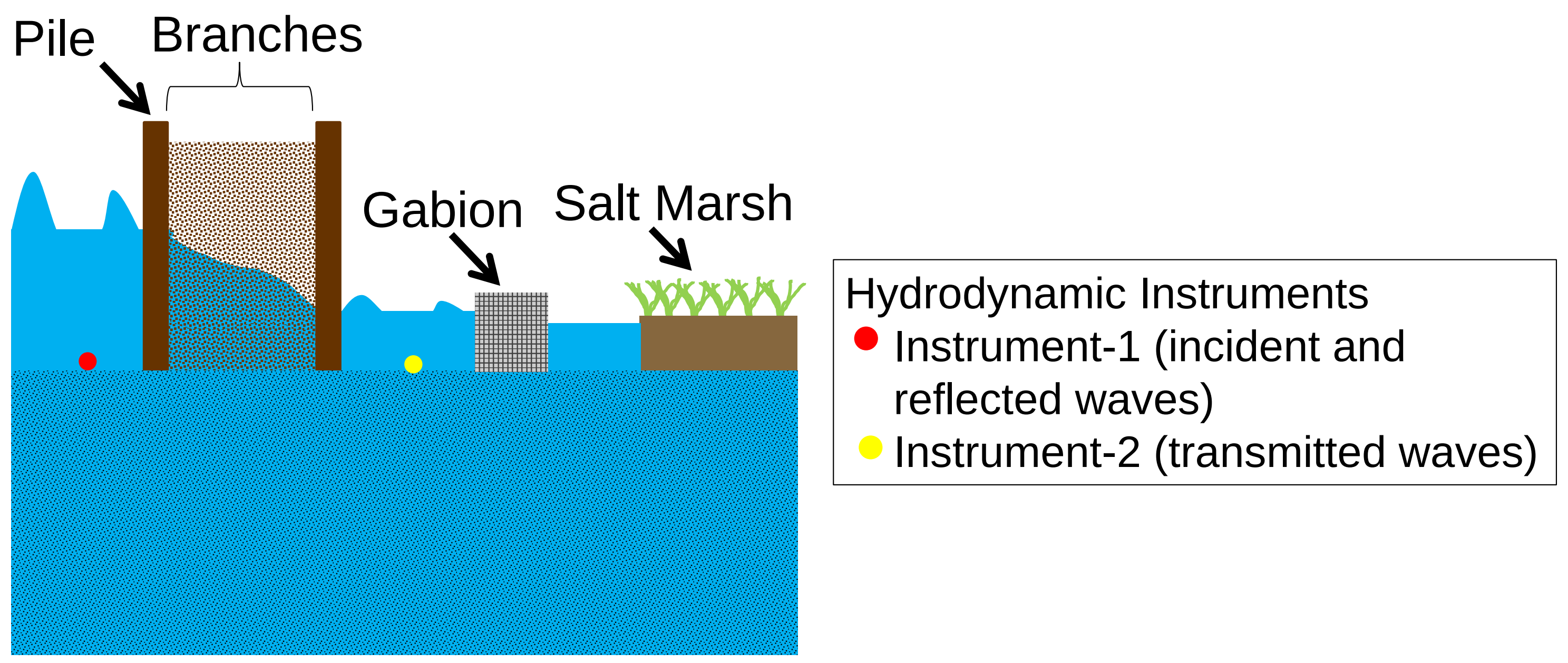

Figure 1. Experimental shoreline with acting incident and transmitted waves

Geotechnical Site Investigation

- Standard Penetration Test (SPT) was performed at 2 locations to identify the subsurface soil types and estimate their engineering properties.
- Soil type and properties used to estimate axial and lateral pile capacity

