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LAND SUBSIDENCE IN SHANGHAI (P.R. of China)

LE TASSEMENT DES SOLS À SHANGHAÏ (R.P. de Chine)

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Abstract

This study has been carried out under an International Cooperation Agreement between the People's Republic of China and Belgium. The final aim of the work is the detailed analysis of the geology, hydrogeology and engineering geology in the central area of Shanghai with an accurate simulation by a mathematical model of the subsidence occurring in this town and caused by groundwater withdrawals.
The detailed study of the Quaternary layers in the upper portion of 70 meters has revealed a complex geometry of the different units composed of clay, loam, silt and sand. The features of the deposits have shown variation of the sedimentation process from estuarine to fluviatile conditions as a function of sudden river avulsions and tidal changes.
Synthesis and compilation of all the hydrogeological and geotechnical tests made *in situ* on samples habe been completed. Many complementary tests (pumping tests, well-logging, pressuremeter tests, high and low pressure oedometer tests) have given the data needed by the mathematical model. On the basis of the results, hydrodynamic and geomechanical parameters of all the geological units have been determined.
Data relative to withdrawal or recharge of water in the zone have been introduced in the model. Compaction and subsidence measurements in different places allow the calibration of the model.
The Finite Element Method has been chosen using the LAGAMINE code developed at the University of Liege. This method allows to the use or very accurate spatial separation taking into account heterogeneities and facies variations of the layers. The simulation has comprised a 3D flow model giving as results the values and spatial distribution of the water pressures at each time step. Then, a coupled non-linear flow-compaction model has computed the subsidence as a function of time, taking the pressure variations in the aquifers as stress data. After the calibration procedure, simulations have been computed with « neutral » conditions (recharge ≥ pumping) and with "intensive pumping conditions" (pumping = 1.3* recharge).
The computed additional compactions between 1989 and 2000 in the last conditions are from 1.4 to 7.9 cm. The more sensitive zones have been located and the pumping effect on the subsidence rate has been quantified.

Résumé

Cette étude a été réalisée dans le cadre d'un contrat de Coopération Internationale entre la République Populaire de Chine et la Belgique. Le but de la recherche est l'étude approfondie des conditions géologiques, hydrogéologiques et géotechniques de la zone centrale de Shanghaï et la réalisation d'un modèle mathématique permettant de simuler avec précision les phénomènes de subsidence qu'a subi cette ville suite aux pompages d'eaux souterraines.
L'étude détaillée des terrains supérieurs du Quaternaire a été réalisée jusqu'à 70 mètres de profondeur et a permis de distinguer une séquence de géométrie complexe composée d'argiles, de silts et de sables. Les caractéristiques de ces sédiments ont indiqué une sédimentation oscillant entre un régime estuarien et un régime fluviatile en fonction des déplacements du chenal et de l'estuaire du fleuve.
Après compilation et synthèse de tous les essais hydrogéologiques et géotechniques réalisés *in situ* et en laboratoires, une série d'essais complémentaires (essai de pompage, diagraphies, essais pressiométriques, oedomètres basse et haute pression) ont permis de compléter les données indispensables au modèle mathématique. Sur base des résultats, les caractéristiques hydrodynamiques et géomécaniques de toutes les formations présentes ont été déterminées.
Les données relatives aux quantités d'eau pompées et réinjectées ont été introduites dans le modèle et d'autre part, les tassements mesurés en différents endroits de la zone étudiée permettent de calibrer le modèle.
La méthode utilisée est celle des éléments finis, en utilisant le programme LAGAMINE développé à l'Université de Liège. Cette méthode permet une discrétisation spatiale très précise, tenant compte des hétérogénéités et des variations de faciès des terrains. La simulation a comporté un modèle écoulement 3D fournissant les valeurs et la répartition des pressions d'eau dans la zone modélisée à chaque pas de temps. Ensuite, un modèle écoulement-tassement non-linéaire et couplé a calculé les tassements en fonction du temps, en reprenant comme « sollicitation » les variations de pression aux aquifères. Après la phase de calibration, des simulations ont été réalisées en conditions « neutres » (réalimentation ≥ pompages) et en conditions de pompage intensif (pompage = 1.3* réalimentation).
Les tassements calculés entre 1989 et 2000 dans ces dernières conditions sont de 1.4 à 7.9 cm selon les endroits. Les zones les plus sensibles aux tassements ont été localisées, les effets sur les tassements d'une éventuelle reprise du pompage ont été quantifiés.

