# A modified uniaxial *Bouc-Wen* model for the simulation of transverse lateral pipe-cohesionless soil interaction

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## 1. Introduction

- Most of the pipelines are buried underground and can be severely affected by geohazards.
- Therefore, it is vital to understand the interaction between the pipe and surrounding soil.
- The current practices use elasto-plastic and nonlinear load-deformation characteristics for soil springs, as in the guidelines of ASCE (1984), ALA (2005), PRCI (2009).
- This paper develops a new versatile physical-based methodology, originated from *Bouc-Wen* (BW) model that is capable of representing a wide range of nonlinearity of the backbone curves.

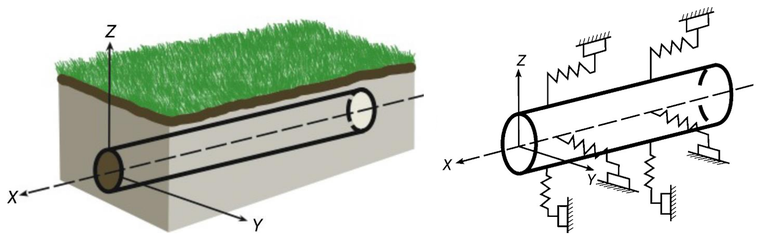



**Figure 1.** Continuum interaction and physical-based model [image by Revie (2015) ]

## 2. Modified *Bouc-Wen* model

- The transverse lateral soil reaction force F per unit length can be expressed by

$$F = \alpha K u + (1-\alpha) F_u \zeta$$

$$\dot{\zeta} = \frac{1}{u_0}\left(1 - \frac{\tanh(\kappa|\zeta|)}{\tanh\kappa}(\beta \mathrm{sign}(\dot{u}\zeta) + \gamma)\right)\dot{u}$$

- Parameter κ controls the smoothness of the transition zone and is the main focus of this study.

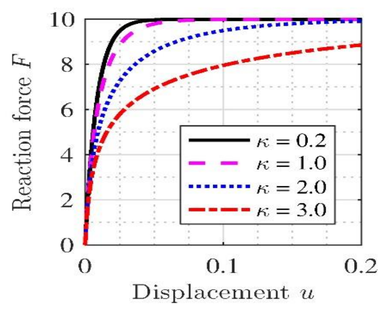



**Figure 2.** Smoothness of transition zones depends on κ

## 3. Determination of parameter κ

- Step 1. Finite element (FE) analyses to generate backbone curves F-u for loose and dense sand. The results were validated with experiments conducted by Trautmann and O'Rourke (1985).

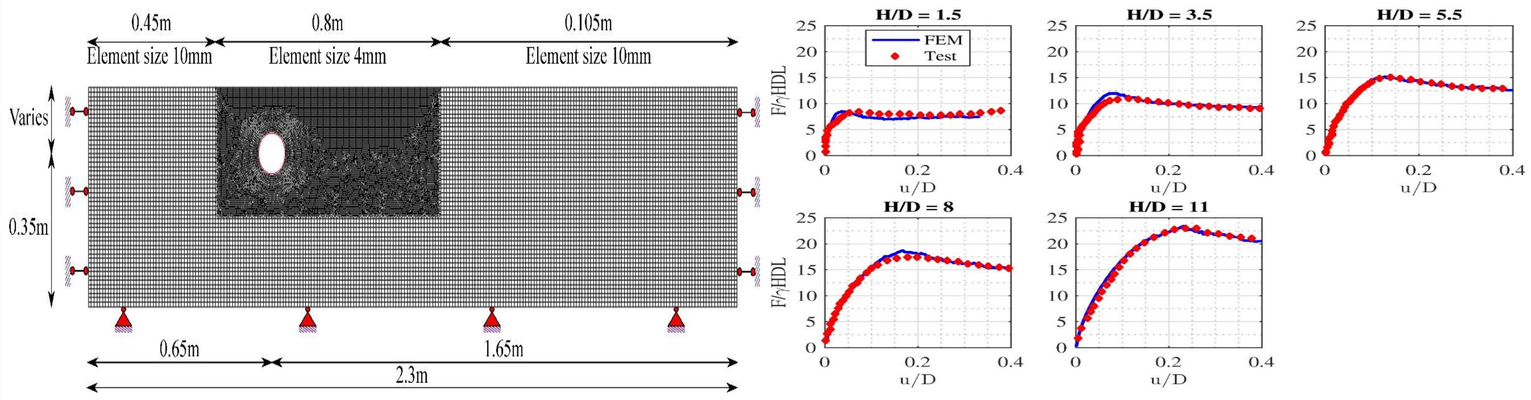



**Figure 3.** FE model and results validation

- Step 2. More curves F-u for different cases of ratio H/D were generated using FE models.
- Step 3. The unscented Kalman filter was used to derive κ from F-u curves generated by FE models.