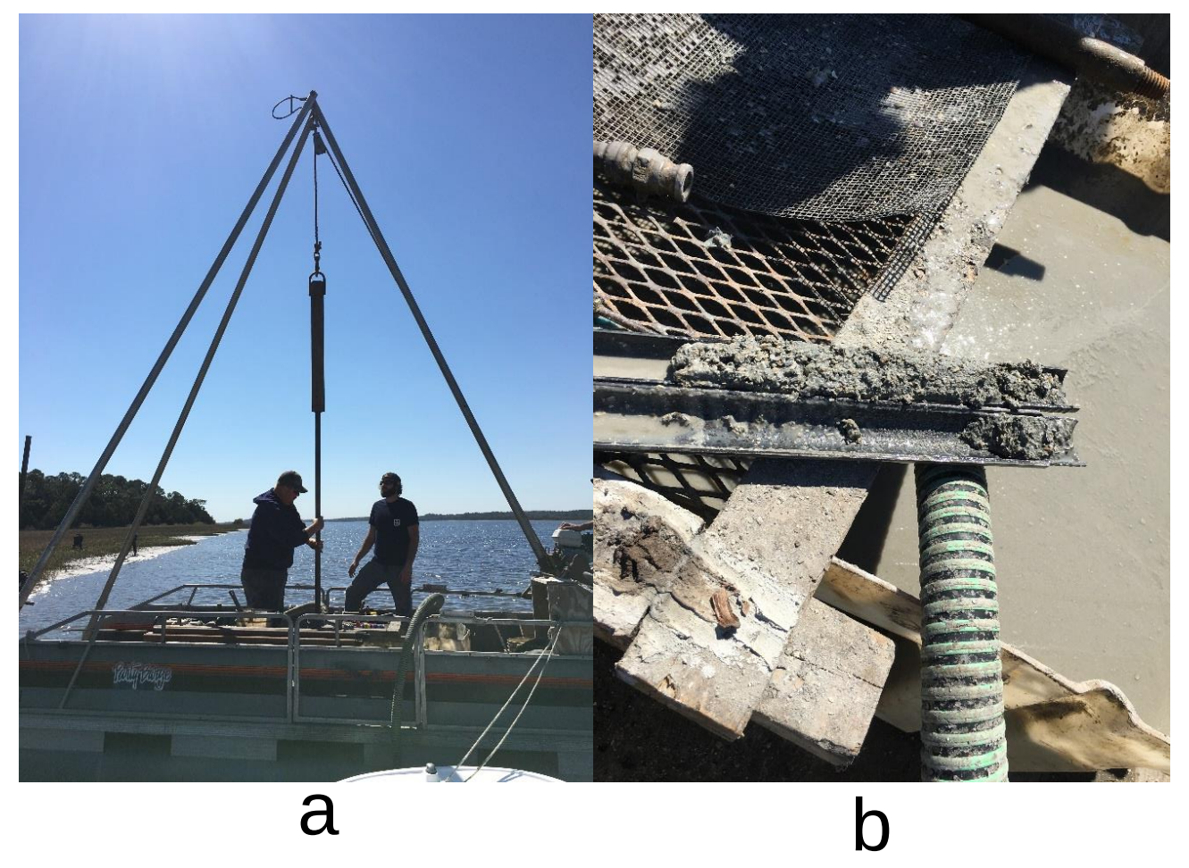

Figure 2. Site investigation (a) performing SPT and (b) SPT soil sample

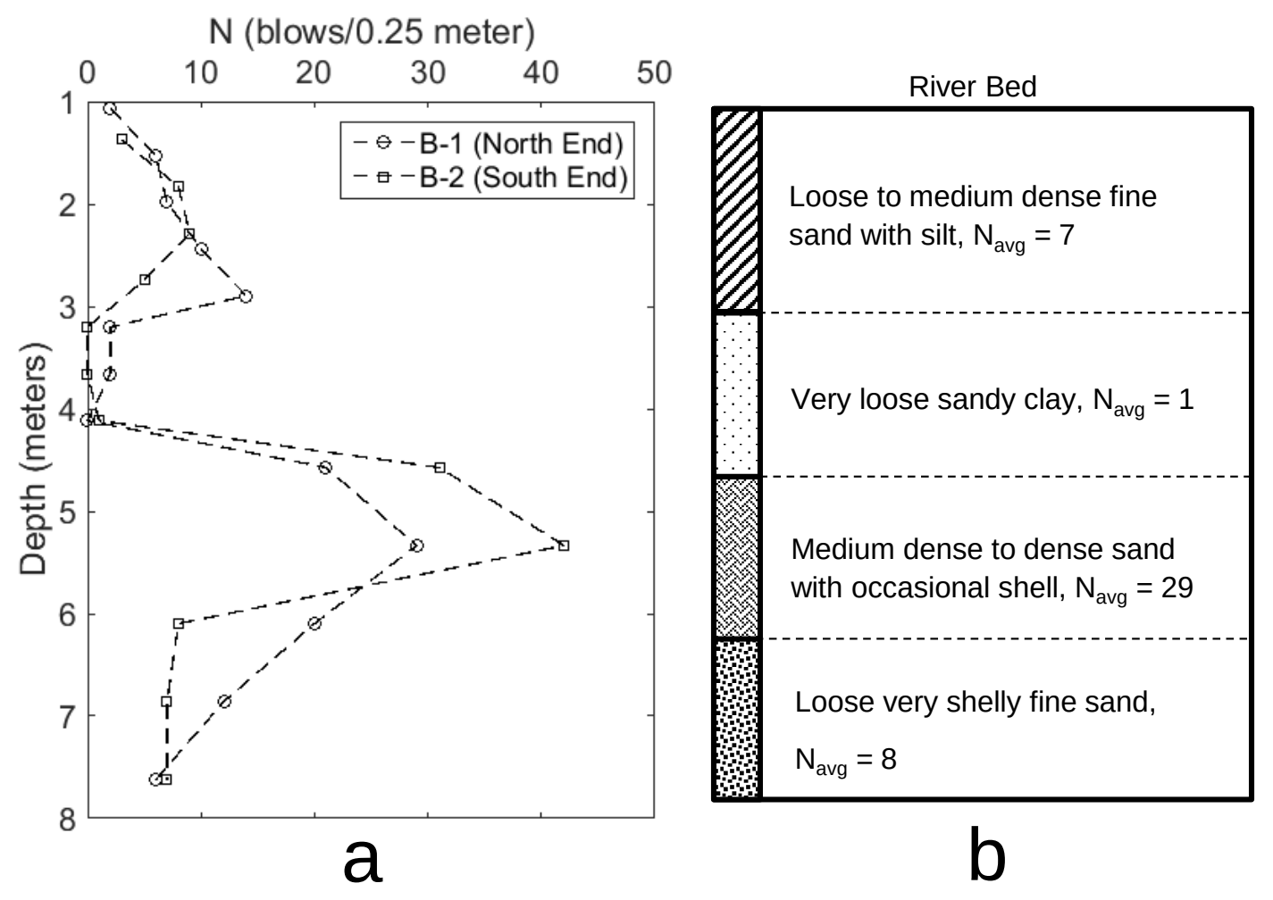

Figure 3. Subsurface profiles (a) SPT blow count and (b) soil stratigraphy

Stability Analysis

Modeling

- Break wall (Figure 4) model (Figure 5) developed using FB-Multipier to investigate stability under wave loading
- Model consisted of 14 piles, 2 m long, 9 cm diameter with properties of southern pine; Beam elements have properties of crepe myrtle
- Each pile has an axial capacity of 1.22kN and a lateral capacity of 1.24kN
- Distributed wave loading was calculated with equations for wave force acting on a pile and fluid force acting within the porous wall
- Calculated wave loading applied to model for dynamic analysis (Figure 6)

Figure 4. Break wall (Herbert, et al., 2018)