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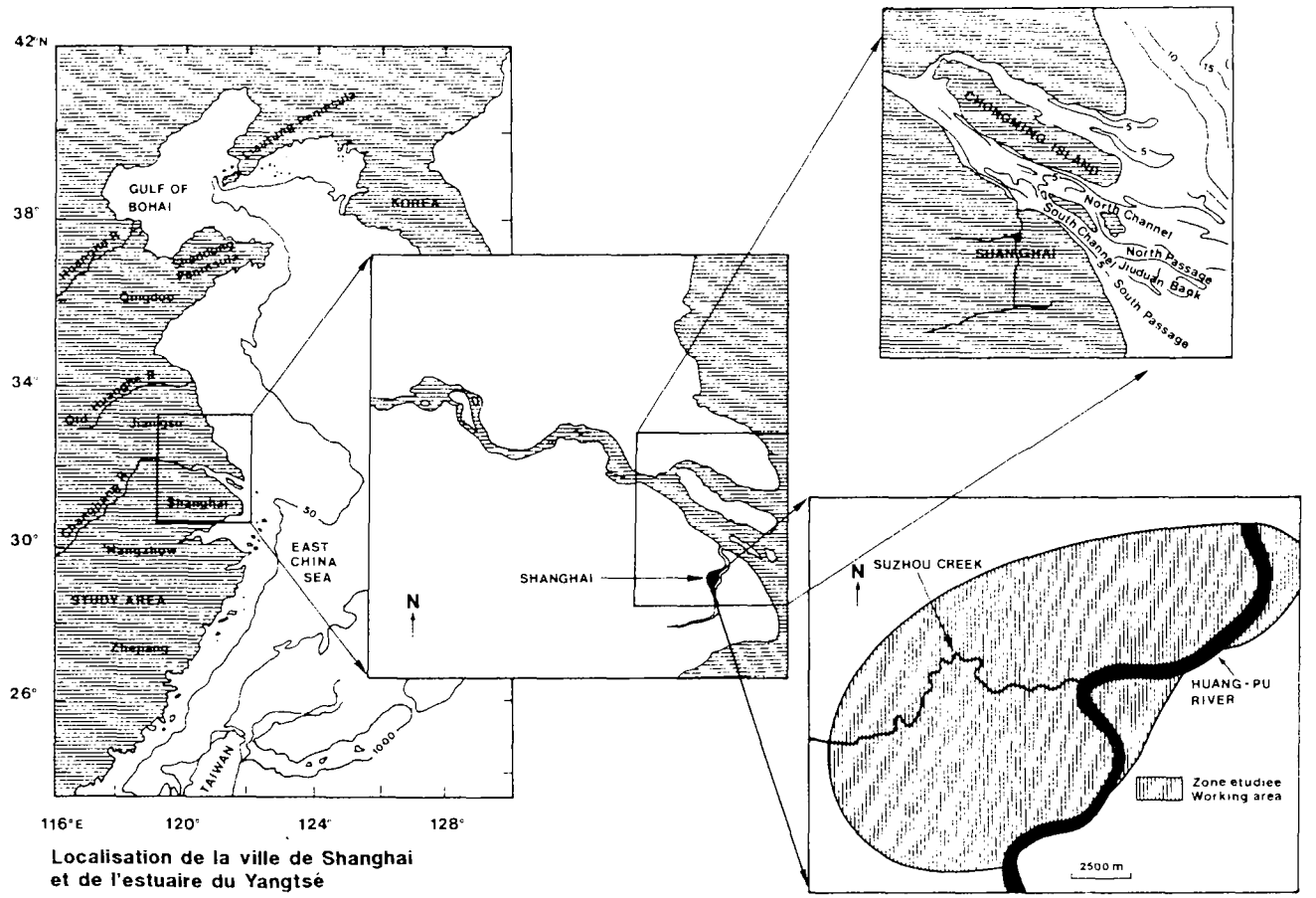

