Computational Dynamic Analysis of Raw Concrete Vibropressing Process

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Abstract

The paper describes the dynamics of vibration under pressure. The testing machines Instron and Zwick were implementing the vibropressing regime. The material testing machines were used for experiments with raw concrete. The form of samples was cylindrical with diameter 84.5 mm. The series of experiments was conducted according to the Mean Square Error Latin hypercube design [1]. All experiments with raw concrete were the examination of the influence of vibropressing characteristic parameters (pressing load, vibration force amplitude and frequency) on the quality of concrete samples. The vibropressing regime is described by formula $f = f_0 + f_A \sin(\omega t)$ was realizing changing three parameters – f_0 pressing force (10–50 kN), f_A force amplitude (1–11 kN) and frequency(10–50 Hz). Fourier analysis was used for the analysis of implemented parameters. The testing machines implement some input parameters very accurately, therefore a locally weighted sinusoidal approximation with Gaussian weighting function was [2,3] used for smoothing and numerical differentiation of the registered functions. The correlation between input parameters investigated.

Keywords

Vibropressing process, parametric identification, computational dynamic analysis.

1 Introduction

There are many types of concrete available, created by varying the proportions of the main ingredients indicated below. By varying the proportions of materials, or by substitution for the cementitious and aggregate phases, the finished product can be tailored to its application with varying strength, density, or chemical and thermal resistance properties. The mix design depends on the type of structure being built, how the concrete will be mixed and delivered, and how it will be placed to form this structure [4, 5].

The vibropressing technology is generally used for compaction of high-strength concrete blocks such as paving bricks. A large range of block making machines is available on the market from manufacturers like "Poyatos", "Prensoland", "Masa–Henke", "HESS" and many others. They are based on the following principle: the pressure is combined with forced vibrations, and for

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some models with vibroimpact as well, see QFT8-15 Brick Making Machine [6] for example.

A two-side vibroimpact press was also patented and investigated [7, 8].

The most important characteristics of such blocks are strength and freeze-thaw durability. Both of them increase by increasing the density of the block using the same raw concrete composition – sand, cement, water and chemical additives.

Point-mass systems and continuous medium models are used to describe the concrete vibration process. Consolidation by vibration is mostly described as consisting of two stages – the first comprising subsidence or slumping of the concrete, and the second a deaeration (removal of entrapped air bubbles). A different model should be used for each stage [9].

The change of viscosity of raw concrete mixture under the influence of vibration is a well known phenomenon. I. Blekhman introduced the name vibrorheology for the field of science which operates with rheological models subject to a vibration. Vibrorheological properties of raw concrete are included in the analysis. The properties of concrete blocks depend on recipe, chemical and granulometric characteristics of concrete mix components, as well as on the dynamic action on the raw material during the forming process – the constant pressure component, amplitude and frequency of forced vibration and length of the forming cycle.

In this study the influence of dynamic parameters on the forming process was analyzed on the basis of mathematical models, identified from natural experiments without application of classical rheological hypotheses. The material testing machines Zwick and Instron 8802 were used instead of a specialized forming machine. A special cylinder-piston construction with the diameter 84.5 mm was built for the experiments. The variable factors were the values of the constant pressure component, the frequency and amplitude of vibration force and the duration of vibration. The same amount of sand and cement was used for all experimental trials.

2 Experimental design

The experiments were conducted according to the Mean Square Error Latin hypercube design [1] using EDAOpt software. The three variable factors were: constant pressure component, frequency and amplitude of vibration force, Fig. 1. The intervals of the values of variable factors depended on vibrorheological properties of raw concrete and testing machines possibilities. The frequency ω was changing from 10 Hz to 60 Hz, constant pressure component f_0 – from 1 kN to 5 kN and amplitude of vibration force f_A – from 0,1 kN to 1,1 kN.

