5th International Symposium on Sediment Management (I2SM 2016)
Montreal - July 10-13 2016

PACKING DENSITY OF FINE AND SANDY MATERIALS, EXPERIMENTAL AND MODELING APPROACHES.

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ABSTRACT

The prediction of compactness in granular mixtures is a question common to many technical and scientific domains. In the last decades several models have been developed. These models allow, to some extent, predicting granular mixture compactness. The Compressible Packing Model (CPM) which is an improved version of the solid suspension model based on the linear model of compactness is one of predictive models allowing the estimation of compactness on the basis of components characteristics and the compaction mode. However this model has not been validated on alternative materials and in its initial form the measurement of some parameters is based on the derivative of experimental curves. In this context, the present paper aims to present a model which allows predicting the granular mixtures compactness on standards and alternatives materials, using the intrinsic parameters of the components, easily accessible to experiment. The model is issued from the application of the Genetic Programming approach.

Keywords: Compactness, alternative materials, Genetic Programming, machine learning.

RESUME

La prédiction de la compacité (ou de la porosité) d'un mélange de grains secs est un problème, commun à bien des domaines techniques et scientifiques. Au cours des dernières décennies, plusieurs méthodes Dans le domaine de la formulation des bétons, on se restreint dans plusieurs méthodes à la question de la détermination des granularités conduisant aux compacités maximales. En reprenant le problème dans son contexte général, et devant l'empirisme des approches conventionnelles, plusieurs modèles ont été développés antérieurement qui permettent de prédire avec une certaine précision la compacité d'un mélange granulaire. Le Modèle d'empilement compressible MEC, qui est une version améliorée du modèle de suspension solide qui est lui-même basé sur le modèle linéaire de compacité. C'est un des modèles prédictifs qui permet de bien estimer la compacité d'un mélange en fonction du mode de serrage et des proportions des composants. Cependant ce modèle na pas été validé sur les matériaux alternatifs, en il perd de sa force de prédiction puisqu'il nécessite la mesure au laboratoire d'un certain nombre de paramètres. Dans ce contexte là, on propose par le présent travail d'utiliser l'apprentissage automatique afin de présenter un modèle qui permet de prédire la compacité granulaire et uniquement en fonction des paramètres intrinsèques des constituants facilement accessibles à l'expérience.

Dans ce travail, nous utilisons la Programmation Génétique (PG) dans la modélisation de la compacité granulaire des matériaux alternatifs et standards. La PG est un algorithme d'apprentissage automatique supervisé.

Mots clès: Compacité, matériaux alternatifs, programmation génétique, apprentissage automatique.

INTRODUCTION

The compactness of a granular mixture is a major problem for the concrete but also for many industrial applications [1], indeed a lot of composite materials (such as concrete) are manufactured by granular inclusions embedded in a binder matrix. The objective is often to combine the grains to minimize the porosity in order to minimize the use of binder. Taking up the issue in its general context, several models have been developed previously and that predict the compactness of a granular mixture. They require the knowledge of some basic data on the components that make up the mixture. De Larrard [2] proposed a predictive formula based on his model. In spite the success of this model, proved on the bases of studies on standard materials, the use of the derivative of experimental curves to define few parameters could in some situation be a problem. Moreover, until now the success of the model on the bases of alternative material is not yet proved. In this context the use of machine learning technique to provide an equation to predict the granular compact will be tested. This model will be based on the intrinsic parameters of the components, easily accessible to experience, unlike conventional models. It's to note that this developed model will be used in combination with other objectives in the framework of our multi-objective optimization approach in the formulation of concrete. The proposed model will be tested alternatively on standard materials as on alternatives materials.

MATERIELS AND METHODES

To perform the modeling work of the compactness of granular mixtures, we started with an experimental parametric study that determines the level of influence of parameters on the granular compactness [3]. Then we developed a database that represents the learning environment for genetic programming. The observed response (Output) is the compactness and the inputs are identified in the parametric study.

Standards and alternative materials are used alternatively or simultaneously in the experimental work. The list of used materials to construct the database are summarized in Table 1

Table 1 : List of used materials

Matériaux	
Standards Material	**Alternatives materials**
Filler of Boulonnais (Filler Bn)	Sediments of Dunkerque (Sed-Dunk)
Sand of Gaurain 0/4 (Gn 0/4)	Sand of foundry (Sab-Fond)
Gravel of Gaurain 4/8 (Gn 4/8)	Concrete Recycled Aggregates (GBR)
Gravel of Gaurain 8/14 (Gn 8/14)	
Gravel of Boulonnais 14/20 (Bn 14/20)	

To study the influence of tightening mode on the compactness of binary mixtures, four modes have been used: simple filling, picketing, vibration with a pressure of 10 kPa, shock table with pressure of 10 kPa .

Compaction index was proposed in [2]. This index is calculated by calibration between the theoretical model and the experimental results. The values of K corresponding to the different tightening modes are summarized in Table 2.

