https://doi.org/10.26552/com.C.2002.3.27-30

KOMUNIKÁCIE
COMMUNICATIONS

Jacek Śliwiński – Witold Brylicki *

NÁVRH TUHÝCH BETÓNOVÝCH ZMESÍ ZHUTNENÝCH VIBROLISOVANÍM

MIX DESIGN OF STIFF CONCRETE MIXTURES COMPACTED BY VIBRATION UNDER A SURCHARGE LOAD

V technológii výroby produktov zhutnených vibrolisovaním, ako dlažobné tvarovky, je potrebné použiť betónové zmesi s konzistenciou mimo rozsahu navrhnutého pre obyčajný betón. Aby došlo k súčasnému účinku vibrácie a statického zaťaženia, betónová zmes musí splniť špeciálne požiadavky na konzistenciu a spracovateľnosť. Článok uvádza dve metódy návrhu betónovej zmesi, ktoré sa ukázali ako čiastočne použiteľné pre zmesi zhutnené vibrolisovaním. Jedna z nich je založená na vyplnení medzier medzi zrnami kameniva cementovým tmelom, druhá na obalení zŕn plniva cementovým tmelom.

In the manufacture technology of products compacted by vibration under a surcharge load, such as paving blocks, it is necessary to use concrete mixtures of consistency outside the range designed for ordinary concrete. Due to the simultaneous effect of vibration and static load the concrete mixture must meet special requirements of consistency and workability. The paper presents two methods of concrete mix design which proved particularly useful for mixtures compacted by vibration under a surcharge load. The former is based on heaping up the aggregate void spaces with cement paste, the latter on coating the aggregate grains with paste.

1. Introduction

In the last decade the interest in concrete products manufactured by vibration under a surcharge load, such as paving blocks, kerbs, etc, has increased significantly. In the compaction by vibration under a surcharge load the mixture is subjected to the dynamic effect of vibration and static surcharge load. This combined effect Z must overcome the internal resistance of the mixture W, which is made up of frictional, viscosity and cohesion resistance. As a result the mixture volume V decreases and its apparent density ρ increases.

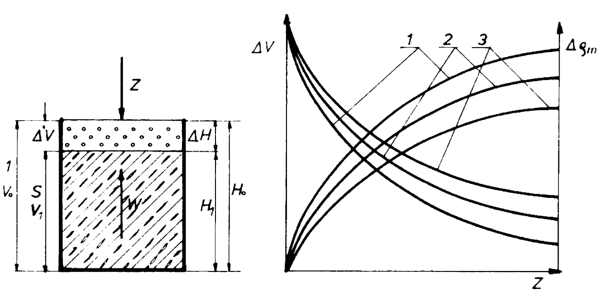

Fig. 1. Changes of volume ΔV and apparent density $\Delta\rho$ of mixture under loads Z

The method of vibration under a surcharge load is a combined method which does not cause a change of the W/C ratio during compaction. The frictional and viscosity resistance is overcome mainly by the effect of vibration, that is applying a multiplied force of gravity. Due to vibration the concrete mixture behaves like a dense, tixotropic fluid and the internal friction decreases. The effect of pressure exerted on the mixture enhances the process of compaction. What is important in this technology is the proportion of the two effects. The most favourable proportion of contribution of the two effects differs for different mix composition (different aggregate grading, different cement paste content, different W/C ratio, different consistency).

The technology of vibration under a surcharge load, described briefly below, requires a particularly careful selection of mix composition which ensures both the concrete assumed strength and proper consistency and workability.

2. Description of two useful methods of concrete mix compacted by vibration under a surcharge load

The methods that have recently proved very useful in concrete mix design for the technology of surcharge vibration are: the method of heaping up the aggregate void spaces with cement paste and the method of coating the aggregate grains. In Poland these methods have been known for years as the Kopyciński method and the Paszkowski method [2].

