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Loading rate effects on pile load-displacement behaviour derived from back-analysis of two load testing procedures

Thesis presented for the degree of Doctor in Applied Sciences

by

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Abstract

Soils, like several other materials, exhibit strong time-dependent behaviour which can be evidenced in terms of creep or strain-rate effects. The degree of this rheological behaviour varies with the type of soil, its structure, and with the stress history. This effect is exacerbated in pile load testing where the procedure duration tends to be shortened under increasing time pressures. The modelling needed to interpret the results therefore becomes more and more complex, including soil viscosity, wave radiation into the soil and other significant phenomena. Within this framework, it would be interesting to study the influence of the loading rate on the load-displacement behaviour of the pile through the results of two testing procedures loading piles with variable duration (Static Loading Test (SLT) used as reference and Dynamic Load Test (DLT)). Based on these data issued from two national research programs organised by the Belgian Building Research Institute (BBRI), the objective of the research reported herein is to refine the rheological parameters characterizing the influence of the loading rate within the framework of a relevant pile/soil interaction model fed with dynamic measurements acquired during pile Dynamic Load Tests. The final goal is to predict and simulate the quasi-static pile load settlement curve.

After an overview of the loading rate effects in the literature through the experimental and modelling aspects, the dynamic data measured on field are analysed. It has been observed that some relationships exist between maximum quantities such as: energy transmitted to the pile, pile head velocity and force and the settlements (maximum and permanent) measured after a sequence of blows during a DLT event. These relationships are similar for the sandy and clayey sites and repeatable in time. It has been found that there are some critical quantities (correlated with the hammer drop height) from which a significant settlement of the pile is possible while the pile does not settle if these quantities are not exceeded.

The pile/soil interaction system is described by a non-linear mass/spring/dashpot system supposed to represent the pile and the soil, with constitutive relationships existing within and between them. These relationships account for the static and the dynamic or rheologic behaviour. A back-analysis process based on a matching procedure between measured and computed curves (force and velocity) allows one to describe the pile/soil interaction in terms of constitutive and rheologic parameters based on the

dynamic measurements. After optimisation of the matching procedure, the parameters obtained are used to simulate the “static” load-settlement curve. The matching procedure is based on an automatic multi dimensional parameter perturbation analysis. Since the parameters influence the system response with a relative weight, they are sorted in order to optimise all the parameters by successively retrieving the most influential ones and working on the remaining ones.

The back-analysis performed on dynamic measurements of both sites of Sint-Katelijne Waver (B) and Limelette (B) are generally successful but the obtained pile/soil system description appears to be unrealistic for some of the parameters. Consequently, the pile/soil model has been readjusted in order to account for the slippage between pile and adjacent soil along the pile shaft. This refinement increases the number of degrees of freedom needed to describe the pile/soil system but brings deeper insight into the behaviour of an interfacing zone of limited thickness surrounding the pile shaft.

Résumé

Le sol, comme bon nombre de matériaux, est fortement influencé par le facteur temps. Cette influence s'exprime par des propriétés de fluage et de relaxation ainsi que par une dépendance vis-à-vis de la vitesse de déformation. Ce comportement rhéologique varie en fonction du type de sol, de sa structure et de son histoire de chargement. Ce caractère est fortement marqué dans les résultats d'essais de mise en charge de pieux effectués à différents vitesses de chargement.

Si la durée de mise en charge tend à être raccourcie pour des raisons de rendement, le travail de modélisation nécessaire pour interpréter les résultats devient de plus en plus complexe du fait des facteurs mis en jeu tels que la viscosité du sol ou le rayonnement des ondes dans le sol. C'est dans ce contexte que s'inscrit cette recherche dont l'objet réside dans l'analyse de l'influence de la vitesse de mise en charge d'un pieu sur sa courbe de chargement. Des données issues de deux campagnes nationales d'essais organisées par le Centre Scientifique et Technique de la Construction (CSTC) et provenant de deux procédures de mises en charge à vitesses différentes (mises charge statique et dynamique) sont utilisées. L'objectif est de quantifier et de caractériser les paramètres rhéologiques définissant l'influence de la vitesse de mise en charge dans un modèle pieu/sol cohérent et, sur base des mesures de chargement dynamique, de simuler la courbe quasi-statique de charge-enfoncement du pieu étudié.

Premièrement, une étude de la littérature traitant du sujet tant sur les aspects expérimentaux que modélisatoires est proposé. Ensuite, une analyse des données dynamiques mesurées est effectuée et des relations particulières entre grandeurs physiques maximum sont mises en lumière. Ces grandeurs sont soit la vitesse particulaire de la tête du pieu, soit l'onde de force la traversant ou soit l'énergie transmise au pieu. Elles sont liées aux enfoncements maximum et permanent du pieu suite au coup donné. Ces relations montrent qu'il existe des seuils, appelés valeurs critiques, au dessus desquelles l'enfoncement permanent devient significatif alors que pour des valeurs inférieures, aucun enfoncement permanent n'est observable.

Le modèle d'interaction pieu/sol est décrit par un système de masses/ressorts/amortisseurs non linéaires modélisant le pieu, le sol et les relations constitutives les liant. Ces relations rendent compte des comportements statique et dynamique. Un processus d'analyse inverse basé sur l'ajustement de signaux mesurés (signaux dynamique et cinématique en tête de pieu) et calculés permet de décrire l'interaction sol/structure au moyen des paramètres constitutifs et rhéologiques du sol. Ainsi

l'optimisation de cet ajustement de courbes implique que la description du modèle pieu/sol y résultant est satisfaisante. La courbe de mise en charge statique correspondante peut être simulée et comparée à celle mesurée lors de l'essai de mise en charge statique.

La phase d'ajustement est basée sur une analyse stochastique des paramètres décrivant le système pieu/sol. Comme chaque paramètre a une influence relative sur la réponse du système, une classification est opérée de manière à optimiser tous les paramètres et à retirer successivement les plus influents pour pouvoir optimiser les paramètres restant. L'analyse inverse effectuée sur les enregistrements des deux sites (Sint-Katelijne-Waver (B) et Limelette (B)) donne de bons résultats en terme d'ajustement mais ne permet pas de caractériser correctement et physiquement le modèle pieu/soil utilisé. Ce modèle a donc dû être modifié pour tenir compte du glissement à l'interface pieu/sol le long du pieu. Cette amélioration du modèle n'est pas sans conséquence sur le nombre de degrés de liberté et donc sur la complexité du modèle et permet d'étudier en détail le comportement du sol dans une zone d'épaisseur limitée entourant latéralement le pieu.

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