Tableau 2 : The K values for different modes of tightening [2]

	Mode			
	simple filling	picketing	Vibration +10 KPa	shock table +10 KPa
K	4,1	4,5	9	9

The culmination to a mathematical model that best represents the entire digital database for particular learning needs to be evaluated in its predictive ability. Three statistical parameters often used [4]: the square root of the mean square error (RMSE), the correlation coefficient (R) and the mean absolute error (MAE). These later are defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Ci - C'i)^2}{N}}$$

$$\mathbf{R} = \frac{\sum_{i=1}^{N}(Ci - \overline{Ci})(C'i - \overline{C'i})}{\sqrt{\sum_{i=1}^{N}(Ci - \overline{Ci})^2 \sum_{i=1}^{N}(C'i - \overline{C'i})^2}}$$

$$\mathbf{MAE} = \frac{\sum_{i=1}^{N}|Ci - C'i|}{N}$$

RESULTS AND DISCUSSION

From Figure 1, it could be noticed that the compactness increases with the increased energy used to compact the materials. This energy is more or less represented by the compaction index as discussed. It looks then relevant to consider this factor as a relevant parameter. This result is also confirmed by the observed behavior on alternatives materials (Figure 2). It's to note also that the maximum compactness is greater for the fine as soon as they are subjected to mechanical stress. Regarding the effectiveness of compaction, it is clear that regardless of the size of the aggregates, the shock table + 10 kPa gives the maximum compactness with respect to other compaction methods tested

Figure 1: Compactness of standards materials depending on the mode of tightening

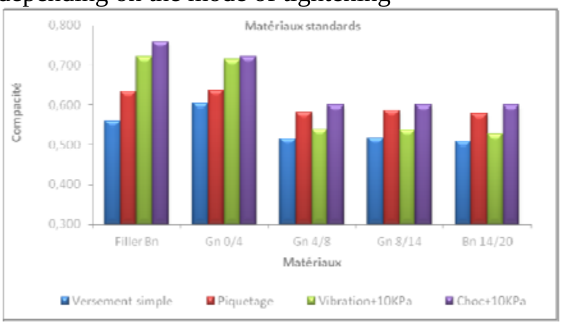
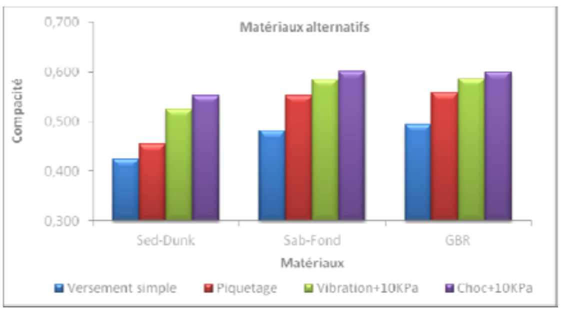


Figure 2 : Compactness of alternatives materials depending on the mode of tightening



In addition to this parameter, we studied the influence of the mass percentage of fine in granular mixtures, the influence of granular extended d2 / d1. The parametric study confirms the great influence of these parameters on the granular compactness. In the input parameters, we also added a parameter which is the ratio of the curvature coefficient of the two granular classes Cc1 / Cc2.

On the basis of the database and the selected parameters, the process of genetic programming is lunched. The mathematical model deduced from this study is as :

$$\beta m=\beta 1-\left[\beta 1-Y2\left(\frac{Y1-\left(\cos\cos\left(\frac{\frac{d2}{d1}-\frac{Cc1}{Cc2}}{\beta 1-\beta 2}\right)-10\right)\left(1-\frac{\frac{d1}{d2}-\frac{Cc1}{Cc2}}{\beta 1-\frac{d2}{d1}}\right)}{\beta 2}\right)\right]*\left[Y2\left(\frac{Y2-\frac{Y1}{\cos Y2*\cos\beta 2}-\beta 2}{10+\frac{Cc1}{Cc2}-Y2}\right)\right]$$

Where : βm is a residual compactness of the mix, β1and β2 are intrinsic compactness of the components, Y1, Y2 are massique percentage of the components, Cc1, Cc2 are coefficients of curvature ..

The predictive model of the granular compactness developed by the genetic programming was compared with the predictions of the Software RENE LCPC [5] based on the compressible packing model, commonly used in estimating the compactness of granular mixtures. The results obtained are shown in Figure 3.

Figure 3: Genetic Programming model Vs RENE-LCPC, in predicting the compactness.

In Figure 3, the predictions of the developped are compared to the prediction of RENE LCPC. We note first that predictions RENE LCPC software are relatively satisfactory in the standard materials, based on the average absolute error of 0.05 and an RMSE and R respectively equal to 0.07 and 0.86 .

The model PG meanwhile, clearly outperforms the RENE LCPC, in predicting the granular compactness. In Figure 3, clearly one notices less dispersion around the axis (x = y) which theoretically represents the ideal model. The PG model gives an EAW and an RMSE of 0.03 and 0.06 respectively equal to R and 0.92 that express a strong linear connection between the theoretical model results and experimental results

CONCLUSION

The granular compaction is a problem common to many applications in the field of civil engineering, modeling this characteristic remains a fgirst step for better prediction of other features that depend on this characteristic, such as workability and strength of concrete.

To model the granular compactness we used in this work Genetic Programming (GP). These machine learning tools on the basis of experience, can model complex problems. In the first step, we first determined the Inputs and Outputs of the system based on a parametric study. In the second step, on the bases of the developed database, we lunch the procedure to identify the mathematical model. This later was compared to the prediction of other models and to experimental data.

The compactness model developed by the PG has a high predictive ability on standard materials with a correlation coefficient R = 0.92, an RMSE of 0.06, against a R = 0.86 and an RMSE of 0.07 for the software RENE LCPC. For alternative materials, the model of GP confirms its high predictive ability compared with the RENE LCPC software. The model of the GP stands out for its great capacity for predicting the compactness of a binary mixture even in the case of uses fine or alternative materials such as recycled aggregates.

This model is adapted to the major issue of the valuation of alternative materials are sui sediments that are difficult to formulate by the methods of conventional formulations. [6]

This model also serves as our objective function in optimizing the skeleton in our multiobjective optimization approach concrete mixtures.

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