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A NEW LOW-TECHNOLOGY, LIGHTWEIGHT CONCRETE BLOCK FOR REINFORCED MASONRY

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Abstract

The paper illustrates the design and fabrication techniques for lightweight concrete blocks for constructing reinforced masonry walls. The methods adopted do not require advanced technologies or high degrees of industrialization, and are therefore suitable for countries or areas where the transportation of prefabricated industrial products is either problematic or uneconomic.
A form made up of two intersecting steel elements has been prepared for casting the concrete mixture into blocks. An expressly designed inert mixture has also been developed using volcanic lapillus or a light aggregate (expanded clay), so as to maintain the blocks' shape soon after casting through bench vibration for about 20-30 seconds. Numerous blocks have been manufactured manually, some of which have been subjected to mechanical performance tests, and have yielded satisfactory results for a wide range of practical applications for masonry buildings.

1 Introduction

Over the last thirty years, the considerable scientific and technological advances achieved in the field of masonry construction have enabled the perfecting and marketing of a number of different types of building blocks, which have been received with a good deal of success in terms of efficiency of application and wide-spread adoption. The blocks currently available in the market can be grouped into three broad categories:

- lightweight aggregate concrete;
- alveolated clay units;
- autoclaved aerated concrete.

The considerable importance that these structural elements have taken on in recent years has made their design and production topics of extreme interest to current technical research and innovation, given that any improvements in their mechanical characteristics can have considerable economic repercussions.
Designing blocks for masonry constructions involves examining physical phenomena of various types and resolving the technical problems involved in their production and

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fitting. Design practice must in fact lead to the conception of new masonry structural elements that are not only able to furnish good physical and mechanical performance, but are, at the same time, easily fashioned, economically competitive and capable of satisfying sophisticated modern builders' demands for practicality.

Nowadays, masonry blocks are produced almost wholly on an industrial scale in special plants that, depending on their dimensions and degree of technological sophistication, reach decidedly advanced operational levels. Such modern productions means contribute to containing the cost of the final products and their eventual competitiveness in the market.

In Italy concrete block manufacturing began in 1910, when the first 'hand blocker' was built (fig. 1). This was a machine with a support base and a form into which the concrete was cast. After the cast was hand pressed, it was left to set and then extracted by overturning and opening the form. Later, in 1930, the first motorized blocker was produced by Rosacometta; this innovation enabled the blocks to be pressed by a belt-driven stamp. However, it was not until 1950 that block production entered the modern era with the introduction of the vibration technique, which is applied to both the stages of pressing the mixture and extracting the block. To this end, two types of blockers were later introduced: mobile and static; the former extracts the elements in special storage areas, while the latter deposits them directly onto a transporter inside the plant.

Figure 1 Hand machine for block production

The first stage of the process carried out in the interior of a modern production plant consists of transporting the aggregates via the loading hopper to the blender, where water and cement are added to yield concrete with a suitably plastic consistency, which the overhead wagon transports to a static blocker. This last represents the true heart of the production system. At the same time that vibrations are applied, a cassette fills the mold and a comb compacts the concrete, remaining in position while the mold is raised. The supports containing the blocks are then loaded into the lift and then transported to seasoning cells. After about 48 hours they are taken up again, arranged in the lowering lift and sent on to the final stage of packaging.

2 The custom-made block

The research work illustrated in the present article is intended to offer some food for thought regarding the possibility that designers conceive and fashion the blocks for constructions independently, rather than systematically assigning such operations to the technical personnel and production sectors of industrial firms. While on the one hand, the custom design and manufacture of structural masonry cannot by any means compete with large-scale industrial plants in terms of efficiency and production rates, on the other, such personalized production enables designers to solve specific problems posed by the job at hand. Such a procedure moreover offers interesting benefits in terms of environmental compatibility, issues which developed societies must devote ever greater attention.

Today's industrial plants are equipped with modern, technically sophisticated production systems that allow for high productivity levels and efficient quality control of the manufactured articles. In addition, production processes are programmed by experienced personnel with a broad-ranging understanding of all the complex technical issues involved in achieving optimal results from plant operations. On the other hand, extensive use of machinery such as kilns and autoclaves involves considerable energy expenditures and a high environmental impact in terms of toxic emissions. Adopting traditional production methods can not only eliminate all such negative aspects, but can more provide further ecological benefits by simply utilizing the by-products of other processes as inert input materials for production. Furthermore, the lack of high technology requisites for implementing such production methods makes them easily exportable to developing nations, once they have been suitably adapted to the demands, resources and building customs of the local area in question. Such aspects are of great current importance, by no means less crucial than considerations of environmental impact.

