Direct method for designing the optimum mix of concrete

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The paper describes a method for designing the optimum mix of concrete. The direct method is carried out in steps, by successive approximations, operating on a concrete made with the same materials (aggregate, cement, admixture) as presently used on works. Workability and compactness are tested at each step, by means of a special device. The optimum mix corresponds to the best values of these properties. The laboratory determinations are carried out in a short time: 20-25 minutes. There is no need of previous data on aggregate, such as grading or fineness modulus. The direct method can be used both for continuous graded and gap graded aggregate, rounded or crushed.

SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>c, C</td>
<td>cement content from Im (kg); cement content from OM (kg/m³);</td>
</tr>
<tr>
<td>dg, Dw</td>
<td>ration of wet gravel (kg); the water which covers the gravel dg (dm³);</td>
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<tr>
<td>As, Ac</td>
<td>correction value of sand (the finest fractional part, if there are more) (kg); correction value of cement (kg);</td>
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<tr>
<td>Dw, Dc</td>
<td>correction value of water (dm³); correction value of sand (the finest fractional part, if there are more) (kg);</td>
</tr>
<tr>
<td>E, g</td>
<td>modulus of elasticity (N/mm²); amount of gravel from Im (kg);</td>
</tr>
<tr>
<td>g*, G</td>
<td>(table II) supplementary correction of gravel (kg); amount of gravel from OM (kg/m³);</td>
</tr>
<tr>
<td>ρ, ρ₁</td>
<td>density of a standard compacted concrete (kg/dm³); theoretical density of concrete (without air) (kg/dm³);</td>
</tr>
<tr>
<td>h, h*</td>
<td>(fig. 2 and 7) value read on the graduated stem of the mallet (cm); control value of h, Om;</td>
</tr>
<tr>
<td>i</td>
<td>number of successive approximations (steps);</td>
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<tr>
<td>Im, Im</td>
<td>(table I) initial mix;</td>
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<tr>
<td>M, Om</td>
<td>amount of mortar from OM (kg/m³); (relationships 4 or 5) optimum mix (kg or kg/m³);</td>
</tr>
<tr>
<td>OM</td>
<td>(relationship 23) final optimum mix (kg/m³);</td>
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<tr>
<td>R</td>
<td>compressive strength (N/mm²);</td>
</tr>
<tr>
<td>T, W</td>
<td>flexural tensile strength (N/mm²); water content from Im (dm³); water content from OM (dm³/m³).</td>
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1. INTRODUCTION

If certain materials (aggregate, cement, admixtures) are considered and the same conditions for plasticity of fresh concrete and cement content, many concrete mixes with different performances can be set out. Among them, there is one mix which has the best compactness and the greatest mechanical strength: the optimum mix.

In this article a method is described for designing the optimum mix of concrete. It was called the direct method, because it does not use previous data, such as grading or fineness modulus of aggregate. The optimum mix is obtained by successive approximations, operating on a concrete made up with the same materials as actually used on works. The laboratory determinations are carried out in a short time: 20-25 minutes, by means of a special device manufactured in Roumania.

The direct method may also be used in other countries, without modifications. In this case national specifications for aggregate, cement, admixtures, and fresh concrete properties must be observed. The specific relationship (depending on cement and type of aggregate) between the compressive strength and water/cement ratio will also be considered.

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2. BACKGROUND OF THE DIRECT METHOD

The designing of the optimum mix is based on the fact, that the increasing of wet gravel (1) in concrete has the effect of improving workability and compactness until a certain degree, corresponding to their maximum, then they are decreasing rapidly. It will be shown that the compressive strength has also the same variation.

The notions of workability and compactness, as they are used in this paper, need some explanations. On one hand, the workability has not yet an unanimously accepted meaning ([1], [2]); on the other hand, an extensive use of air entraining agents in concrete may change the sense of compactness.

2.1. The workability is considered as "the property of fresh concrete to acquire a certain compactness under a given compaction process; a workable concrete is a stable one, i.e. it keeps its homogeneity until the beginning of hardening". If more different concrete mixes were compacted in the same manner (with the same energy, in the same process), i.e. with a standard compaction, the mix composition that fills the best a given mould and has therefore the lowest air content: \( v \to \min. \), will have the best workability. Thus, by using a standard compaction, both workability and compactness can be measured with the help of \( v \). The last statement of the above-mentioned meaning of workability, relating to the homogeneity of concrete is satisfied if \( v + p \to \min. \). A segregated concrete could not satisfy this condition.

The air content is given by the relationship:

\[
v = \frac{\rho_t - \rho}{\rho_t}
\]  

(1)

The relations between \( \rho_t, \rho, v, \) and the amount of wet gravel are shown, in principle, in figure 1a. These curves have been shown to have the same shape, and it is only the position of the curve in the graph that changes, when parameters such as: type of aggregate, cement content, plasticity of fresh concrete, etc., are varied. The curve \( \rho_t \) has a continuous increase, due to the growth of gravel, which has a greater specific density than the concrete. The increasing aspect of the curve \( \rho \) remains whilst there is enough mortar to assure the mobility of the mix during compaction. After this limiting value, which is shown by the maximum point, friction between grains appears during compaction and therefore a decreasing of \( \rho \) occurs. The air content \( v \) is depending on \( \rho \) as it is shown in figure 1a. Thus \( v \) can be determined only as a function of \( \rho \), without making out the calculation or determination of \( \rho_t \). For determining the variation of \( \rho \) and its maximum point, a special device has been designed.

2.2. By mixes without air entraining agents, \( v \) is randomly distributed in volumes of different shape and size, both in concrete and mortar. As it was shown in figure 1a, \( v \) decreases at the growth of gravel, has a minimum, and then increases rapidly. The rising of \( v \) is due to the increasing of volumes of air, mostly between gravel and mortar. This air would be considered as an "unexpected air content", and the main purpose of the direct method is to determine the mix which has the minimum \( v \).

When an air entraining agent is used, it introduces a great number of small bubbles of air, that are uniformly distributed in mortar. This one is an "expected air content \( v_0 \)" and will be considered like any other admixture, such as fine mineral powder. During the successive approximations, the percentage of \( v_0 \) does not change in mortar. Only \( v \) changes. Thus the procedure is the same for both concrete with and without entrained air.

2.3. The compressive strength of concrete has the same variation as workability and compactness at the increasing of wet gravel. This results from the well known formula of Féret:

\[
R = K - \frac{c}{w + v},
\]  

(2)

where \( K \) is a constant value, depending on cement, aggregate, etc. For a concrete with a cement content \( c \) the compressive strength \( R \) will be maximum when \( w + v \to \min. \). The condition \( w \to \min. \) will be satisfied by the aggregate with the greatest amount of gravel. This one is obviously limited, because the concrete must have a good compactness. The best value of compactness will be given for \( v \to \min. \). But \( v \to \min. \) is also the condition of the best value of workability, as it was said in section 2.1.

\[ \begin{align*}
\text{Fig. 1.} & \quad \text{a, variation of } \rho_t, \rho, v, \text{ with the amount of wet gravel; } \\
& \quad \text{b, variation of } h \text{ with the amount of wet gravel.}
\end{align*} \]

(1) Coarse, rounded or crushed, aggregate.