Unsaturated soils are commonly widespread around the world, especially at shallow depths from the surface. The mechanical behavior of this near surface soil is influenced by the seasonal variations such as rainfall or drought, which in turn may have a detrimental effect on many structures (e.g. retaining walls, shallow foundations, mechanically stabilized earth walls, soil slopes, and pavements) in contact with it. Thus, in order to better understand this behavior, it is crucial to study the complex relationship between soil moisture content and matric suction (a stress state variable defined as pore air pressure minus pore water pressure) known as the Soil Water Characteristic Curve (SWCC). This relationship is hysteretic, i.e., at given suction the moisture content differs depending on the drying and wetting paths. This hysteretic behavior is also referred to as hydraulic hysteresis.

The behavior of the SWCC has been widely studied and various models have been developed to capture this hysteretic behavior, but limited experimental data are available under different applied stresses (or at different void ratios) and do not include secondary drainage or scanning curves. The lack of SWCC experimental data is due to the long testing time of unsaturated soils. To this end, a new procedure was developed to shorten equilibrium time and obtain SWCC data as practically fast as possible. This new approach was used and SWCC tests under different stress states on silty soil specimens under drying, wetting, secondary drying, and along scanning curves were performed. Results from this study helped improve and validate existing models such as the elastoplastic constitutive model reported by Miller et al. (2008).

In addition, the influence of hydraulic hysteresis on the behavior of unsaturated soils, soil-structure interaction (i.e. rough and smooth steel interfaces, soil-geotextile interfaces) and pavement subgrade (depicted herein mainly by resilient modulus, $M_r$) was also studied. To this end, suction-controlled direct shear tests were performed on soils, rough and smooth steel interfaces and geotextile interface under drying (D) and wetting after drying (DW). The shearing behavior is examined in terms of the two stress state variables, matric suction and net normal stress. Results along the D and DW paths indicated that peak shear strength increased with suction and net normal stress; while the increase in suction was nonlinear. Contrary to saturated soils, results during shearing at higher suction values (i.e. 25 kPa and above) showed a decrease in water content even though the sample exhibited dilation. A behavior postulated to be related to disruption of menisci and/or non-uniformity of pore size, which results in an increase in localized pore water pressures. Interestingly, DW test results showed higher peak and post peak shear strength than that of the D tests. This is believed to be the result of many factors such as: 1) cyclic suction stress loading, 2) water content (less on wetting than drying), and 3) type of soil. The cyclic suction loading may have induced irrecoverable plastic strains, resulting in stiffer samples for wetting tests as compared to drying. Additionally, water may be acting as a lubricant and thus resulting in lower shear strength for test samples D with higher water contents than DW samples.

Furthermore, various shear strength models were investigated for their applicability to the experimental data. Models were proposed for the prediction of shear strength with suction based on the SWCC. The models are able to predict the shear strength of unsaturated soil and interfaces due to drying and wetting by relating directly to the SWCC. The proposed models were used and partly validated by predicting different test results from the literature. In addition, an existing elastoplastic constitutive model was investigated and validated by comparing the predicted and experimental (stress-displacement, volume change behavior) results obtained from rough and geotextile interface tests.

This study also explores the effect of hydraulic hysteresis on the resilient modulus ($M_r$) of subgrade soils. Suction-controlled $M_r$ tests were performed on compacted samples along the primary drying, wetting, secondary drying and wetting paths. Two test types were performed to check the effect of cyclic deviatoric stress loading on the results. First, $M_r$ were performed on the same sample at each suction (i.e. 25, 50, 75, 100 kPa) value along all the paths (drying, wetting etc.). A relationship between resilient modulus ($M_r$) and matric suction was obtained and identified as the resilient modulus characteristic curve (MRCC). MRCC results indicated that $M_r$ increased with suction along the drying curve. On the other hand, results on the primary wetting indicated higher $M_r$ than that of the primary drying and the secondary drying. The second type of test was performed at selected suction without subjecting the sample to previous $M_r$ tests. Results indicated that $M_r$ compared favorably with the other type of test (i.e. with previous $M_r$ testing), which indicates that the cyclic deviatoric stress loading influence was not as significant as the hydraulic hysteresis. A new model to predict the MRCC results during drying and wetting is proposed based on the SWCC hysteresis. The model predicted favorably the drying and then the wetting results using the SWCC at all stress levels.