* [1]Prof. Jacek Śliwiński D.Sc. Ph.D., [2]Witold Brylicki D.Sc.
[1]Cracow University of Technology, Faculty of Civil Engineering, Warszawska 24, 31-155 Kraków, Poland, E-mail: jsliwins@imikb.wil.pk.edu.pl
[2]University of Mining and Metallurgy, Faculty of Materials Science and Ceramics, Mickiewicza 30, 30-059 Kraków, Poland

In Germany the method based on heaping up the aggregate void spaces with paste was proposed by Zipelius [3] in the 1960s. The method was later used to construct the so-called Econom apparatus [4], due to which it is possible to empirically define the most economical paste content in concrete mix. The empirical design of concrete mix by means of the Econom apparatus takes into account the real conditions of compacting by surcharge vibration, that is, the characteristics of vibration and surcharge pressure are taken into account.

The other method is based on the determination of indispensable quantity of cement paste as a function of aggregate surface area and thickness of paste layer coating its grains.

2.1 Method of heaping up aggregate void spaces with cement paste Econom apparatus method [4]

The method is based on the assumption that in order to make a concrete mixture from the adopted aggregate, the void spaces between the grains have to be heaped up, to some indispensable degree, with cement paste (Fig. 3).

Before we start the empirical design it is obviously necessary to select both the type and class of cement and W/C ratio as well. The value of W/C ratio can be defined from any dependence between concrete strength and its composition, for example from Bolomey's formula. It is also necessary to decide on the aggregate type and design its grading such that the grading curve was within the regions shown in Fig. 2 [5].

Initially we determine the volume of a set portion of aggregate $V_{aggr.}$ [dm^3] (in the Econom apparatus method portion of 10 kg is used) compacted in conditions similar to those of the mixture to be compacted (vibration under surcharge load). The next step is to determine the volume of voids in the aggregate. It can be done easily by infusion of water in the amount of V_{water} [dm^3] to the aggregate compacted in proper conditions so that the water fills all the void spaces between the aggregate grains. Thus the infused water volume V_{water} is equal to the volume of the voids in the tested portion of aggregate V_{av} (Fig. 3a).

The next step is to prepare the cement paste of a certain W/C ratio, its volume V_{paste} equal to water volume V_{water} (equal to the volume of voids V_{av}) is mixed with 10 kg of aggregate identical as before. The concrete mix obtained in this way is compacted in identical conditions as the dry aggregate was compacted initially. Its volume after compaction $V_{concrete\ mix}$ [dm^3] is determined. This volume will be slightly larger than the volume of compacted dry aggregate $V_{aggr.}$ because the aggregate grains will be coated with a thin layer of the paste and will be separated (Fig. 3b). The difference between the volume of the mix composed in this way and the volume of the dry aggregate itself ($\Delta V = V_{concrete\ mix} - V_{aggr.}$) is the volume of void spaces in the prepared mix. It is this value by which the volume of cement paste should be enlarged to obtain a mix with no pores. The final indispensable volume of paste is thus $V_{paste\ def.} = V_{paste} + \Delta V$ (Fig. 3c).

Next, knowing the $W/C = \omega$ characterising the paste, we can calculate its density ρ_{paste} which is:

