Abstract

Vibrations in the ground are a matter of growing concern, especially in densely populated areas. Beside natural vibration sources as seismics and wave loading, manmade vibrations gained in importance in recent years as recent developments lead to a significant increase of the traffic volume. This comes along with higher construction activities in urban areas as the built environment needs to be adapted to new demands. Machine foundations and wind power plants are further examples for manmade vibrations sources. As a result significant higher vibration levels as in the past are observed. This increased dynamic impact may lead to a reduction of serviceability and diminish the lifetime of buildings. For this reason it is important to investigate consequences of vibrations in the ground with respect to their damage risks for buildings. Another important aspect is the consideration of permanent or long term vibrations at low strains in the design process. More detailed understanding of the mechanisms in the soil during dynamic long term impacts would allow for optimisation in dimension foundations, leading to economically advantageous design.

The understanding of mechanisms in the soil caused by low level vibrations, their consequences on the built environment, their modelling and prediction are in the focus of this work. In particular the elasto-plastic long term behaviour of non-cohesive granular soil under cyclic loading at the low strain level is studied in experimental investigations as well as in theory. The conducted literature study revealed that single dynamic events at the low strain level can be considered to be purely elastic as no plastic deformations are detectable. Accordingly, the dynamic soil behaviour can be well modelled using simple elastic constitutive laws. As a consequence, residual deformations cannot be predicted using common dynamic soil models. Both field measurements and laboratory investigations, however, have proven

non-negligible permanent deformations after application of large numbers of dynamic load applications.

This process of strain accumulation is explained as a kind of aging process of the soil, comparable to creeping due to dynamic loading in other materials. In general, the accumulation process is characterised by three main influencing aspects: the current state of the soil, the current state of stress and the characteristics of the dynamic impact. The combination of these parameters defines the intensity as well as the direction of accumulation. Theoretical considerations in combination with experimental studies on these accumulation phenomena are subject of main interest in this thesis. Constitutive models for accumulation prediction in the literature are studied and evaluated regarding their power and applicability.

Based on these cognitions a new accumulation model is proposed for prediction of accumulation problems. The essential advantages of this approach are the small number of model parameters, the simple formulation and the proper implementation in a commonly used finite element code. All model parameters can be determined from a single kind of laboratory test, namely the cyclic triaxial test. The simple formulation allows for easy comprehension, extension and general applicability for a wide range of practical problems. The implementation in the finite element code supports the use of the model in practical applications.

The validation of any accumulation model is difficult. Up to now experimental investigations considering all, current state of the soil, current state of stress and the characteristics of the cyclic loading, are quite rare both in the field and in laboratory tests. For this reason advanced cyclic triaxial and bender element test equipment is set up at the Laboratory of Geotechnics, Department of Industrial Engineering Sciences, KHBO in Ostende, Belgium in the frame of the present work. A test procedure including sample preparation, saturation, consolidation, bender element and cyclic triaxial testing of cylindrical soil samples is defined. The apparatus allows for the investigation of elastic material properties and the accumulation behaviour of soil. A wide range of test options allows for consideration of many influence parameters in laboratory tests.

In testing campaigns the influence of different parameters on the elastic material behaviour as well as on the accumulation properties of the sand of Mol is investigated. Thereafter a hyperbolic non-linear constitutive model well describes the degradation of soil stiffness with increasing cyclic

strain amplitudes. An empirical formulation, developed on the basis of resonant column tests to describe the maximum shear modulus as a function of the void ratio and the mean effective stress, is also valid for bender element test results. An influence of the cyclic loading frequency on the elastic material properties is not detected in the range of 0 to 10*Hz*.

Test results confirmed the applicability of elastic constitutive laws for description of the dynamic soil behaviour. The elastic material parameters are found to be independent from the number of load cycles already applied. During accumulation of large numbers of cycles, however, non-negligible residual deformations are observed. Increasing void ratios and cyclic strain amplitudes lead to increasing strain accumulation rates. An influence of the cyclic loading frequency on the accumulation behaviour is not detected in the range of 0 to 10*Hz*. Therewith the frequency content of a dynamic impact is of minor importance for accumulation predictions. Test results of long term cyclic triaxial tests are used for validation of the proposed accumulation model. The procedure of parameter identification is described. Good agreement of test data and the accumulation model under consideration is achieved.

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Ghent, September 2007