In the present article we wish to demonstrate how, through careful design, it is possible to fashion building blocks, which though produced through traditional, low-tech means, not only possess high-quality physical and mechanical properties, but can moreover best satisfy a designer's specific needs in the context of a particular construction to be erected. The fashioning of the prototype block illustrated in the following reveals the simplicity of such operations, carried out without recourse to technologically advanced tools and via procedures that allow keeping production costs within acceptable limits, even for relatively large numbers of units.

3 Design of the block

In the following we illustrate the main steps in designing a vibration-compressed concrete block for use in reinforced masonry. The goals of designing such blocks, whatever material they be made of, are represented by the following fundamental requisites:

- high bearing capacity;
- good living comfort, that is, in terms of thermal, hygrometric and acoustic aspects.
- adequate fire resistance;
- manageability and simplicity of casting and laying;
- satisfying the economic and aesthetic demands of local markets.

Figure 2 Air cavities in a standard mold

This last aspect, which may appear secondary in importance, actually often turns out to be a strong determining factor in the design process. For instance, in the specific case illustrated, the design adopted calls for building the entire structure with only one type of block, thereby avoiding special pieces for the wall intersections. Besides, in deciding the block's dimensions, the ratio of thickness to length must be carefully considered, as

it strongly influences the building's design and construction. With the aims of limiting the block's weight to about 16-18 kg and constructing walls 30 cm in thickness, it was decided to adopt a square plane element 300x300 mm with a height of 190 mm, which would minimize at the same time the geometric constraints on the building design.

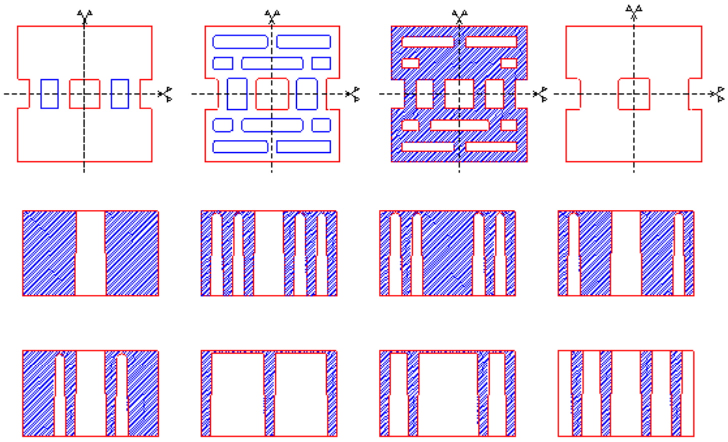

Figure 3 Block sections

The choice of the block's section was guided by UNI regulation U73.06.080.0 (1999), which is specific for vibration-compressed concrete elements and prescribes a maximum air cavity percentage of 45% for a semi-solid block, with a total air space of less than 10% of the overall area of the face, internal and external ribbing 20 mm in thickness and a coring of at least 60x60 mm for the fitting of vertical reinforcement. Given the dimensions of the block, it was decided to position the vertical reinforcement in the central part of each block and in the gaps between two adjacent blocks.
Looking at a standard mold, it can be seen that the air cavities are created with hollow steel wedges with rectangular or circular cross sections welded on their upper parts to horizontal rectangular cross-sectional profiles; the main direction is dictated by the horizontal profiles, to allow for the entry of the concrete, while the staggering of the vertical cavities is useful in order to optimize the thermal insulation between the two faces of the wall.

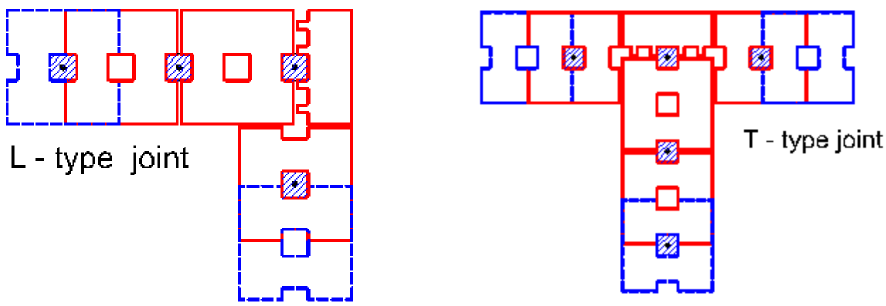

Figure 4 "L" and "T" type wall intersections

After some preliminary studies of various test sections, we defined the experimental section as one with a total air cavity percentage of 44.8%. The illustrations in figure 3 show the presence of a 70x70 mm central core on the lower laying surface (to allow for greater tolerance in arranging the vertical reinforcement rods from the foundation or floor), and the beveling of the sharp edges with a curvature radius of 5 mm, to reduce friction between block and mold and avoid stress peaks, while the block vertical sections show the 3 mm splay on both sides of the cavities to ease detachment of the block from the mold. Lastly, all the vertical cavities, except the central one, are blind-

