



## Modeling the Effect of Air Voids on the Strength and Durability of Innovative Technical and Technological Solutions for Building Blocks

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# Modeling the Effect of Air Voids on the Strength and Durability of Innovative Technical and Technological Solutions for Building

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**Abstract.** Reducing the cost of construction of buildings and structures was very attractive both under socialism, when they sought to increase the number of high-quality housing for the people, and under the chrematistical orientation of the "economy", which allows to increase the profit of the enterprising part of the community engaged in construction by selling housing to people. In these conditions, usually used masonry of chalk bricks, which were formed from baked clay, or monoblocks of solid concrete, which were bound with special binding solutions in the joints of the masonry. This dramatically increased the allowable stresses, the main contribution to which was made by the deformation of the seams. To reduce the cost of construction, it is proposed to use large building blocks with air slotted voids of the "nf15" type of Pobeda-Knauf company, which allows you to sharply reduce the amount of material for their manufacture; it makes the blocks lighter, and the presence of voids ensures the preservation of heat in the premises. In addition, the use of metal joints and composites that allow you to create in the factory articulated, quick-assemble, modular sections, armed with lock-free connections of parts, dramatically reduces the conduct of installation (de-installation). The simulation of the influence of air voids on durability of building blocks method "allowable stress" subject to "creep" completely eliminate possible doubts about the quality of these blocks and showed that the length of a possible crack growth the load can be increased, but the voltage at the vertices of the unit is clearly reduced. The rejection of expensive cement mixes in masonry, which significantly reduce its strength, and the transition to the use of smooth "beds" of monoblocks, which can be achieved by using appropriate forms during their "casting", as well as the use of appropriate adhesives for their additional binding contributes to further cost reduction. The results obtained can be widely used in the practice of building construction, for calculating the permissible stresses in large building blocks with air slits of different configurations.

**Keywords:** Cost, construction, buildings, structures, brick, brickwork, masonry, environmental construction, accelerated installation, high-speed construction.

## 1 Introduction

At all times, the construction and, above all, that of housing for people has been a vital social issue. Having a home, which literally means "to have a roof over your head," allowed you to create a family, facilitated the birth of children, made conscious the existence and survival of the family, which is considered the vital cell of any society.

Under socialist social and economic order, on the one hand, the construction of housing was financed from the state budget and distributed by the corresponding state funds, if there were legal grounds, among the members of the company on the terms of lease, and on the other hand, if there were legal grounds, the financing was carried out from their personal funds and became their personal property.

The transition to the post-socialist social and economic system in Russia pushed it to Chrematistics in which the vital activity of society began to be ensured by enriching its enterprising part (the Russian bureaucratic apparatus that had been formed and the Russian capitalists that had appeared), under the a priori assumption that once they had been enriched, general welfare would immediately come [10, P. 8]. The refusal to provide the country's population with state housing led to a sharp increase in market demand for it, which turned its construction into an hyper-profitable business based, as a rule, on "the work of legal entities on someone else's money", including budgetary funds. The peculiarity of such a construction business and providing its "federal programs" was that any building and structure, which has always been built at cost of production, which literally means "at the amount spent in the manufacture of goods" 24, C. 569], was given for the construction to legal entities (or, rather, at their mercy), which also built it at cost of production, but this cost was immediately added to the "market delta" known to all, intended for their pocket; and therefore, naturally, they sold housing to the population at a very high "market price", significantly higher than the specified cost.

It becomes clear that under of the socialist order as well as in the post-socialist system, the reduction of the prime cost is quite attractive, because if under socialism it became possible to increase the quantity of satisfactory housing for the people, the Chrematistics orientation allowed to increase even more the profit of the adventurous part of society engaged in construction by selling housing to the people.

The reduction of the cost of construction of buildings and structures has always been based, first of all, on new technologies in the production of construction materials, new technologies in their use, as well as on innovations in the development of mortars for joints when laying construction materials.

