# Summary

There is a growing need for in situ testing in day to day geotechnical projects, especially for soils that cannot be easily sampled in the undisturbed state and for increasing the cost effectiveness of the soil investigation. The flat dilatometer test (DMT) is one of the major in situ tests adopted in many parts of the world, as it is a simple, reliable, and robust tool to obtain common soil parameters in situ. With the rapid advance in both the manufacturing means, such as the (metal) 3D printing, and the instrumentation means, such as the mini sensors and the LabVIEW system, it is of great interest to further discover the potential of the DMT by obtaining more measurements of the soil response. This thesis presents a review of the DMT and the modified DMT followed by the design, use, and interpretation of an instrumented dilatometer test (iDMT) to cope with the problems recognized in the review.

First, this thesis explores the existing literature on the DMT and the modified DMT in many aspects. The review of the DMT underpins further development and interpretation of the iDMT, and, more importantly, reveals the stress relief phenomenon during the blade installation stage. During the initial phase of the membrane expansion, this stress relief, in turn, results in a reloading process and therefore may influence the determination of the contact pressure $p_0$. Since the $p_0$ pressure is crucial in the DMT indices and consequently plays a pivotal role in the interpretation for soil parameters, it is of great interest to mitigate the influence of the unload-reload effects. Furthermore, the data analysis out of the literature of the modified DMT sheds light on the non-linear nature of the pressure-displacement measurements regardless of whether a membrane expansion or a piston expansion and thus recognizes the need for measuring full pressure-displacement curve in a larger displacement range for non-linear soil behaviours. The review of the modified DMT with regard to the devices and the instrumentations opens the way for the design and development of the new iDMT. In addition, the relationship between the DMT and the cone penetration test (CPT) is reviewed and discussed, which paves the way for the comparison in the in situ testing campaign.

The design and development of the iDMT were iterative processes through prototyping. A laboratory prototype was first built for the proof-of-concept purpose. Details of the development with a 3D printing technique and calibrations in the lab are given and followed by the discussion on a preliminary calibration chamber test with both the iDMT blade and the DMT blade wished-in-place in a dry Mol sand for a comparison. With the experience gained in this pilot study, the iDMT and its test procedure are standardized for in situ testing. The latest iDMT is featured by the use of a 60-mm diameter rigid piston with a displacement up to 2.5 mm and pore-water pressure measurements at the piston center. The fabrication of the iDMT uses a hybrid manufacturing method which combines the metal 3D printed parts in 420 stainless steel infiltrated with bronze and the machined parts in 420 stainless steel by means of tungsten inert gas (TIG) welding with $CuSi_3$ as filler, which proves sufficiently robust for the geotechnical testing applications and may inspire future development of other geotechnical testing devices. Moreover, with the help of automatic control and continuous measurements, a pseudo displacement-controlled algorithm programmed in the state machine architecture in LabVIEW is developed for an iDMT test procedure allowing comparable conditions with the DMT. This may allow the use of the well-established DMT correlations with common soil parameters in the iDMT interpretation.

A testing campaign using the iDMT, the DMT, and the CPT is conducted at three sites in Belgium. Based on the observed pressure-displacement curves of the iDMT results and the presented review on the stress relief phenomenon, an analytical approach is proposed to estimate the iDMT contact pressure $p_c$. This approach programmed in MATLAB consists of determining the transitional "yield" point on the corrected loading curve and then estimating the iDMT contact pressure $p_c$ using the post-yield phase of the curve via a proposed exponential-linear regression model. Note that an adapted Casagrande method is proposed for locating the "yield" point in case that a smooth loading curve is measured, rather than having an angular discontinuity. To investigate the rigid piston expansion process, a finite element method (FEM) analysis is carried out. Despite the simplification of the boundaries and the approximation of numerical results, the results indicate that the pressure $p_1$ required for a 1.1 mm central movement of the 60-mm diameter membrane can lead to approximate 0.56 mm and 0.85 mm displacement of a rigid piston with a diameter of 40 mm and 60 mm, respectively. Note that an alternative elliptical boundary is used in the FEM analysis to prevent the broken elements (displacement jump). Then, the iDMT indices can be calculated based on the $p_c$ pressure and the $p_{0.56}$ pressure at 0.56 mm/the $p_{0.85}$ pressure at 0.85 mm. The iDMT indices allow the potential derivation of common soil parameters via the well-established DMT relationships. Good agreement is achieved not only between the DMT indices, the CPT-predicted DMT indices, and the iDMT indices but also among the iDMT-derived, the-DMT derived, and the CPT-derived common soil parameters such as the coefficient of earth pressure at rest $K_0$, the overconsolidation ratio $OCR$, the undrained shear strength $C_u$, the effective friction angle $\phi^{'}$, and the DMT determined vertical drained constrained modulus $M_{DMT}$.

It is worth mentioning that the presented work in this thesis is the first stage of the use of iDMT in soil investigation. There is inevitably a trade-off between sticking to the original DMT test procedure or establishing a completely new iDMT test procedure. The adopted path, for now, is in the middle, which allows comparable conditions between the DMT and the iDMT. Albeit in this way the potential use of iDMT advantages such as the pore-water pressure measurements has not yet been fully taken. The iDMT is at least fully operational with the classic DMT relationships to derive common soil parameters for day to day geotechnical applications, and the problems, such as the influence of unload-reload effects on $p_0$, identified in the literature review has been successfully addressed.