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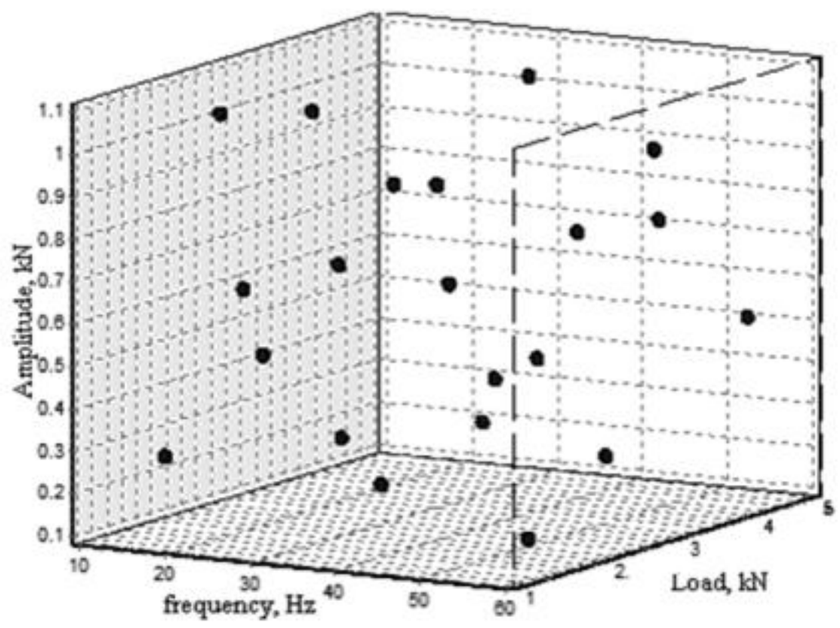

Fig. 1. Mean Square Error Latin hypercube design

The dynamics of vibration under pressure are described by the following force function:

$$f = f_0 + f_1 \sin(2\pi\omega t) \tag{1}$$

where f_0 – the constant pressing force, f_1 – the force oscillation amplitude and ω – the frequency in RPM. At the beginning of the process this pressure cannot be applied since the raw concrete has a low compacting rate and accordingly a low resistance force. Therefore before applying vibration, the two-stage pressing without oscillations was used, see Fig. 2.

The first pressing stage is different between required (*a*) and implemented (*b*) vibropressing regimes. The crash of the largest particles of concrete mixture and the movement of air bubbles can affect the implemented vibropressing regime visualization.

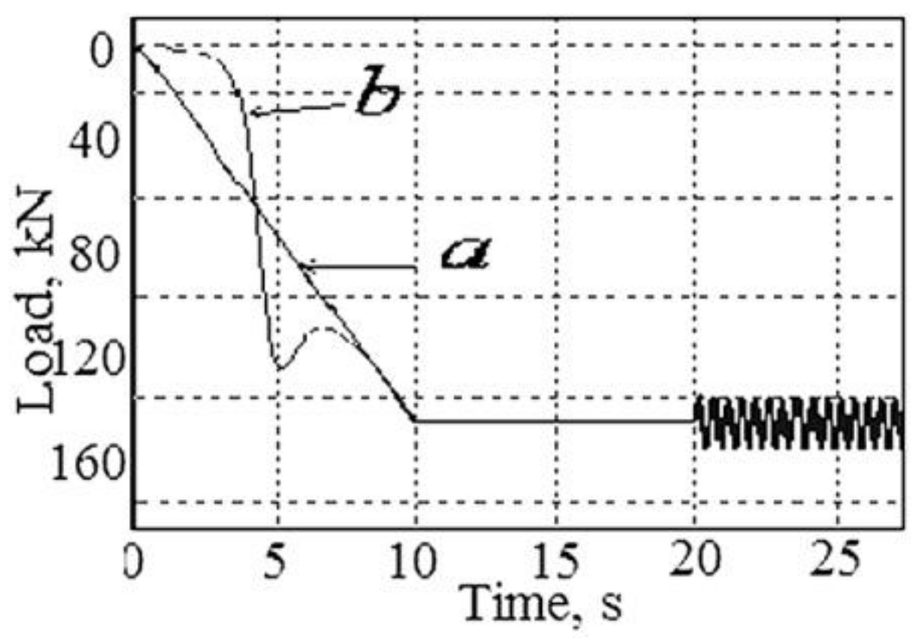

Fig. 2. The example of required (*a*) and implemented (*b*) vibropressing regimes

The influences of constant pressing force, vibration force frequency and amplitude on the compacting process were analyzed. The same cement (class 400), sand filling aggregate (0.3–12 mm, moisture 0.2%) and water-cement mass ratio (W/C) 0.36 was used for all experimental runs.