ended, with the aim of avoiding penetration of the mortar within the block. The block design enables both “L” intersections with three vertical reinforcement rods and “T” intersections with four rods (fig. 4).

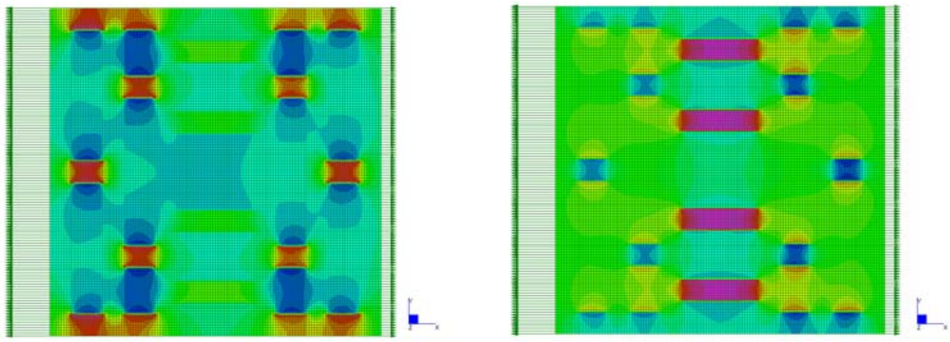

Figure 5 Thermal mappings of the block sections in F.E.M. analysis

The temperature, humidity and physical requisites of a wall made with the proposed blocks were checked via preliminary calculations of the Thermal Resistance R, using the F.E.M. model, as prescribed by UNI regulations 10355 and 10351: the thermal power Q, exchanged by the block when a temperature gradient $\Delta T = 20°C$ is applied on the external faces, is given by the sum of the thermal power Q_1, transmitted by a 180 mm high hollow block, and the thermal power Q_2, transmitted by the lower section of a 10 mm high block filled with mortar. In both cases, we mapped a two-dimensional plane section (fig.5) and calculated the conductivity of the concrete, as per UNI 10351, as well as the equivalent conductivity of the air-filled cavities according to UNI 10355. Then, the calculation code was applied to obtain the integral of the thermal flow of the longitudinal section, whence we obtained the following:

- $Q_1 = 6.902$ W/m * 0.18 m = 1.242 W ; $Q_2 = 9.752$ W/m * 0.01 m = 0.098 W
- $Q = Q_1+Q_2 = 1.34$ W; R = 1.175 m^2 K/W

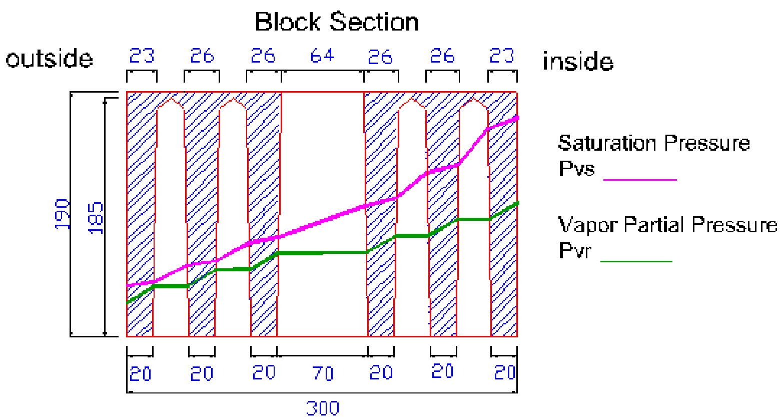

Figure 6 Pvs and Pvr lines in the block section

Hygrometric checks were carried out via the Glaser method. For reinforced masonry it is particularly important that the formation of internal condensation be avoided, because it would rust the reinforcement rods and thereby lead to degradation of the block. Examination of the block section (fig 6) reveals that the saturation pressure lines Pvs do not encounter the vapor partial pressure lines Pvr, indicating the absence of condensation in the block interior for a temperature gradient, $\Delta T = 20°C$.
The Sound Insulation Capacity, R_w, was evaluated via the “mass law”, which for a 1 m^2 wall composed of 16 blocks and weighing 341 kg, including the mortar and plaster

