Investigation of a nonlinear gradient elasticity model for the prediction of seismic waves

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Abstract. A novel nonlinear gradient elasticity model for predictions of the seismic waves has been proposed by the authors in previous works, where higher-order gradient terms are introduced to capture the effect of small-scale soil heterogeneity/micro-structure. Here, several characteristics of the proposed model are investigated in depth. More specifically, the behaviour of the system is investigated for initial conditions that induce different levels of nonlinearity. Results show that when the initial conditions induce a high nonlinearity in the system, the response can exhibit peculiar shapes. Furthermore, the nonlinear system predicts a non-zero plateau trailing behind as the initial shape propagates away. It is shown that the higher the initial nonlinearity, the more pronounced the plateau. These findings offer insight into the characteristics of the proposed nonlinear gradient elasticity model.

Introduction

The prediction of the so-called seismic site response (i.e., the response of the top soil layers induced by seismic waves) is important for designing structures in earthquakes prone areas. For seismic loads that induce large soil strains, accounting for the nonlinear behaviour of the soil can be of importance for accurate predictions. In a previous authors' work [1], a nonlinear gradient elasticity model was proposed for predicting the seismic site response. The nonlinear constitutive behaviour of the soil is governed by the hyperbolic soil model, in which the (secant) shear modulus G is dependent on the shear strain γ through a non-polynomial relation, as follows

$$G(\gamma) = \frac{G_0}{1 + \left(|\gamma|/\gamma_{\text{ref}}\right)^{\beta}}, \tag{1}$$

where G_0 is the small-strain shear modulus and γ_{ref} and β are material constants. Furthermore, the classical wave equation was extended to a nonlinear gradient elasticity model to capture the effects of small-scale heterogeneity/micro-structure. The same model is used in this work too, in which a Gaussian pulse is imposed as an initial condition and the solution is determined using a novel finite difference scheme (see Ref. [1]). This work investigates the behaviour of the proposed model for different levels of initial nonlinearity. Namely, γ_{ref} is varied such that the initial nonlinearity induced by the initial conditions varies. This study offers insight into the characteristics of the proposed nonlinear gradient elasticity model.

Preliminary results

Compared to the classical continuum, higher-order gradient terms are introduced into the equation of motion, which lead to dispersive effects [2] prohibiting the formation of un-physical jumps in the response. Fig. 1 shows that the higher the induced nonlinearity, the more skewed the response; for extremely high nonlinearity, the response exhibits peculiar shapes (see right panel). Furthermore, the higher the nonlinearity, the more pronounced the plateau trailing behind the bulk of the propagating shape. The in-depth investigation of the proposed model's characteristics can be helpful when using it to accurately predict the seismic site response.

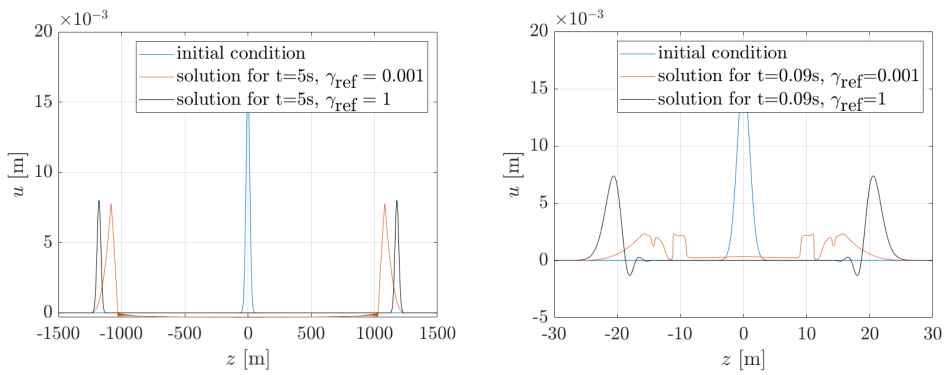

Figure 1: Displacement fields for varying levels of initial nonlinearity: quasi-linear ($\gamma_{\text{ref}} = 1$), mild nonlinearity ($\gamma_{\text{ref}} = 0.001$, left panel) leading to $G(\gamma_{\max}) = 0.6G_0$, and extreme nonlinearity ($\gamma_{\text{ref}} = 0.001$, right panel) leading to $G(\gamma_{\max}) = 0.1G_0$. The initial pulse is much thinner in the right panel causing a higher nonlinearity.

References

[1] Dostal L., Hollm M., Metrikine A.V., Tsouvalas A., van Dalen K.N. (2022) Localized stationary seismic waves predicted using a nonlinear gradient elasticity model. *Nonlinear Dyn* **107**:1107-1125.

[2] Metrikine A. (2006) On causality of the gradient elasticity models. *J. Sound Vib.* **297**:727-742.