Concrete cylinder blocks with diameter 84.5 mm and weight 1 kg were compacted, see Fig. 3.

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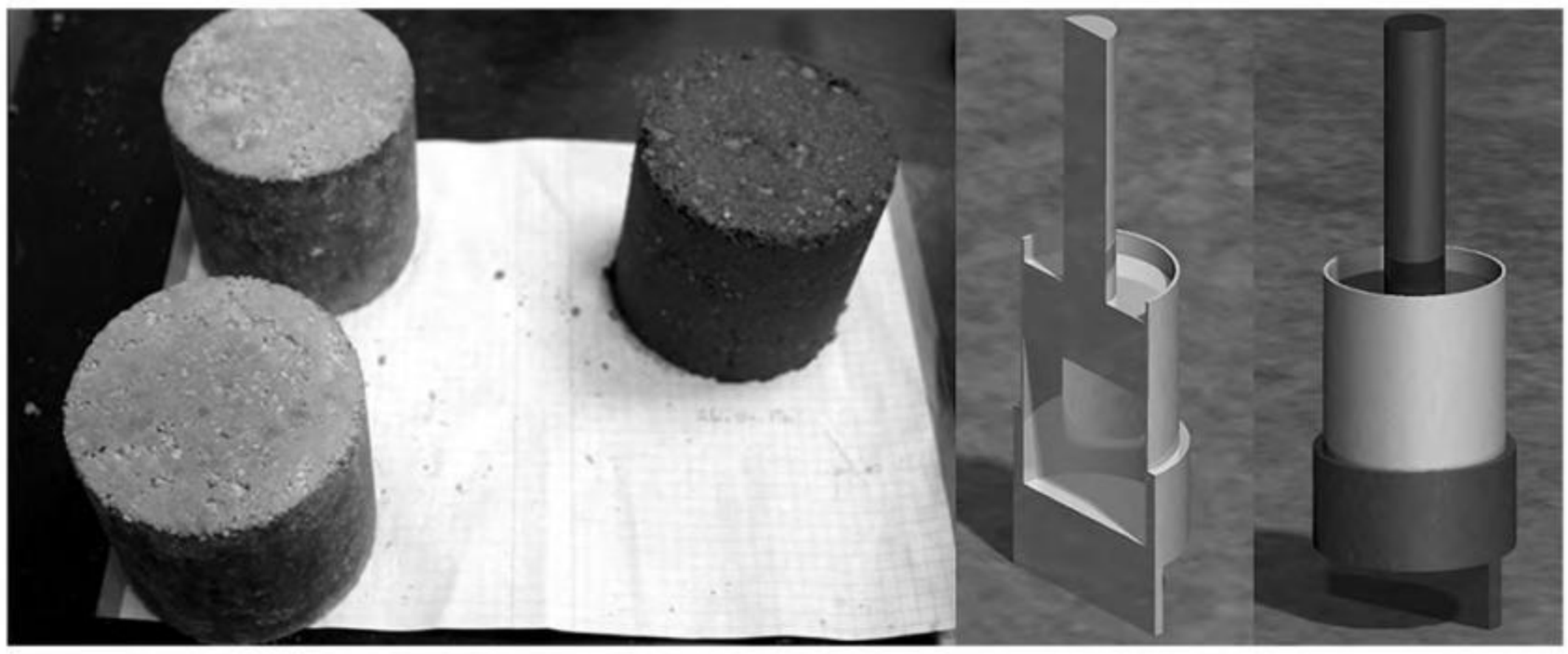

Fig. 3. Pressing plunger, mold and compacted concrete block specimens

3 Computational dynamic analysis

The experiment for three variable factors f_0, f_1, and ω was planned according to the Mean Square Error experimental design [1]. During the experiments, the testing machine was registering the compacting displacement of the plunger.