## 2 Technology and Methods

It must be remembered that even the term itself, *technology*, takes its origin from the Ancient Greek *τέχνη* — mastery and *λόγος* — word, science).

At the time of V.I. Dahl, *technology* literally meant "the science of technology; factory, handicraft, and industrial way of life". 7, P. 234], where *science* was understood to mean "discipleship, learning, and training" [6, P. 406], and "way of life" was understood to mean "household or craft, trade, embracing the activity and the subject, with all its accessories" [6, P. 486].

The socialist and post-socialist models of social and economic order in relation to their time clarified the semantic content of the term *technology*. It was understood as "a set of processes of processing or recycling of materials in a certain branch of production, as well as scientific description of production methods" [25, P. 638].

The technology of production of construction materials has gone a long way, the beginning of which can be associated with the production of dolmens and, later, construction of Inca pyramids of stone blocks, as well as the pyramids of Cheops (Khufu) of limestone blocks, each of which weighed several tons. Both the dolmens and the blocks were carefully set, polished, and "masterfully adjusted one to another so that it was impossible to sink a knife blade into the gap between two stones" [24]. Unfortunately, the methods of making and grinding stone and limestone blocks are lost beyond recall, just as the way they were delivered to their present location.

Among the historically important revolutionary changes in construction technology is the use in masonry instead of stone and limestone blocks of basic adobe bricks, which in the interior rooms began to be faced with stone. Studies of such bricks showed that some of them were polished only on one "bed," and some were polished on two "beds," so that the breaking stress in the first case amounted to an average of 47 kgf/cm<sup>2</sup>, and in the second case - of 71 kgf/cm<sup>2</sup>.

The labor intensity of manufacturing and grinding raw bricks forced the whole world to move to small bricks, which were formed from the fired clay.

Subsequent exceedingly long construction practice showed that the use of small bricks from baked clay turned out to be associated with significant labor costs for their production, long construction time and known difficulties in the operation of built objects.

The need for accelerated environmentally friendly construction of buildings and structures has led to the use of full modular construction, which was based on the example of ancient pyramids, large factory-made building blocks.

The blocks of NF15 type, with sizes  $510 \times 250 \times 219 \text{ mm}^3$ , produced by *Pobeda-Knauf* company, with their geometric volume not filled by a uniform isotropic medium, became a disruption in the manufacture of such large building blocks, dramatically reducing the cost of their manufacture, the reason they became exceedingly widespread. On the one hand, slotted air voids in these blocks sharply reduced the amount of material used for their manufacture, making the blocks lighter; these voids also provided heat preservation in the premises; on the other hand though the strength of such building blocks was questioned. The latter was determined by the fact that almost 50% of the slotted air voids, which were perceived by all as strong stress concentrators, were weakening the horizontal cross-section of such blocks.

In order to reveal possible negative influence of air slotted voids on the strength of building blocks and to eliminate possible disagreements in this regard, it was natural to turn to the modeling, which is the process of forming a model, under which V.I. Dahl understood "a sample in small form; object, especially in construction (church, ship, bridge), in a reduced size" [6, P. 286]. As applied to our time, the model was understood as "display of actual reality in its basic, essential properties" [10, P. 8], the basis of which is the theory of similarity, which, in the opinion of academician M.V. Kirpichev [13; 14, 15; 16], is to some extent the "grammar" of the experiment.

The theory of similarity is based on the following three theorems [9, P. 25-26]

The first similarity theorem formulates the properties of similar objects, stating that such phenomena, processes, subject areas, and objects have the same similarity criteria, thus indicating the necessary conditions of similarity.

The second similarity theorem (Buckingham  $\pi$  theorem) defines the possibility of bringing the equation to a criterial form, arguing that the functional relationship between the values characterizing the process can be represented as a relationship between the similarity criteria composed of them.

Finally, the third theory of similarity theorem defines the limits of natural distribution of an isolated experience and summarizes as follows: similar phenomena will be those that have single-valuedness condition and the same defining criteria.

