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Cone Penetration Testing, a new approach to quantify coastal-deltaic land subsidence by peat consolidation

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It is undisputed that land subsidence threatens coastal-deltaic lowlands all over the world. Any loss of elevation (on top of sea level rise) increases flood risk in these lowlands, and differential subsidence may cause damage to infrastructure and constructions. Many of these settings embed substantial amounts of peat, which is, due to its mechanically weak organic composition, one of the main drivers of subsidence. Peat is very susceptible to volume reduction by loading and drainage induced consolidation, which dissipates pore water, resulting in a tighter packing of the organic components. Often, the current state of consolidation of peat embedded within coastal-deltaic subsidence hotspots (e.g. Venice lagoon, Mississippi delta, San Joaquin delta, Kalimantan peatlands), is somewhere between its initial (natural) and maximum compressed stage. Quantifying the current state regarding peat volume loss, is of utmost importance to predict potential (near) future subsidence when draining or loading an area.

The processes of subsidence often afflict large areas (>103 km2), thus demanding large datasets to assess the current state of the subsurface. In contrast to data describing the vertical motions of the actual surface (geodesy, satellite imagery), subsurface information applicable for subsidence analysis are often lacking in subsiding deltas. This calls for new initiatives to bridge that gap.

Here we introduce Cone Penetration Testing (CPT) to quantify the amount of volume loss peat layers embedded within the Holland coastal plain (the Netherlands) experienced. CPT measures soil mechanical strength, and hundreds of thousands of CPTs are conducted each year on all continents. We analyzed 28 coupled CPT-borehole observations, and found strong empirical relations between volume loss and increased peat mechanical strength. The peat lost between $\sim$20 – 95% of its initial thickness by dissipation of excess pore water. An increase in 0.1 – 0.4 MPa of peat strength is accountable for 20 – 75 % of the volume loss, and 0.4 – 0.7 MPa for 75 – 95 % volume loss. This indicates that large amounts of volume by water dissipation has to be lost, before peat experiences a serious increase in strength, which subsequently continuous to increase with only small amount of volume loss.

To demonstrate the robustness of our approach to the international field of land subsidence, we applied the obtained empirical relations to previously published CPT logs deriving from the peat-rich San Joaquin-Sacramento delta and the Kalimantan peatlands, and found volume losses that correspond with previously published results. Furthermore, we used the obtained results to predict maximum surface lowering for these areas by consolidation.

In conclusion, these promising results and its worldwide popularity yielding large datasets, open the door for CPT as a generic method to contribute to quantifying the imminent threat of coastal-deltaic land subsidence.