joints, yielded a value of 53.1 dBs. The result was also corroborated by calculating the STC index (Sound transmission class), introduced by the National Concrete Masonry Association, which yielded a similar value of R_w = 53.8 dBs.
Evaluation of the concrete elements' resistance to fire cannot be accomplished by direct application of the UNI 9502 analytical procedure, which is not applicable to masonry structures. We therefore calculated Fire Resistance R, via the method of "Equivalent Thickness" deduced through laboratory tests standardized by the "American Concrete Institute" and "The Masonry Society." The wall's equivalent thickness, t_e, was calculated to be 175 mm, corresponding to a value R = 360 min. for the block alone, which by adding the contribution of the plaster on both sides of the wall, R = 40 min., gives a total value of R = 400 min.

4 Fashioning the prototype

The prototype form is represented by the chamber between two metal elements, called the "mold" and "comb" (fig. 7-8), which is to contain the concrete constituting the block. The mold is made by cutting the profiles for the interior air cavities and a 3 mm connection plate, which are then welded together. Lastly, two vertical guides are inserted. The comb is assembled in a similar fashion. Figure 7 shows the central open-ended core and the lateral blind cavities, while figure 8 illustrates the entire mold and comb assembly within the guides.

Figure 7 Components and final arrangement of the mold

Figure 8 Comb insertion in the vertical guides

The optimal concrete mixture for the block was determined by performing numerous trial extractions from the form, as the successful outcome of a cast is quite susceptible to the varying proportions of the different constituents. The following percentages were used as a starting point for 1 m^3 of concrete:

- 1500 kg of aggregates, composed of 83.33% volcanic lapillus, 3.33% expanded clay, 13.33% calcareous sand;
- 320 kg of R 42.5 cement;

- 150 kg of water.

The mixture for the prototype was prepared manually in order to simulate an actual low tech-setting. The consistency of the mix was adjusted by adding water and cement as needed to obtain a relatively low plastic paste with an Abrams slump value in the range of 0 to 3 cm (fig. 9).

Figure 9 Concrete used for castings

The block was created posing the form on a vibrating table run by a simple electric motor powered by a generating system. The mold was filled with concrete, and the vibrating table operated for about 20-30 seconds, applying a load of 50 daN to the comb in order to exert adequate pressure. The mold was then released with the help of some taps of a hammer: once the friction adherence was overcome, the mold was lifted off, taking care to keep it in the vertical. The blocks were then deposited in the shade to let them set (fig. 10). A production rate of about 30 blocks/hour was attained by one person using a single form, which corresponds to about 2 m^2 of wall surface per hour, quite similar to the average construction rate of a bearing wall (fig. 11).

Figure 10 Final phases of production process

A series of sample blocks was fashioned and subjected to tests of mechanical compliance. After checking the blocks' surface flatness, dimensions and the thickness of their ribbing, an immersion water absorption test was performed: the sample block was dried at 70°C in a ventilated oven until a constant mass of 15.2 kg was reached. The sample was then submerged in water for 24 h with a water head of over 50 mm. The saturated weight obtained was 17.7 kg, which corresponds to a water absorption value below the regulation limit of 26%. The test of capillary absorption was performed by immersing one face of a dried block on 5 mm spacers and maintaining the water level constant and weighing the entire block after 600 sec. The water absorption by

capillarity thus measured was 327 g/m^{2}s, only slightly above the limit value of 300 g/m^{2}s. In order to evaluate vertical compressive strength, the block faces were smoothed by milling and inserted under a rubber-lined press to guarantee uniform contact. Three blocks were thereby brought to rupture, yielding a mean compressive stress value of 4.1 N/mm^2, below the limit value of 5 N/mm^2, but high for a hand-made block fashioned with simple, low technological means and involving modest expenditure of electrical energy (used during the vibration stage alone).