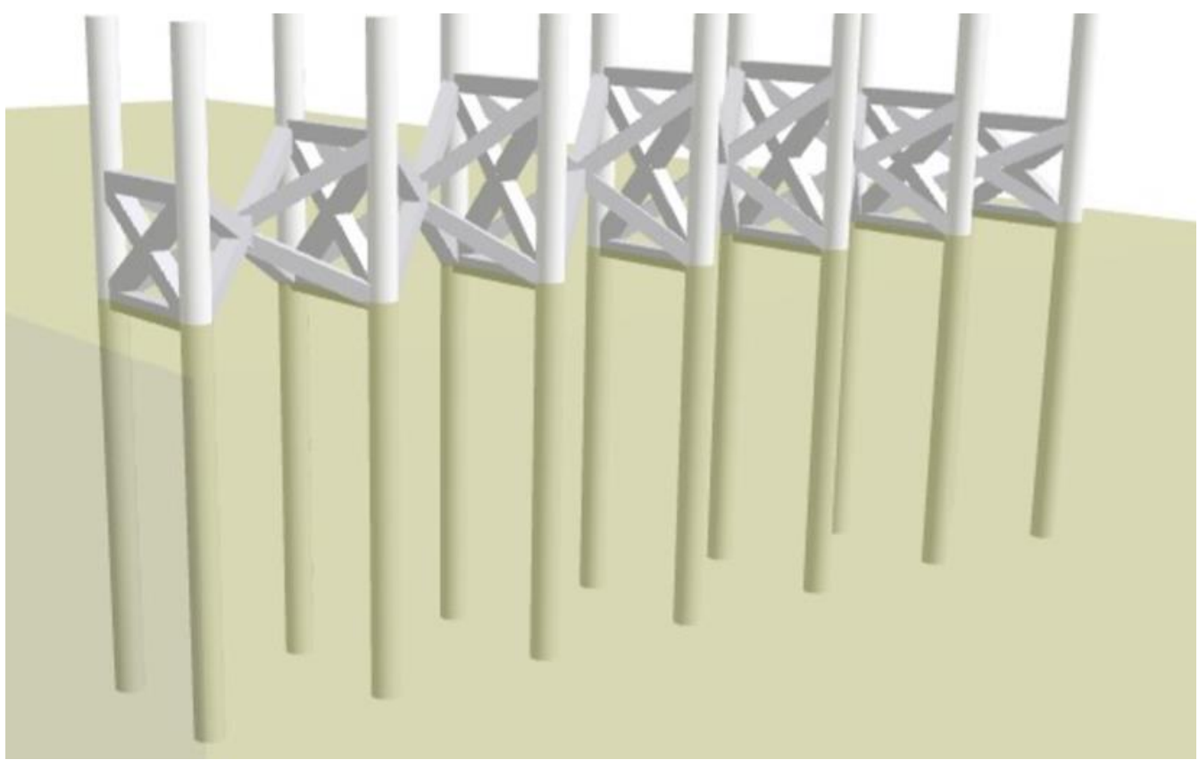

Figure 5. Model Break wall

Equations

- Non-breaking wave force on a pile (Morison et al., 1950)

$$F_p = (p_d + \rho g z)d + C_d \frac{1}{2}\rho d v_x|v_x| + C_m \rho \frac{d^2\pi}{4}\frac{\partial v_x}{\partial t}$$

- Fluid force within porous wall (Sollit and Cross,1972)

$$F = \frac{1}{\rho}\nabla(p_d + \rho g z) + \frac{\upsilon}{K_p} n v_x + \frac{C_d}{\sqrt{K_p}} n^2 v_x|v_x| + \frac{(1-n)}{n} C_m \frac{\partial v_x}{\partial t}$$

- Drag Coefficient (Arbhabhirama and Dinoy, 1973)

$$C_d = 100\left[d_{50}(m)\left(\frac{n}{K_p}\right)^{1/2}\right]^{-1.5}$$

- Permeability Coefficient (McDougal, 1993)

$$K_p = 1.643 \times 10^{-7}\left[\frac{d_{50}(mm)}{d_o}\right]^{1.57}\frac{n^3}{(1-n)^2}$$

- Inertia Coefficient (Liu et al., 1999)

$$C_m = \gamma \frac{1-n}{n}$$

where p_d is dynamic wave pressure, g is gravitational acceleration, d is pile diameter, ρ is density of saltwater, v_x is wave velocity perpendicular to wall, and $\frac{\partial v_x}{\partial t}$ is component of local acceleration of incident wave, d_{50} is median diameter of crepe myrtle branches, and n is porosity (volume of voids/total volume) of the break wall.

Lateral Displacements

- Distributed wave loading (Figure 6) changes with increasing wall porosity
- Lateral wall displacements are a minimum when wall porosity is 0.5 (Figure 7)
- Above porosity values of 0.50, lateral displacements increase a result of C_d.

