Bolt looseness evaluation using highly nonlinear solitary waves in a granular chain

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In this study, we experimentally and numerically confirmed the potential of detecting bolt looseness using highly nonlinear solitary waves (HNSWs) in a granular chain and analyzed the underlying detection mechanism. The non-dispersive nature of solitary waves makes them useful in nondestructive testing (NDT), which has been explored across various fields in recent years. Upon the impact of a solitary wave onto inspection media, multiple reflected waves are generated with varying amplitudes, speeds and timings depending on the inspection medium. The measurement and analysis of these reflected waves offer valuable insights into the mechanical properties or alterations in the mechanical status of the inspection media. To investigate the effect of bolt looseness on the solitary wave reflection, we construct a specimen consisting of two stainless steel plates bolted together, where the bolt load is easily controllable. A granular chain consisting of 21 stainless steel beads, including a sensor particle designed to measure the solitary waves in the chain, is positioned on top of the bolt head. We confirmed that the HNSWs reflections changes depending on the fastening torque applied to the bolt. We numerically analyze the frequency response of the specimen and simulated the solitary wave inspection, which lead us to confirm that the change of vibration characteristics of the specimen depending on the bolt load substantially affects the solitary wave reflection. This finding shows that the HNSWs can distinguish not only the mechanical properties (i.e., young's modulus) but also the change of vibration characteristics of a structure. Thus, the HNSWs can be used to inspect the safety of various civil structures assembled using bolts.