Fig. 4 shows a typical compacting displacement curve. The approximation with a power function was used in the form

$$\hat{x}(t) = x_0 + R(t - t_0 + \Delta)^p \tag{2}$$

with four parameters x_0, R, Δ and p for curve fitting according to least-squares method. This approximation gives a very accurate approximation of displacement curves, see Fig. 4:

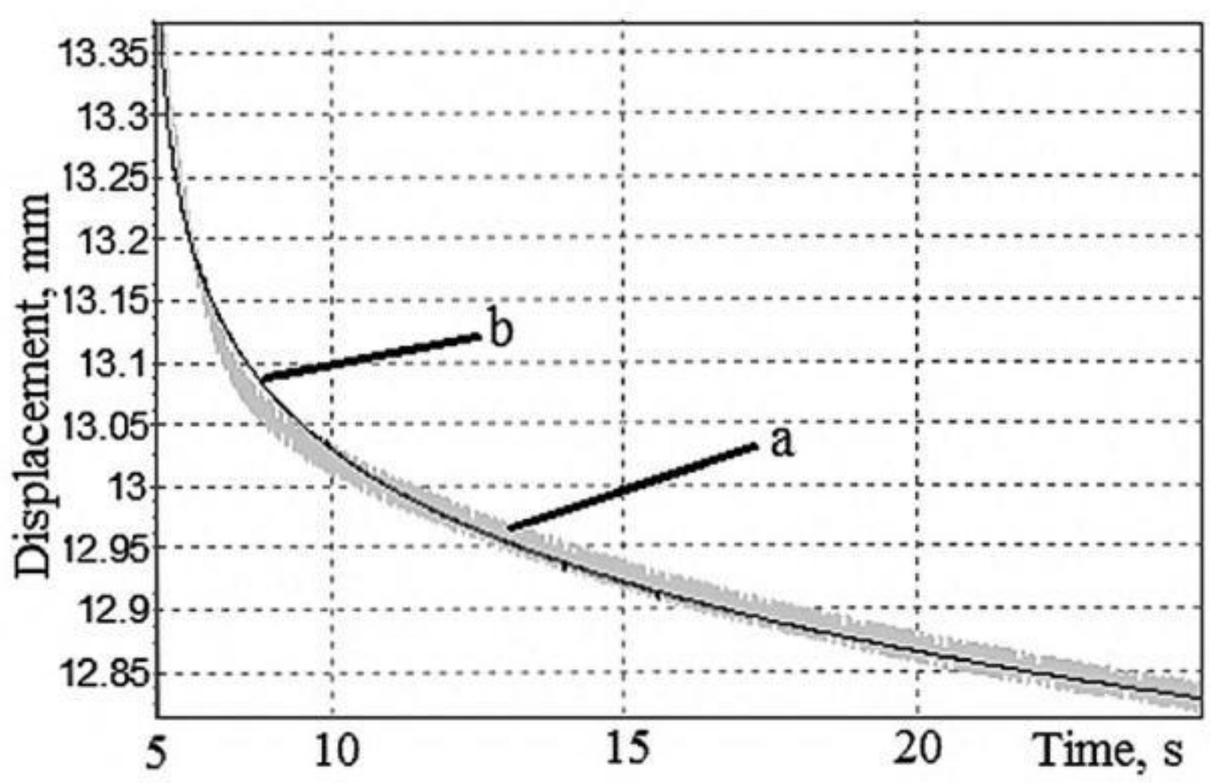

Fig. 4. Registered (a) and approximated (b) plunger displacement graph

Furthermore, quite good approximations for all our experimental runs could be obtained using fixed values of $x_0 = x(t_0)$ and $\Delta = 0.02$, $p = 0.05$ and fitting only the one value – coefficient R. By determining the value of R the compacting process can be entirely characterized in the given time interval. So

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the approximation of the dependence $R = R\,(f_0, f_1, \omega)$ gives the possibility to analyze and to optimize the vibropressing process. The greater compaction (and density, respectively) gives higher concrete block strength. However, compaction ratio is limited by the granulometric characteristics of the filler material and cannot be infinitely increased.