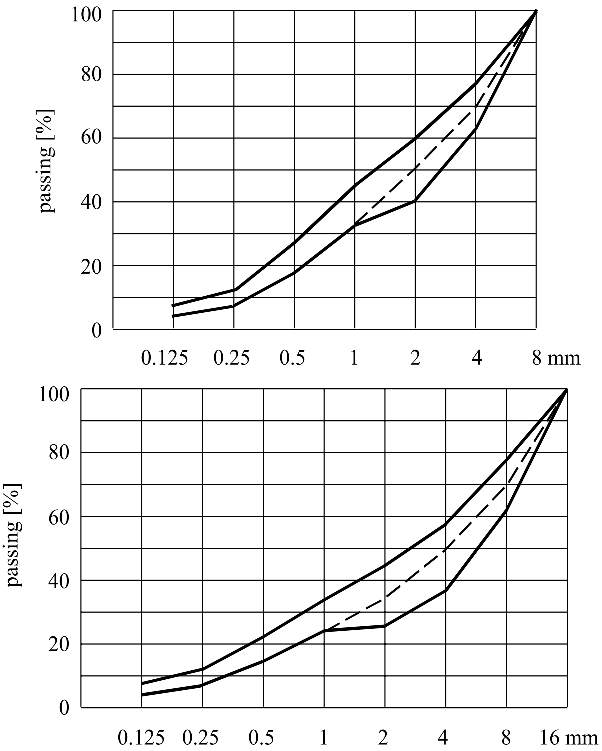

Fig. 2. Approximate areas of good grading of aggregates 0/8 mm and 0/16 mm for concretes compacted by vibration under a surcharge load [5] (the area between upper and lower broken curve – for rounded aggregate, the area between the upper and lower solid curve – for crushed aggregate).

$$\rho_{paste} = \frac{\omega + 1}{\omega + \dfrac{1}{\rho_c}} \quad [\mathrm{kg/dm^3}] \qquad (1)$$

where: ρ_c – cement density, commonly adopted as 3.1 [kg/dm^3]

Knowing that the mass of paste of volume $V_{paste\ def.}$ is:

$$m_{paste\ def.} = V_{paste\ def.}\, \rho_{paste} \quad [\mathrm{kg}] \qquad (2)$$

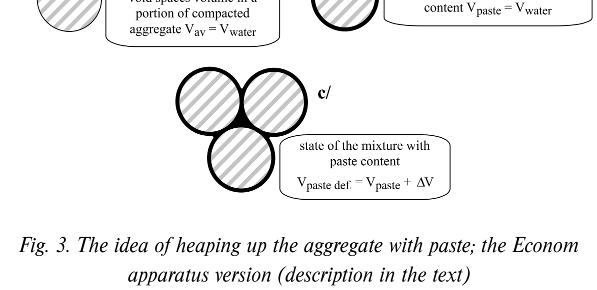

Fig. 3. The idea of heaping up the aggregate with paste; the Econom apparatus version (description in the text)

the content of cement C' and water W' in concrete mix containing aggregate quantity A = 10 kg can be calculated from formulae:

$$C = \frac{m_{paste\ def.}}{1 + \omega} \quad [\mathrm{kg}] \tag{3}$$

$$W = m_{paste\ def.} - C \quad [\mathrm{kg}] \tag{4}$$

Since from the quantities of components given above we have obtained the compacted concrete mix of the volume $V_{concrete\ mix}$, the composition of 1 m^3 of the mix is:

$$C = \frac{C'}{Vconcrete\ mix} 1000 \quad [\mathrm{kg/m^3}] \tag{5}$$

$$W = \frac{W'}{Vconcrete\ mix} 1000 \quad [\mathrm{kg/m^3}] \tag{6}$$

$$A = \frac{10}{Vconcrete\ mix} 1000 \quad [\mathrm{kg/m^3}] \tag{7}$$

Despite the fact that the mix composition was designed empirically, it is necessary to verify it additionally in production conditions. This refers to both the correct consistency and workability in the compacting conditions on a real surcharge vibration machine.

2.2 Method of coating aggregate grains with paste

As in any design method, also in our case it is necessary to start with the assumptions as to the quantitative selection of ingredients, i.e. type and class of cement and aggregate grading as well as the value of W/C ratio that ensures the proper strength of concrete.

