Centrifuge modelling of root-soil interaction of laterally-loadedtrees under different loading conditions

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Supplementary Material

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Reproducibility of push-over tests

A series of standard direct shear tests (following the ASTM standard D3080-04) on the model soil (prepared by the standard dry deposition technique, following Hariprasad *et al*., 2016) at a dry bulk density of 1.67±0.02g/cm^3 were conducted, including strictly repeated tests at two effective stresses (i.e., 100 and 200 kPa). The results are shown in Figure S1.

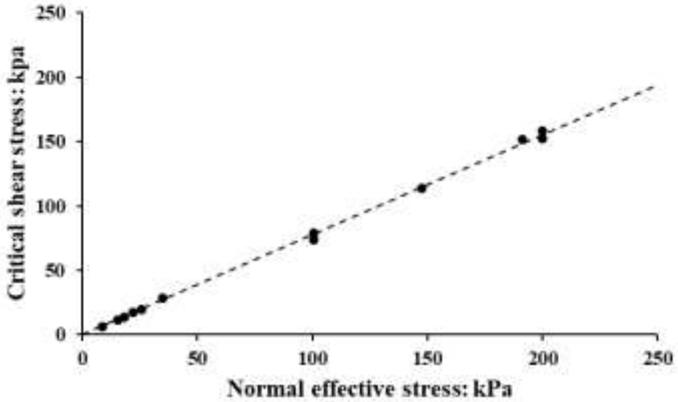

Fig. S1 Direct shear tests of model soil under different normal stress

Moreover, soil uniformity was verified in the centrifuge models, given that the soil volume was much larger than a shear box sample. During model preparation, six density cups (small circular open-topped containers with a sharp top edge and of known internal volume) were placed away from the root models to determine the spatial distribution of relative density of the soil as the soil was pluviated (following the standard procedures in Hariprasad *et al*., 2016, as used in the direct shear test). The relative density so measured remained in the range of 45-50%, which was deemed acceptable given the large size of soil model produced and typical of the variability expected in carefully-prepared centrifuge models using coarse-grained soils. The density measurements, combined with the direct shear tests suggest a high level of repeatability for the model soil beds used across the centrifuge test programme.

The material used to print the root models (ABS plastic) is reproducible following Liang *et al*. (2015), where repeated uniaxial tension tests (following the ASTM standard D638-14) and bending tests (following the ASTM standard D790-02) on the plastic model root analogues of different diameters were conducted.

Finally, a pair of centrifuge tests using the same ND root models at the same effective stress regime although under different ***g***-levels and water conditions (i.e. 12***g*** dry compared to 20***g*** fully saturated) was performed in Zhang *et al*. (2020). They can be considered as repeated tests to the extent that the effective stress regime is the same and the tests were conducted at a fully drained loading rate. As shown in Figure S2, the curves are in excellent agreement for the first 10° of trunk rotation, and the initial rotational stiffness was practically identical. Beyond 10° rotation, the maximum difference in peak moment resistance was within 15%. Based on careful inspection of exhumed root models post-test, the positions of root breakage were found to be almost identical (Zhang *et al*., 2020).

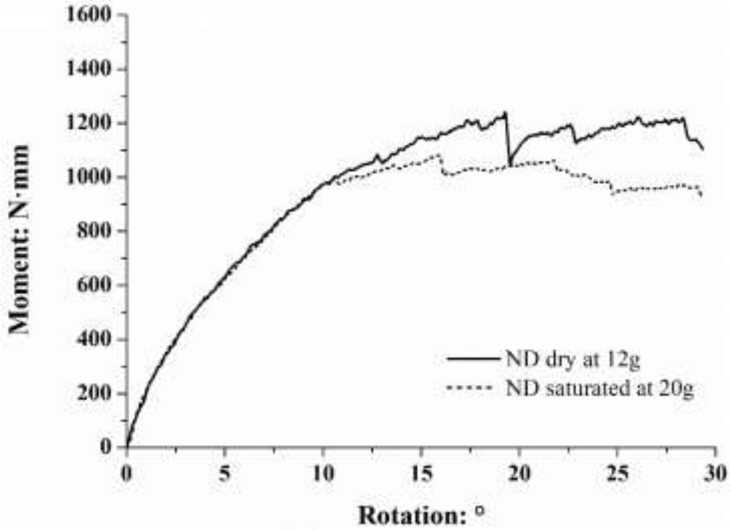

Fig. S2 Push-over curves of ND model roots in centrifuge at the same effective stress regime (expressed at model scale, after Zhang *et al*., 2020)

A pair of push-over tests using the ND root models at 1***g*** in both dry and fully saturated soil was also conducted in Zhang *et al*. (2020). With water buoyancy effects removed (i.e. the ratio of effective to dry unit weight of the model soil, 0.6, was used to multiply moments from the dry case for comparison), these curves matched similarly well (Fig. S3).

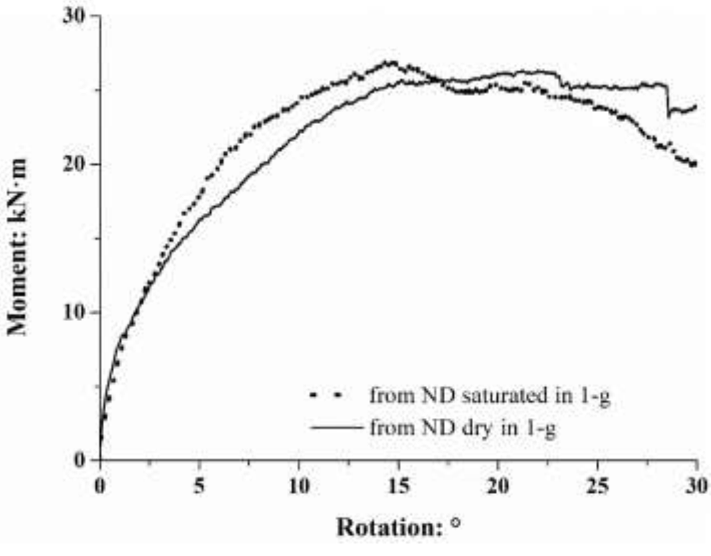

Fig. S3 Push-over curves of ND model roots at prototype derived from in 1g tests, with water buoyancy effects removed (after Zhang *et al*., 2020)

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