Due to technical characteristics of the testing machine Instron, the initial pressing stage was implemented with some inaccuracy that contributed to increasing the result dispersion. The testing machine was also not capable of implementing high frequency ($\omega > 50$ Hz) force vibration with high pressure force amplitude ($f_1 > 0.5$ kN). In such cases the vibrations were nearly chaotic and only Fourier analysis showed the prevalence of required frequency, see Fig. 5.

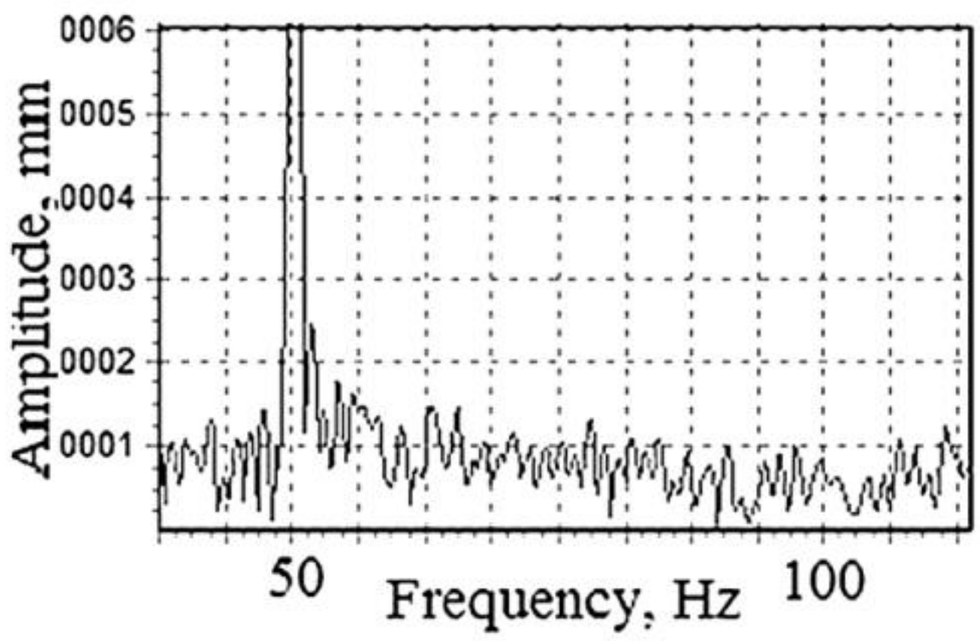

Fig. 5. Displacement graph, 50 Hz force oscillations and Fourier spectral analysis of displacement oscillations with 50 Hz pressing force

Further analysis requires values and numerical differentiation of measured functions; therefore the registered data must be smoothed. The testing machine implements the required frequency very accurately; therefore a locally weighted sinusoidal approximation with Gaussian weighting function [1, 3] was used for smoothing and numerical differentiation of the registered functions. Fig. 6 shows measured and smoothed results.