However, the practice of modeling in construction often did not require an exact similarity of the model to the original and allowed the use of modeling based on incomplete and approximate similarity, the main provisions of which were developed by V.A. Venikov [2], A.A. Gukhman [4] and A.G. Nazarov [23].

Having this in mind, only an approximate modeling was used for strength estimation of building blocks with air slotted voids, which were perceived by all as strong stress concentrators. It was based on the "allowable stresses" method of design, actively used in mechanical engineering to identify the influence of air voids on the strength of the material. Using this method to study "allowable stresses" in building blocks instead of a single criterion – "safety factor" – several differentiated criteria were taken, i.e. coefficients (multipliers to normative values of strength of materials or loads), such as uniformity coefficient, load factor etc.

### **3 Results and Discussion**

Identification of "allowable stresses" was carried out on the most typical example of "stress concentration" when a crack in a stretched plate has no thickness. Such a crack is known as the strongest concentrator, because of the highest stresses at its tip. The nature of stress concentration in a plate made of physically nonlinear material and weakened in the middle by a crack, which has no thickness (the most dangerous concentrator), is shown in Fig. 1 [1; 11].

Fig. 1 shows a plate 5 cm long with a crack, which length naturally increases with load growth but at the same time stresses at its tip decrease, so that the stress concentration factor becomes 2 times less than initial one, in spite of the load increasing by 1,75 times.

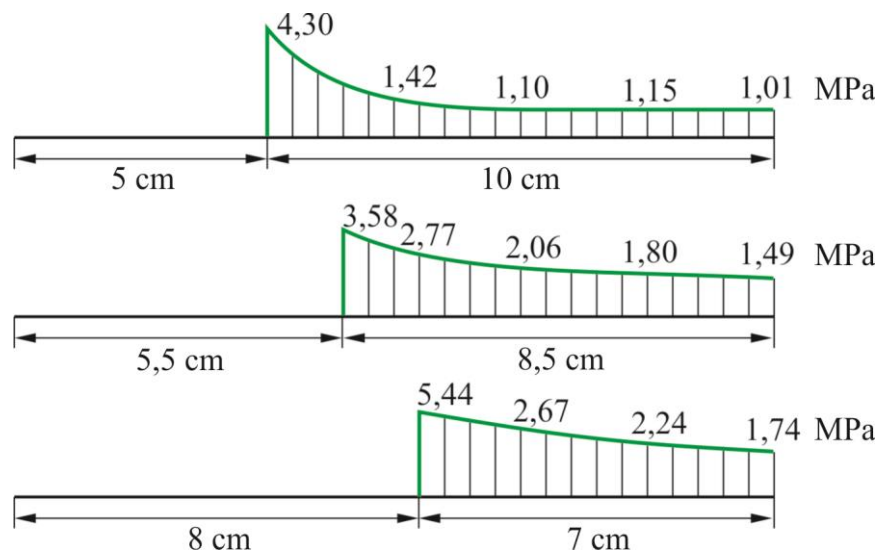


Fig. 1. Curves of normal stresses in the vicinity of a crack without sickness

A further technological innovation that reduces the cost of building blocks of type "NF15" was the production of new types of building structures on their basis with the use of metal joints and composites, which allow you to shop mount the articulated, quick-assemble, modular sections, now even with lock-free connections that allow for a high speed and quality installation or disassembly. The achieved levels and limits of "speed of construction" of buildings are presented in Table 1 [30-41].