In the presented method the calculations are based on the aggregate surface area $F_{aggr.}$, i.e. the total surface of aggregate grains of 1 kg mass. Since aggregate is a mixture of grains of various sieve size f_i, its surface area can be calculated as a weighted average of the surfaces F_{ai} of all the sieve sizes found in it:

$$F_{aggr.} = \frac{\sum_{i=1}^{i=n} F_{ai} f_i}{100} \quad [\mathrm{dm^2/kg}] \tag{8}$$

where: F_{ai} – the surface of i-th sieve size [dm^2/kg],
f_i – the content of i-th sieve size [% mass]

The values of surface areas of particular size of grains of rounded aggregate nearly spherical in shape and density $\rho_a = 2.65$ kg/dm^3 have been presented in Table 1.

When crushed aggregate is used, the values in Table 1 should be multiplied by 1.15. For aggregate from material of density $\rho_a \neq 2.65$ kg/dm^3 the values in Table 1 should be additionally multiplied by quotient $\rho_a/2.65$.

When the surface area of the aggregate used $F_{aggr.}$ is known, it is possible to calculate the paste demand for 1 kg of aggregate $v_{paste/1\ kg}$:

$$v_{paste/1\ kg} = F_a\, t \quad [\mathrm{dm3/kg}] \tag{9}$$

Specific surface of grains of various sieve size of rounded aggregate with density $\rho_a = 2.65$ kg/dm^3 Table 1

Sieve size f_i [mm]	Specific surface F_{ai} [dm^2/kg]	Sieve size f_i [mm]	Specific surface F_{ai} [dm^2/kg]
0/0.125	≈ 4000	2/4	100
0.125/0.25	1600	4/8	50
0,25/0.5	800	8/16	35
0.5/1	400	16/31.5	12.5
1/2	200	31.5/63	6.2

where: t – required thickness of paste layer coating the aggregate grains [dm], after [3] to obtain the consistency proper for compacting by vibration under a surcharge load the values of t are:

for $W/C = 0.8 \rightarrow t = 0.0004$ dm (0.04 mm),
$W/C = 0.6 \rightarrow t = 0.0005$ dm,
$W/C = 0.4 \rightarrow t = 0.0006$ dm

The thickness values of the paste layer coating the grains have been selected in such a way that the necessity of heaping up the voids between the grains has been taken into account.

The total volume of 1 kg of aggregate and quantity of paste necessary for its grain coating is:

$$v_1 = \frac{1}{\rho_a} + v_{paste/1\ kg} \quad [\mathrm{dm^3}] \tag{10}$$

while the necessary paste volume in 1 m^3 of the mix is:

$$V_{paste} = \frac{1000}{v_1} v_{paste/1\ kg} \quad [\mathrm{dm^3/m^3}] \tag{11}$$

It should be noted that the $1000/v_1$ quotient gives the necessary quantity of aggregate A in 1 m^3 of concrete mix.

In the following sequence of a set of equations:

$$\frac{W}{C} = \omega \tag{12}$$

$$W + \frac{C}{\rho_c} = V_{paste} \tag{13}$$

cement and water content in 1 m^3 of the mix can be calculated:

$$C = \frac{V_{paste}\rho_c}{\rho_c \omega + 1} \quad [\mathrm{kg/m^3}] \tag{14}$$

$$W = \omega C \quad [\mathrm{kg/m^3}] \tag{15}$$

The aggregate content, as mentioned above, is calculated as:

$$A = \frac{1000}{v_1} \quad [\mathrm{kg/m^3}] \tag{16}$$

or from the volume balance:

$$A = (1000 - V_{paste})\rho_a \quad [\mathrm{kg/m^3}] \tag{17}$$

Similarly as in the first method, the final step is empirical verification of the designed concrete mix in which the compaction process and properties of hardened concrete in product are checked.

3. Additional remarks

The technology of concrete products manufacture by vibration under a surcharge load makes the designer of concrete mix face many specific requirements. Besides the obvious necessity to obtain concrete of assumed technical properties, these requirements include proper consistency and workability of concrete mixture. Even minor changes in mix composition can make it useless in product manufacture by this method. The two presented methods of concrete mix design, used for ordinary concretes for a long time, have proved very useful also in the design of concretes vibrated under a surcharge load.

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