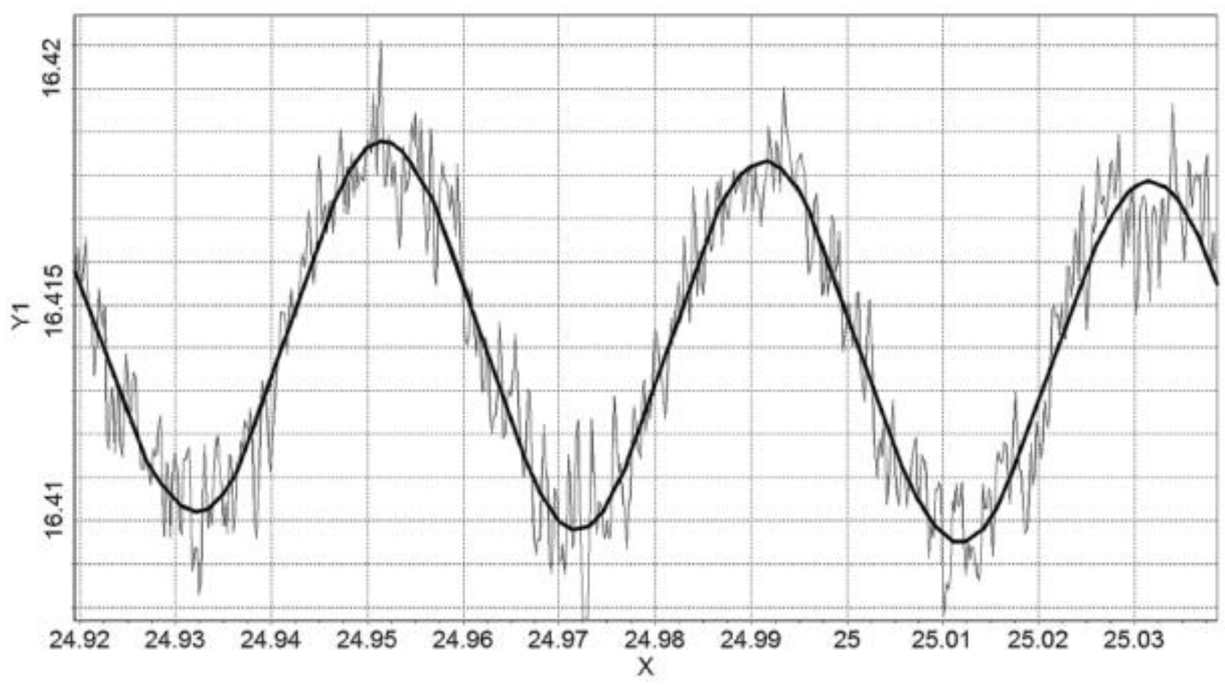

Fig. 6. Registered and smoothed plunger displacement graphs

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At the next step all concrete block specimens were approved by the crash test. The crash test results were registered (kN) and the correlation between three input parameters and the strength of specimens – P was found, see Table 1. The correlation coefficient between f_0 – the constant pressing force and P – strength of specimens is 0.24, between f_1 – the force oscillation amplitude and P – strength of specimens is 0.42, and the correlation coefficient between ω – the frequency and P – strength of specimens is 0.62. This means that the most important influence on the vibropressing process is exercised by frequency.

Table 1. The correlation coefficient between three variable parameters.

Input parameters	*Correlation coefficient*	*Strength of specimens*
f_{0i}, *kN*	$-1 < 0.24 < 1$	P_i, *kN*
f_{1i}, *kN*	$-1 < 0.42 < 1$	P_i, *kN*
ω_i, *Hz*	$-1 < 0.62 < 1$	P_i, *kN*

6 Conclusions

Computational dynamic analysis of raw concrete vibropressing process shows the identification function and parameters of the specimens compacting curve $R = R\ (f_0, f_1, w)$, giving the possibility to analyze and optimize the vibropressing process. The greater compaction (and density, respectively) gives higher concrete block strength. However, compaction ratio is limited by the granulometric characteristics of the filler material and cannot be infinitely increased. The correlation analysis between input parameters and the strength of samples showed the prevalence of pressing frequency as most important factor.

The future work should concentrate on building more accurate models for concrete strength dependency on vibropressing parameters, using robust non-parametrical approximations, as well as the multiobjective optimization of vibroprocessing process.

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Vibration Problems ICOVP 2011 : Supplement : The 10th International Conference on Vibration. Liberec : Technical University of Liberec, 2011. ISBN 978-80-7372-759-8.

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