Localisation de la ville de Shanghai et de l'estuaire du Yangtsé

Fig. 1 : The city of Shanghai is situated in the vast low lying coastal plain bordering the East China Sea and characterized by the lower reach of the Changjiang (Yangtze) River. The city is crossed by a tide-influenced channel, the Huang Pu River.

General introduction

Large coastal lowlands, in particular those along estuaries and deltas are very vulnerable areas. Flooding, disturbance of the natural drainage, salt-water intrusion, coastal erosion and natural and man-induced subsidence are potential threats. Moreover most of these areas are characterized by a high density of population. This implies great investment for the economy, industry and, in certain cases, tourism in recent decades. It is obvious that these areas with a high societal pressure require proper coastal management.

Many of the world's great cities located in these coastal lowlands where the subsoil consists of hundreds of metres of Quaternary sediments, mainly fluvial, marginal-marine and marine. These sediments are all characterized by low consolidation, hence they are very sensitive to compaction which evidently results in land subsidence. Almost all of the great coastal cities have aggravated their vulnerable situation by the withdrawal of groundwater from beneath them.

The city of Shanghai (Fig. 1), with a population of more than 12 million, also belongs to this problematic group of sinking cities. As from 1921, with industrial development, groundwater from the 60 to 80 m deep aquifer beneath the city has been withdrawn. The prompt result was land subsidence. Subsidence was already evident in 1921 and by 1965 it had reached a maximum of 2,5 m up to even 3 m at some localities (Fig. 2). The greatest subsidence happened between 1956 and 1959 with an annual rate of 98 mm (Su and Hu, 1980). As from 1962 the recharge of the aquifer during winter seasons contributed to a significant halt of the subsidence, however, a residual consolidation of 3 mm/year is still recorded.

In the framework of an International Cooperation Agreement between P.R. China and Belgium, a research program has been undertaken in order to manage ground water withdrawal and control land subsidence. The ultimate aim of the research was the design of a finite element model.

Therefore, intensive investigations of the Quaternary geology, hydrogeology and engineering geology were carried out simultaneously, providing the basic elements for the elaboration of the mathematical model.

The aquifer flow equation is solved in a full three dimensional space and the assumed one-dimensional layer deformation is computed by one-dimensional consolidation equations. On the whole, a 3D study has been realized neglecting the lateral deformations. The con-