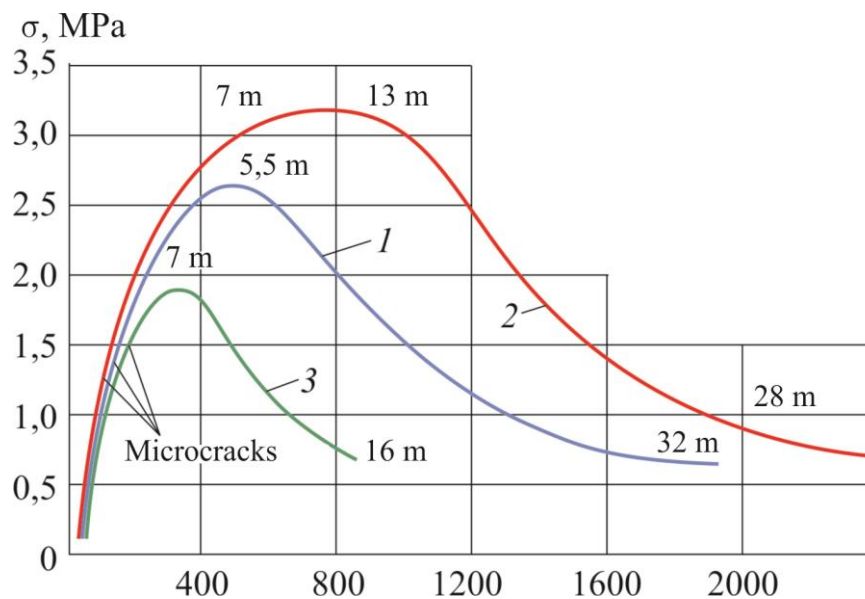
Table 1.

Qualitative levels of construction speed using "NF15" type building blocks	Quantitative values of construction speed limits using "NF15" type building blocks, m/day
High Speed	23,2 ± 2
Speed	0,14 – 0,46
Quickly built	0,14 – 0,46
Normal	0,09 – 0,29
Slow	0,06 – 0,17

A technological innovation in the use of large building blocks with air slotted voids of type "NF15" of the company "Pobeda-Knauf" was the additional account-

ing of "material creeps". According to the data of numerous tests for masonry from building blocks "NF15" the coefficients of their "creep" were experimentally established. They were taken equal to "2,5" after 10 years of operation and "5" - after 100 years of operation.

The role of "crack formation" taking into account "material creep" was confirmed by additional experiments on "stretching" of ceramic building block with air slotted voids and is visually illustrated by descending branches of deformation curve (Fig. 2) [11].



**Fig. 2.** Curves  $\sigma \sim \varepsilon$  when stretching concrete with indication of the width of microcracks opening:

- 1 - composition of concrete 1:1:2; water-cement ratio - 0,45; age of concrete - 65 days;
- 2 - composition of concrete 1:2:4; 0,6; 270;
- 3 - composition of concrete 1:3,6:0,99;70.

Besides, at the same time the non-linearity of the construction ceramic block with air slotted voids was investigated, for which a single equation of axial deformation was used in calculations as a mathematical model [1]:

$$\sigma_i = [1 - \Pi(\varepsilon_i, \gamma)] \cdot E_0 \cdot \varepsilon_i$$

(1),

where  $i = 1, 2, 3$

$\sigma_i$  and  $\varepsilon_i$  – stresses and deformations at a given point in the body;

$i$  – main index;



$\Pi(\varepsilon_1, \gamma)$  – the Gaussian probability of failure for mechanical connections at a given point of the body;

$E_0$  – Young module;

$\varepsilon_1$  – transverse strain coefficient;

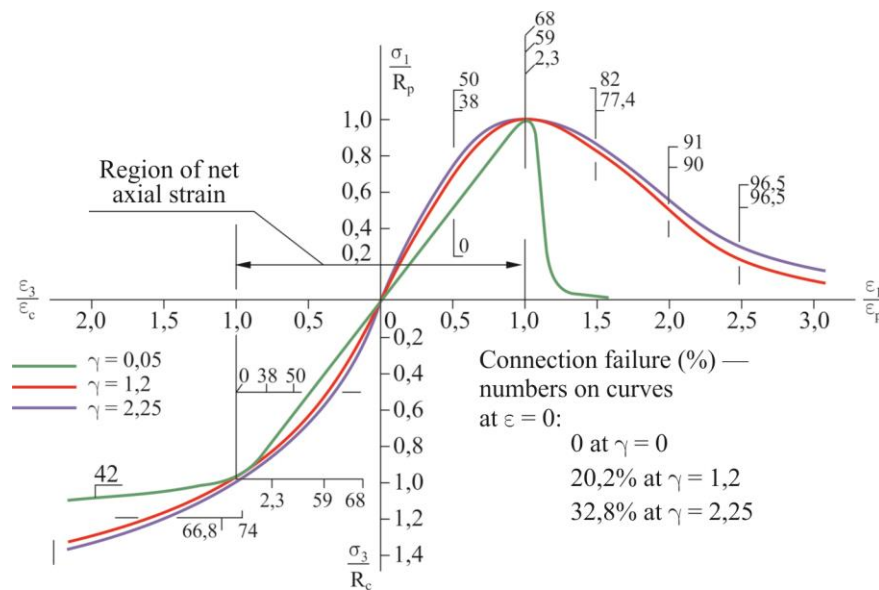
$\gamma$  – degree of mechanical heterogeneity of the material;