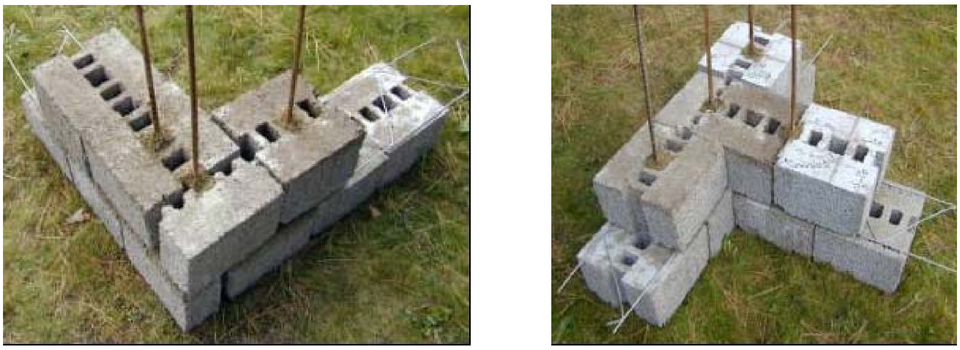

Figure 11 Reinforced masonry walls intersections

5 Conclusions

The vibration-compression technique enables producing concrete blocks for reinforced masonry with high-quality mechanical, thermal and hygrometric characteristics. The properties of the blocks described in the foregoing stem in large part from the use of light aggregates, such as volcanic lapillus and expanded clay, which lower the mixture's specific weight without compromising the element's bearing capacity, and at the same time improve its performance in terms of insulating properties. In fact, such material's uniform micro-porosity (fig. 12), together with a suitable arrangement of the cavities cast in its interior, constitutes an effective obstacle to heat conduction.

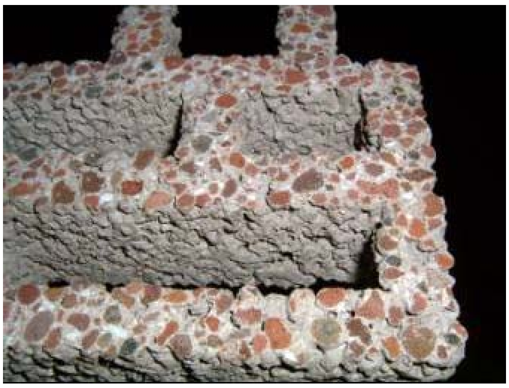

Figure 12 Porosity of the block material

This type of block also offers the further advantage of great manageability, which makes casting and laying in constructions quite easy. In the example illustrated, the resulting concrete specific weight value of 1600 kg/m^3 enabled manufacture of a 30 cm thick block whose weight did not exceed 16 kg. Lastly, the properties and physical appearance of the material moreover can be varied so as to enable its use in constructing “raw-masonry” outer walls, that is without plastering or stucco, with interesting aesthetic effects.

In addition, the application discussed shows how designers can, in practice, independently conceive and define concrete blocks “from scratch” to be used for a specific structure. The design in question was in fact developed using precise, but

widely available calculation methods, by simply applying the guidelines furnished by the relevant regulations. The result is a newly conceived block able to meet all the specifications required by the market. Lastly, the fact that the prototype was fashioned by hand underscores that this type of structural element can easily be produced by “cold-working”, without harmful effects on the environment or recourse to expensive equipment or advanced technologies. A further benefit from the perspective of eco-sustainability is the possibility of using the by-products of other production processes as inert aggregates for fashioning the block.

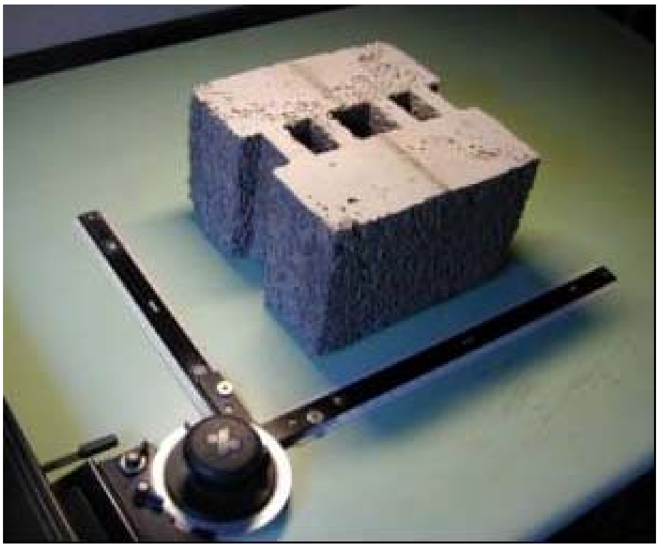

Figure 13 Designing a block

In conclusion, it seems safe to state that the vibration-compressed concrete block clearly represents an efficient, versatile, economically competitive product. Its exploitation represents a valid response to the demands of both the world of traditional construction and recent societal evolution, especially with regard to mitigating the poverty and lagging technological development of wide areas of the globe. Hence, it seems bound to play a promising role in developing countries.

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