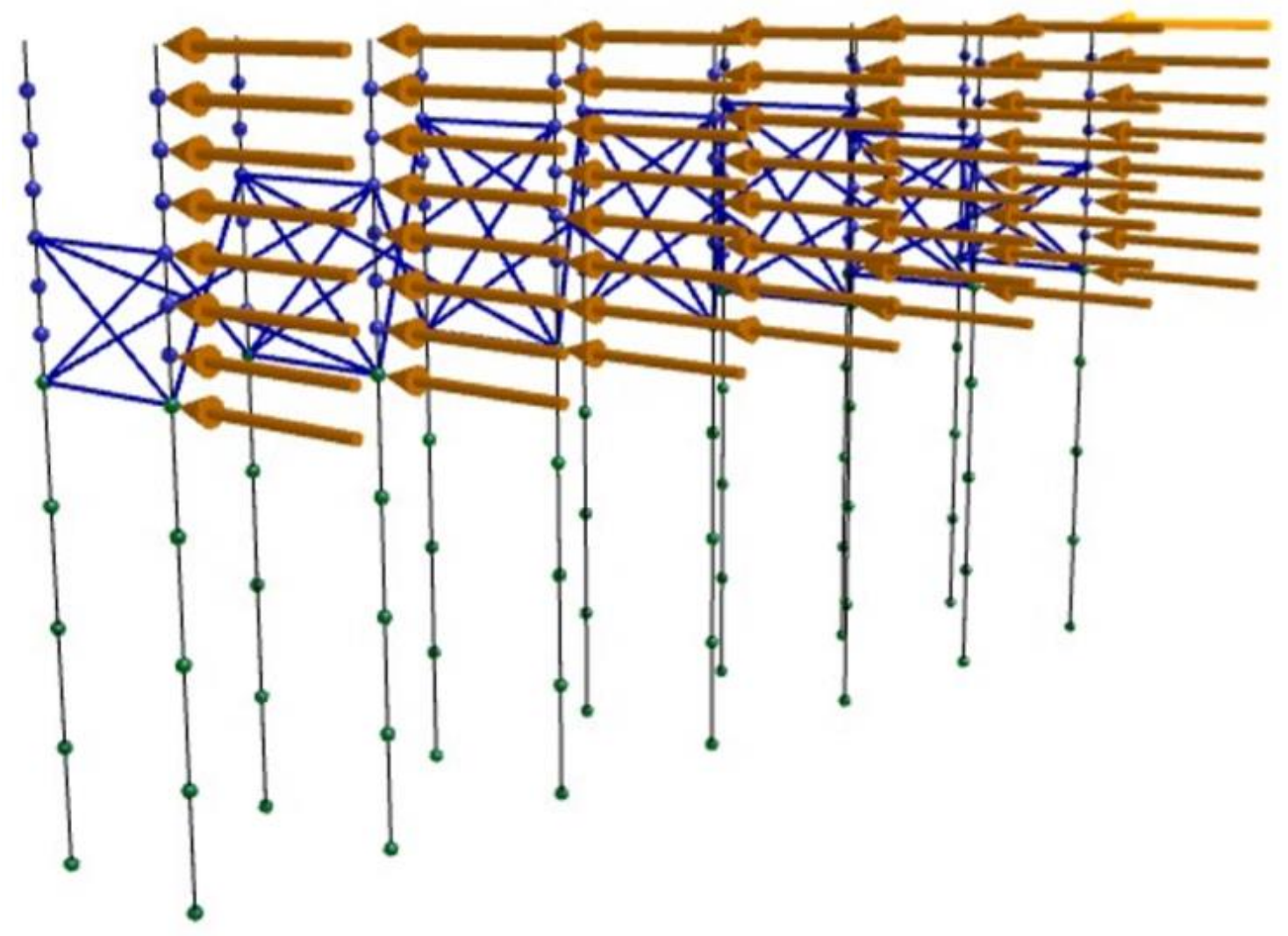

Figure 6. Thin Element Model with Distributed Load

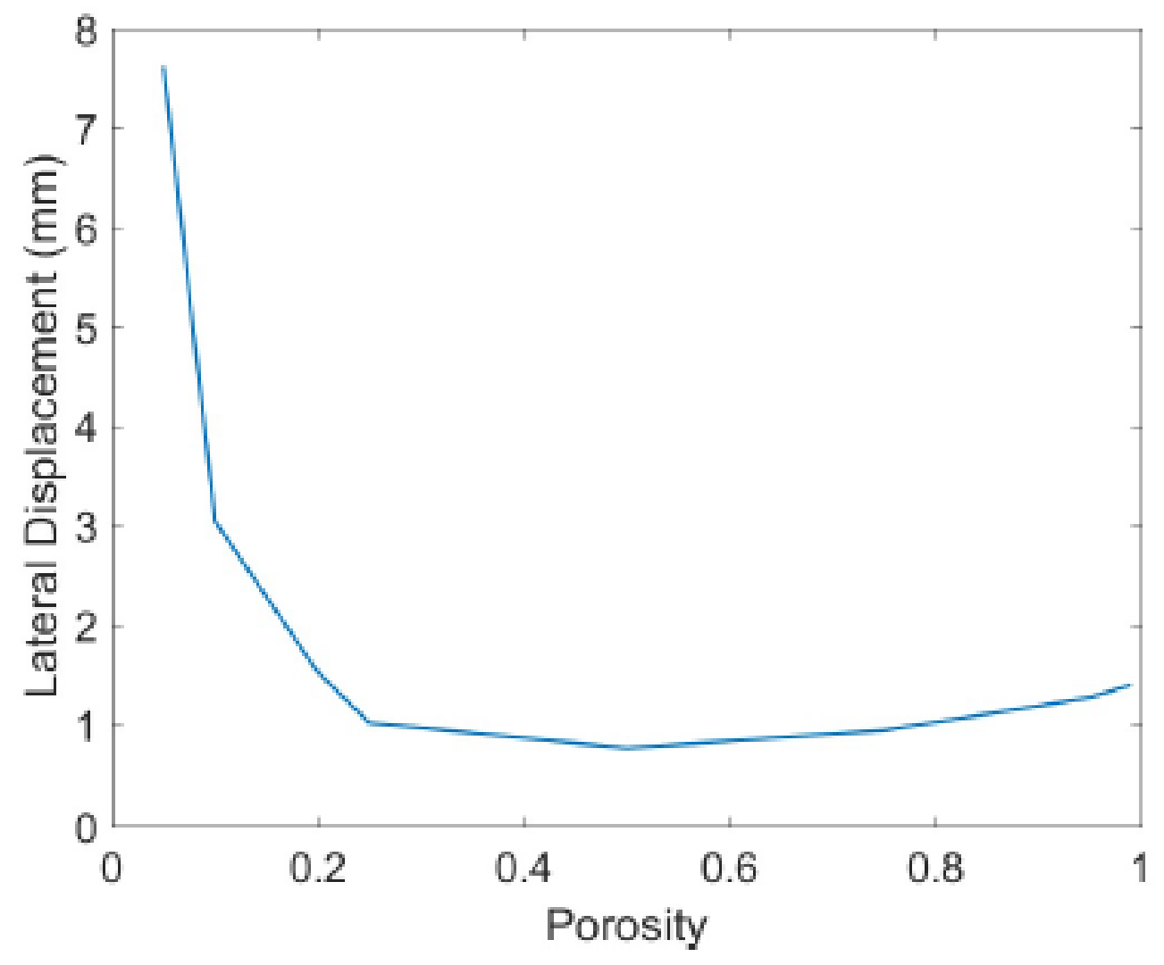

Figure 7. Wall lateral displacement (Herbert, et al., 2018)

Energy Dissipation Analysis

Energy Analysis

- Wave energy in three components: incident (E_i), reflected (E_r), and transmitted (E_t).

$$E_{i,r,t} = \frac{1}{8}\rho g H_{i,r,t}^2$$

  where ρ is density of saltwater, g is gravitational acceleration, and H is wave height
- Transmitted wave energy can be expressed as the transmission coefficient K_t.

$$K_t = \frac{H_t}{H_i} \text{ or } K_t = \sqrt{(1-(1-\eta)^2)}, \text{ when } H_t \text{ isn't known}$$

- The dissipated energy, E_d, for a porous break wall ((Figure 8) was calculated using