$\nu_0$  – Poisson's ratio.

Equation (1) determines the quantitative relationship between all necessary mechanical characteristics of the material and its physical constants, which allows to quantify the proportion of microcracks at the "loading" stage under standard test conditions. Destruction at the point of the body began at a certain value of the highest relative strain of the bond rather than the stress at the bond, which allows the normal distribution law to be used to estimate the strain at which failure begins.

The axial strain curve equation (1) is an average statistical expression that establishes a relationship between stresses and strains in a ceramic building block with air slotted voids. This bond is most clearly (and steadily) manifested within the limits lying between the compression and tensile strength limits, i.e., between the highest values of stresses (Fig. 3) [27].

Evaluating the results of the experiments, however it should be borne in mind that large-format samples of building ceramic block with air slotted voids are objects that naturally have a certain degree of homomorphism in relation to the rod used as a model in the study of its axial strain, because their limit of strength they is clearly overestimated. This is well visible in the graphs in Fig. 3, when, under certain ideal conditions, the material of a ceramic building block with air slotted voids can resist above its axial tensile strength. The increase in the strength of masonry with its "eccentric" compression is explained by the curvature of the stress diagram and the achievement of greater compression of the edges of section, at which the stresses increase by 6 - 7%.



**Fig. 3.** Single axial strain curves by equation (1)

The application of new technologies both in the production and in the use of construction materials, providing their cost reduction, has naturally led to innovation in the development of mortars for seams used in construction, where the *innovation* literally means "any changes, innovations in technologies" [29, P. 513].

The lost nowadays methods of manufacturing, processing and polishing of stone and limestone blocks, as well as the methods of thorough grinding of one or two "beds" at raw bricks, which allowed them to simply lie on top of each other, led later to the advent and use of special mortars for joining unfinished bricks from fired clay [12].

The important role of such a mortar for seams in the brickwork was confirmed by V. A. Gastev, who cited data on the value of relative breaking stress of a product composed of two bricks with different types of material in the seam between them (Table 1) [3, P. 104-130].

**Table 1.**

<b>Type of seam material</b>	<b>Rate of the relative breaking stress of the product</b>
<b>Pure Cement</b>	<b>100%</b>
<b>Cement mortar 1:3</b>	<b>100%</b>
<b>Wet filings</b>	<b>87%</b>
<b>Broken cement powder</b>	<b>83%</b>
<b>Lime mortar</b>	<b>78%</b>
<b>Fine wet sand</b>	<b>77%</b>
<b>Fine dry sand</b>	<b>73%</b>

Table 1 clearly shows that the breaking stress of a product, composed of two bricks, significantly depends on the type of material seam between them and has the minimum value in a total absence of moisture in the seam.