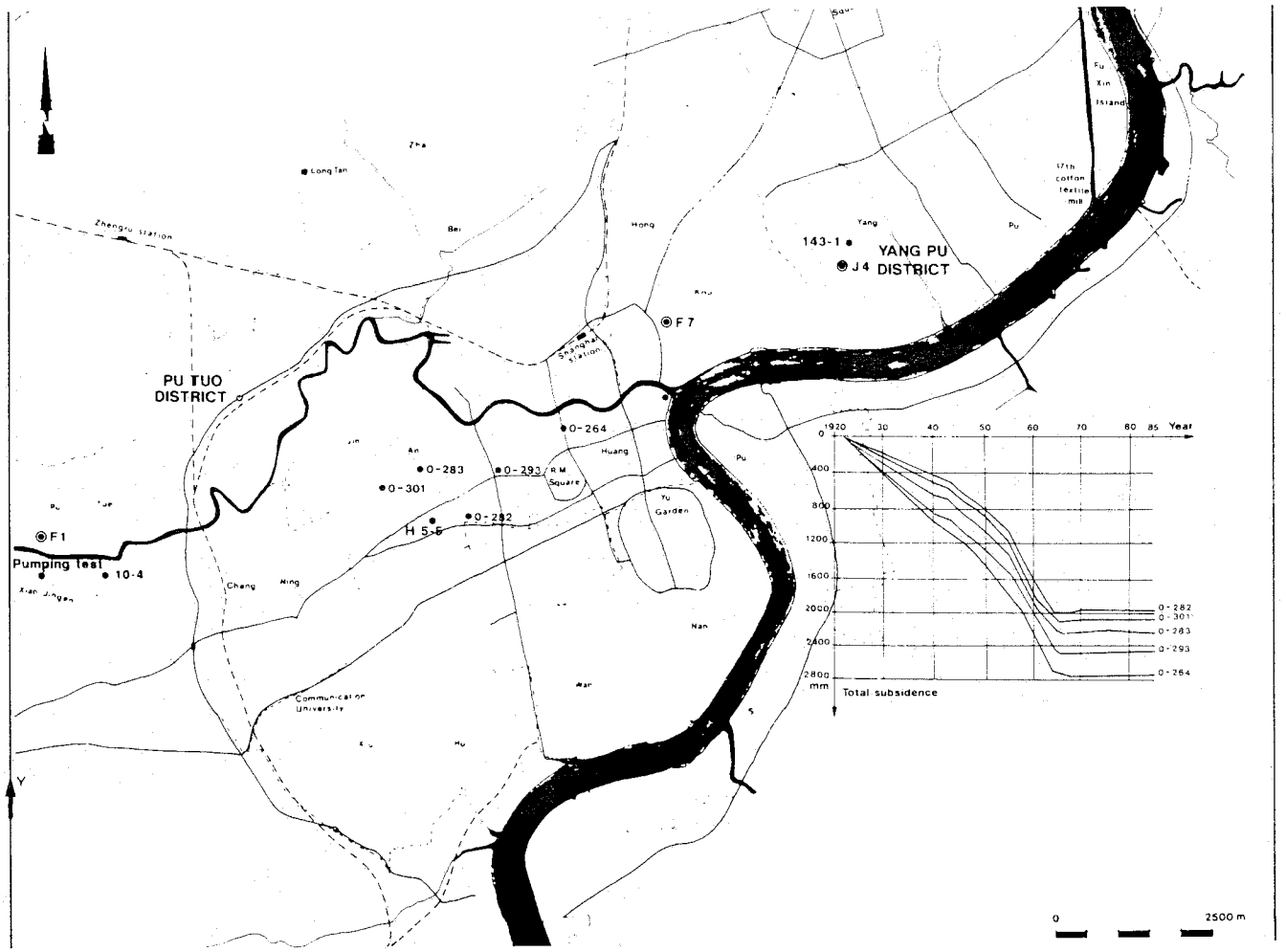

Fig. 2 : Land subsidence in the city of Shanghai was evident as from 1921 and reached a maximum between 1956 and 1965 (from Su and Hu, 1980).

solidation model uses the oedometric elastoplastic law, including non-linear analysis of the vertical permeability coefficient.

A concise version of the investigations and results of the various disciplines are presented here.

The following content is proposed :

• The quaternary deposits of the Changjiang coastal plain – Shangai area – Baeteman C., Bogemans F., Govaert E., Huang H.Z. and Ling J.X.

• Land subsidence in Shanghai : Hydrogeological conditions and subsidence measurements – Dassargues A. and Zhang J.

• Engineering geological conditions in the central area of Shanghai – Schroeder Ch., Dassargues A. and Li X.L.

• A finite element model for subsidence problem : LAGAMINE-Charlier R., Radu J.P. and Li Q.F.

• Applying the LAGAMINE model to compute land subsidence in Shanghai – Dassargues A., Schroeder Ch. and Li X.L.

• Computed subsidence in the central area of Shanghai Dassargues A., Radu J.P., Charlier R., Li X.L. and Q.F.

• General conclusions.

• Acknowledgements.

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