Micropiles are slender structural elements, which are capable of carrying large loads when constructed with high-strength steels and embedded in soils of good load carrying capacity. Micropiles that penetrate soft soils are, however, in danger of buckling, which can limit their load carrying capacity.

The National and European standards state that for slender piles embedded in soils with undrained shear strengths of $c_u < 15$ kN/m^2 and $c_u < 10$ kN/m^2 respectively, the possibility of buckling must be checked. As a general rule there is no need to check the possibility of buckling for soils of higher shear strengths. However, examples indicate that these rules are not altogether reliable and that buckling is the limiting factor before the ultimate bearing capacity of the pile's cross section is reached. Literature outlining computational models for solving the buckling problem or pile load tests clearly provide indications that the risk of pile-failure due to buckling is underestimated in the current standards. To investigate the buckling behaviour in soft soils beyond an analytical consideration, appropriate tests were undertaken within the research assignment as described by this report.

As an initial step, a small-scale research device was designed, in which 80 cm long piles can be loaded, laterally supported by very soft and soft soils. Piles of different cross sections were tested in soils of various consistency. Buckling regularly determined the ultimate state of the system, even in soils with an undrained shear strength of $c_u > 15$ kN/m^2. During the load tests the axial forces on the pile and the lateral displacements of the pile axis where measured.

With the experience gained from the small-scale tests, a test device was developed in which 4 m long single piles pinned at their top and bottom were loaded experimentally. This involved the construction of two cylindrical containers, within which the test piles were centrally placed and the containers were filled with highly plastic clay. To assist in the placement of the soil and to ensure homogeneity concerning its undrained shear strength, the clay was remoulded to a liquid consistency and then pumped into the containers. The desired undrained shear strength, at which the pile load tests would be performed, was achieved by means of controlled consolidation with the help of additional surcharge and electroosmosis. The ultimate bearing capacities of unsupported composite piles, whose cross section consisted of a central 28 mm diameter steel rod surrounded by a hardened cement grout to form a 100 mm diameter composite pile, were determined. The ultimate bearing capacities obtained varied due to the uncertain tensile strength of the grout. For this reason additional tests were performed on aluminium piles with a profile of 40 mm x 100 mm, which provided a similar flexural rigidity as in the composite piles. Altogether 4 laterally supported piles where loaded until failure and documented extensively. The undrained shear strength varied between 8 kN/m^2 and 25 kN/m^2. The test-piles initially reacted very rigidly with hardly any lateral displacements. In all cases there was no sign of the onset of failure. Moreover, it occurred spontaneously, long before the fully plastic normal forces were reached in the pile section. When buckling was reached horizontal displacements increased significantly. Even on reducing the pile load a state of equilibrium could not be found. After the piles were dismantled, the aluminium profiles revealed no plastic deformations. During all loading tests the piles buckled in buckling modes whose half-wave lengths were clearly shorter than the maximum length of the test piles.

The calculation of the ultimate loads of embedded piles that are in danger of buckling is carried out on the basis of assumptions and estimates found in the currently available literature , which in this report were reviewed critically and compared with the results of the loading tests. Either the soil as well as the pile material are assumed to be linear elastic (ENGESSER'S solution (1885)) or the soil modelled as ideally plastic (WENZ (1972)) or thirdly, starting from a lateral displacement of the pile axis, bending deformations are computed as a result of the increasing normal and soil reaction forces, until the pile material starts yielding as a result of the induced stresses (e.g. solutions by MEEK (1999), WIMMER and ETTINGER (2004)). All of these models cannot characterize the present problem appropriately.

Therefore, mathematical models based on numerical methods were developed in the course of research work, which are able to describe all fundamental effects exhibited in the loading tests. The lateral reaction of the soil is described as a bilinear mobilisation function, in which a maximum soil resistance, characterising the flow of soil around the pile, is included. It is capable of considering imperfections in and limited strengths of the pile materials in the calculations. Load-displacement curves are computed showing the states of equilibrium of the non-linearly embedded pile. Two branches can be identified: prior to reaching the maximum soil resistance, the pile's normal force increases; if the maximum lateral deflection of the pile axis exceeds the deflection needed for full mobilisation of the ultimate lateral soil resistance, the normal forces, for which a state of equilibrium is possible, diminish with increasing lateral deflection. The equilibrium is unstable and the inflexion point of the two branches indicates a failure caused by the loss of stability. Additionally a check is performed as to whether the normal and bending strength of the pile material is exceeded prior to reaching this inflexion point. Because the mentioned states of equilibrium depend on the length of the buckling mode's half wave, it is necessary to check several possible modes.