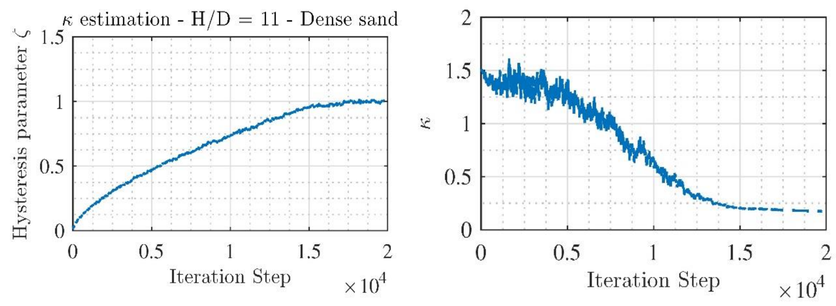



**Figure 4.** Unscented Kalman filter results

## 4. Validation

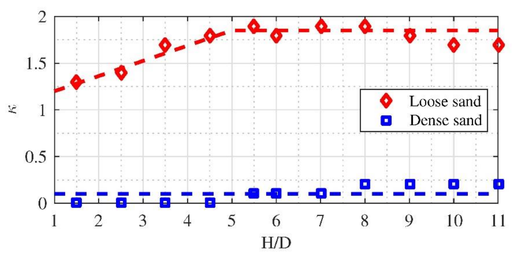
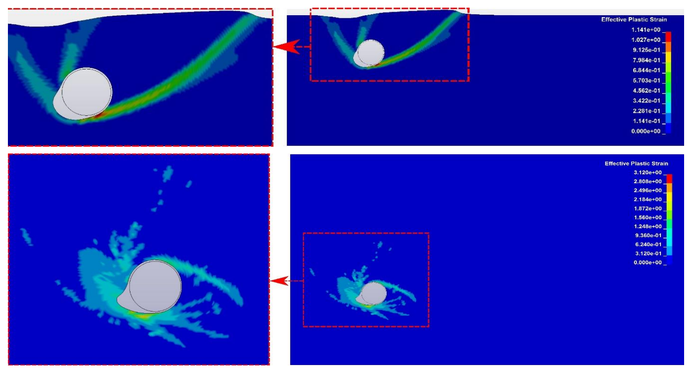



**Figure 5.** Variation of κ with depth. The trend of κ has a lot to do with the failure mechanism of the soil.



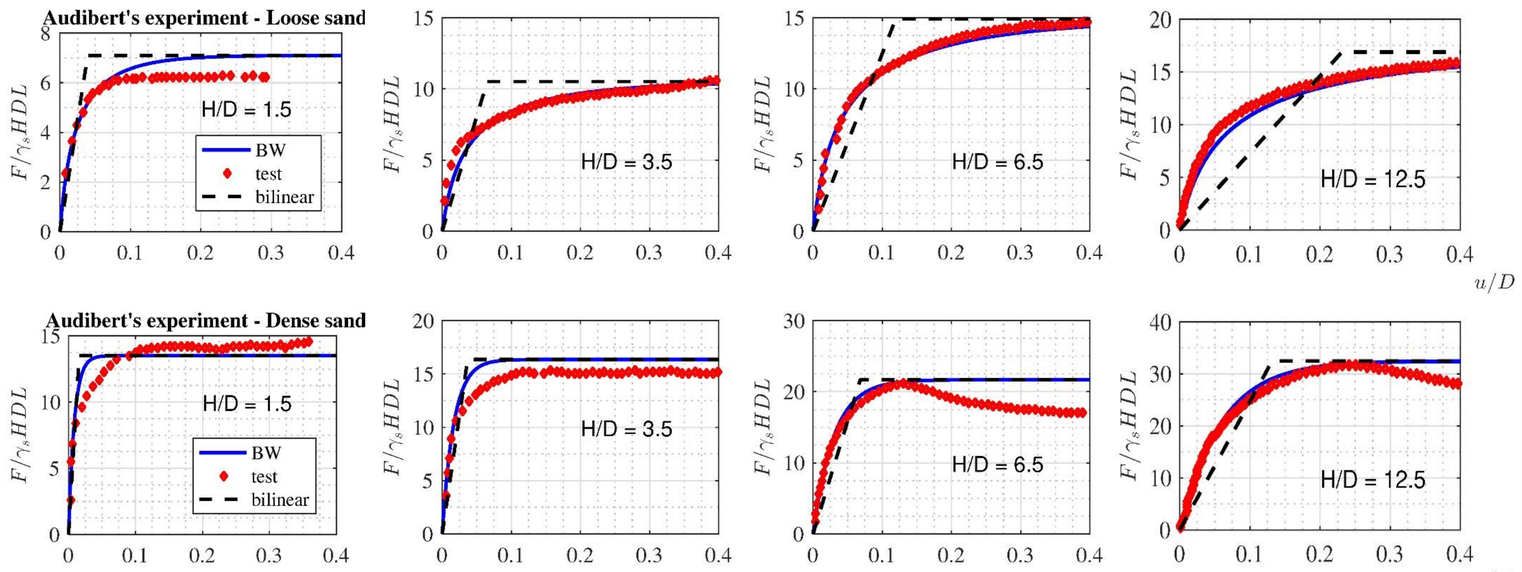



**Figure 6.** Comparison between modified BW model, experiments and bilinear model

## 5. Conclusion

- Loose sand κ = 1.2-1.9; dense sand κ = 0.0-0.2
- In region of "passive-wedge" failure mode, κ increases with H/D. In region of "plow-through" mode, κ approximately levels off.
- Results of modified BW model match well with experimental data.

## References

Audibert, J. M., & Nyman, K. J. (1977). Soil restraint against horizontal motion of pipes. *Journal of the Geotechnical Engineering Division, 103*, 1119-1142.

Bouc, R. (1971). Modele mathematique d'hysteresis. *Acustica, 21*, 16-25.

Revie, R. (2015). Oil and gas pipeline: Integrity and safety handbook. Wiley.

Trautmann, C. H., & O'Rourke, T. D. (1985). Lateral force-displacement response of buried pipe. *Journal of Geotechnical Engineering, 111*, 1077-1092.

Wen, Y.-K. (1976). Method for random vibration of hysteretic systems. *Journal of the engineering mechanics division, 102*, 249-263.

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