$$E_d = 2E_i K_t(1-K_t)$$

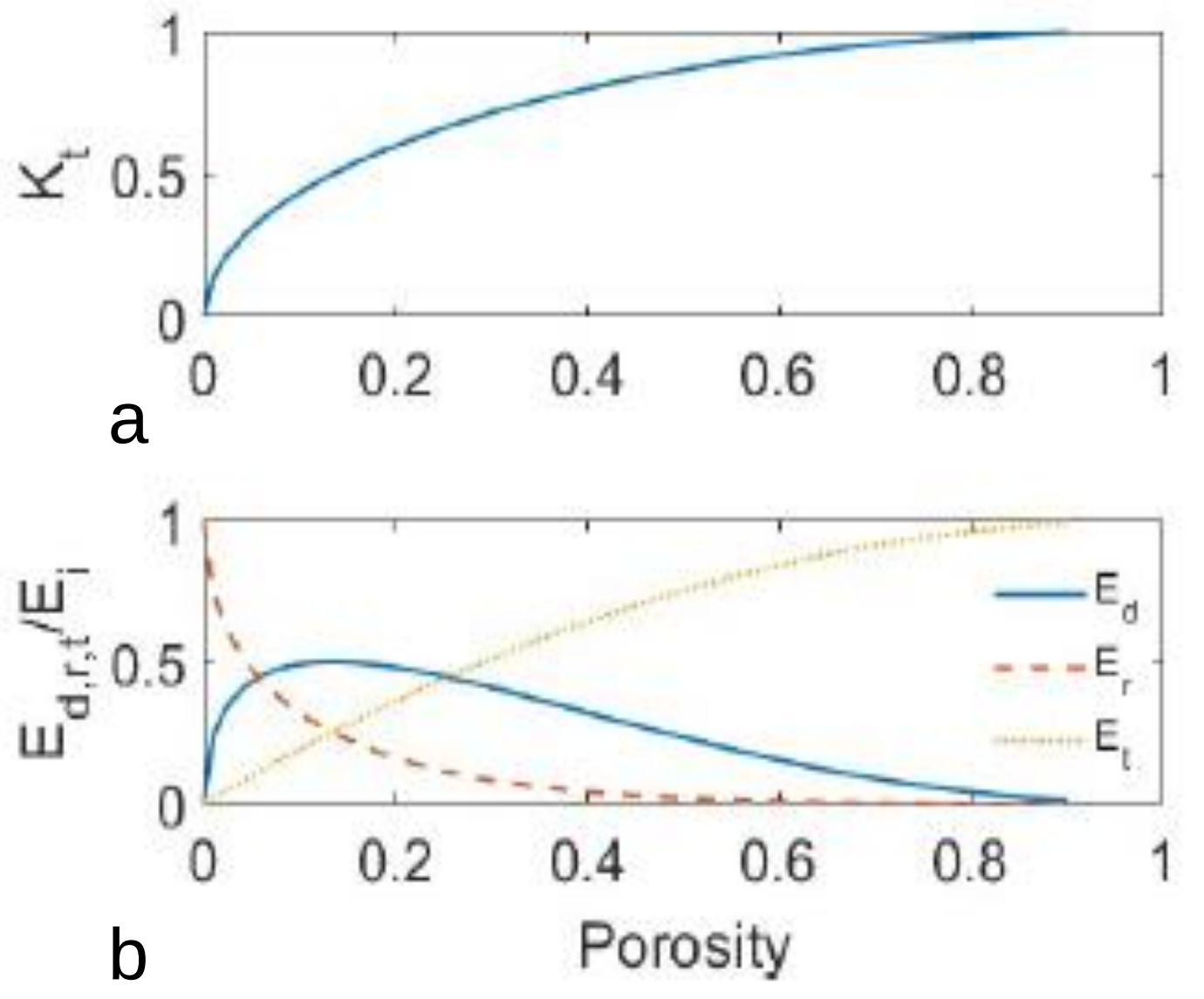

Figure 8. Influence of wall porosity (a) K_t and (b) normalized E_i, E_r, and E_t. (Herbert, et al., 2018)

Conclusions

- Lateral displacements are a function of the force within porous wall
- Drag, permeability, and inertia coefficients are function of porosity and physical characteristics of solids in porous volume
- Equations for coefficients used herein are only approximation for crepe myrtle branches and should be experimental determined
- Porosity of wall should be known for optimizing wall performance
- Analysis suggests maximum energy dissipation occurs at low porosity (0.18) while minimum lateral displacement occurs at higher porosity (0.5).
- Low porosity necessary to optimize wall performance and larger lateral displacements should be anticipated

Future Work

- Measure porosity and drag coefficient to compare how it affects the lateral displacement and energy dissipation versus the estimated values.
- Perform field experiments at pilot site wall which uses voided piles and measure incident, reflected and transmitted waves for various wall porosities while simultaneously measuring wall deflection.
- From wall deflections, estimates of dissipated energy will be made.

Acknowledgements

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