Following V.A. Gastev, we will consider that the main elements of masonry are, on the one hand, stone material - natural or artificial, and, on the other hand, the joints made of mortar, for which the age and conditions of its hardening become very important. At that time, based on the results of his analysis of an extensive number of experiments with masonry, we can say that [3, P. 104-130]:

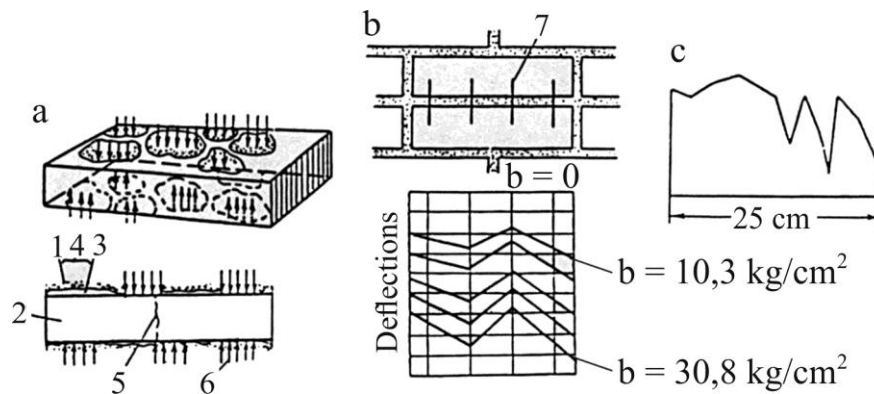
- When a massive masonry is compressed, the unevenness of the joints deformation caused by the interaction of stones and mortar is manifested, and as a result, transverse to the masonry deformation axis becomes active;

- the effect of transverse to the axis of masonry deformation causes the phenomenon of irregularity in compression and bending of stones in the masonry, which is especially pronounced when it is broken;

It follows from this that the unevenness of the joints actually determines the dependence of the masonry strength on the size of individual stones in the masonry, their quality, thickness of joints, height of the massif, the method of dressing the joints and the qualities of the mortar.

Detailed experiments carried out by the Central Research Institute of Building Constructions named after V.A. Kucherenko confirmed the accuracy of V. A. Gastev's opinion about the influence of brick bending in brickwork; the main reason for

this phenomenon is found out to be the uneven shrinkage of the mortar in the joints (Fig. 4) [26].



**Fig. 4.** Stress states of brick in brickwork:

- a) - distribution pattern of normal stresses on the bearing surfaces in the brickwork;
- b) - brick bending measured by strain gauges;
- c) - change of mortar density along the horizontal seam of the brickwork according to the same experiments where 1 - mortar seam;
- 2 - brick;
- 3 - air layer;
- 4, 5 and 6 - bending, shearing and local compression areas;
- 7 - strain gauge

According to S. A. Sementsov, when stresses are close to allowable, masonry deformation is a 25% to 75% mixture of brick and joint deformation, and when stresses are close to failure, 10% to 90% of brick deformation and mortar deformation [28].

It becomes clear that the elimination of negative effects of joint deformation is possible, in particular, by means of integration, which literally means "optimal combining of objects to achieve new maximum possible properties of this combination on the basis of known past experience" [8, P. 11]. Regarding the problem under consideration, it might be reasonable to speak about integrating such objects as:

- modernized large building blocks with air slotted voids;
- new mortars for joints when laying building materials.

So, remembering that the new is a well-forgotten old one, it is only natural to come back to the idea of using smooth "beds" of monoblocks, which can be achieved by using appropriate forms during their "casting". As for their additional binding, it is reasonable to use appropriate adhesives on smooth "beds" acting as mortars. Such innovative integration will allow *Pobeda-Knauf* to add to the ad-

vantages of large building blocks with air slotted voids of the NF15 type that of their further cost reduction [17-21].

Thus, the decrease in the cost construction of buildings and structures is now inseparably connected with the integration of the use of new technologies into the production of building monoblocks with air slotted voids and smooth "beds" of the "NF15" type by *Pobeda-Knauf* company and the application of new technology of their installation with the use of corresponding adhesives acting as mortars for joints.

#### 4 Conclusions

The reduction in the cost of construction of buildings and structures is inextricably linked to the integration of the use of new technologies in the production of construction monoblocks with air slits and flat "beds" and the use of a new technology for their installation using appropriate adhesives as binding solutions

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