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Monolithic Structure Technology: A New Construction Process to Enhance Traditional Construction

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Abstract: Let's imagine a low clay soil or aggregates, lime or cement and fibers; how can we create value with these three materials or rather how can we achieve an affordable, sustainable building with low environmental impact that requires less maintenance. The elimination of steel increases the life span of buildings by avoiding the corrosion of steel through the phenomenon of the concrete carbonation. So what is the proposed mix and with what mode can we build. The objective of this paper is to propose and evaluate a new construction technology: the technology of monolithic structures applied to low-rise buildings. This technology focuses on the valorization of local materials through a modern construction process. Thus, in this paper describes the process, propose and analysis the adequate models in materials and architecture. Finally, it analyze the feasibility, the ecological and economic profitability of this technology. This construction process uses the same ingredients as traditional buildings, but with innovative approaches in design and execution.

Keywords: Monolithic structure, arched frame, constructive processes, local materials, vault

1. Introduction

The advent of reinforced concrete has diverted human thought to a single simple and practical solution with a catastrophic impact on the environment. Cost-effective solutions that are easy to achieve with minimal impact on the environment exist, just look at the subject of construction differently. With hybrid technology, promising alternatives can be developed for low-rise buildings; Traditional materials with modern processes to produce value. Soil, binder and fibers will be mixed to produce fiber concrete. The building structures; walls and floor (in the form of a vault) will be cast spontaneously using monolithic formwork. The formwork can be modulated and used several times, which will greatly reduce the cost of construction.

Historically, Roofs are made from wood or materials with low tensile strength (masonry, stone, rubble, brick, concrete, steel and wood) by mobilizing the form of the arch, vault and dome that work mainly in compression, limiting the shear forces and bending moments, thus allowing materials with low tensile strength to be used for the covering of houses. This last process has been abandoned because of the complexity of implementation to be replaced by modern procedures of covering more practical and effective based in general on concrete and reinforcement. In spite of the

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technical and economic advantages that they present, the ecological problem and their relatively low life span encourage us to develop alternatives at least for low-rise buildings. In the same sense, wood, which is the traditional material for roofing, is becoming increasingly rare and expensive, hence the interest in seeking to enhance the old roofing techniques (arches, vaults and domes) by modern construction processes through the implementation of adequate formwork or prefabrication techniques.

The technology of the monolithic structures will allow to cohabit the advantages of the traditional construction (Ecological, thermal insulation, good hygrometric regulation, fire resistance, 100% recyclable) with the advantages of the modern processes of construction (Minimization of the costs of production, the acceleration of the rate of production). Although the first models of this technique are intended for areas of low seismicity, they will allow us to enhance the value of local materials and increase the life of buildings by eliminating the reinforcement that corrodes over the years due to the phenomenon of carbonation (Bertolini, 2008). In the same sense, the industrialization of the construction procedure of the traditional will allow us to reduce the cost and facilitate access to housing for a large population of low income. In short, this technique will allow the coexistence in the same project of requirements that are often contradictory in nature, such as ecology, economy, performance and sustainability.

The principle of stability of monolithic structures is based on the mobilization of the shape (arched frame) to make all the ecological concrete of the building structure work in compression. This technique will allow us to valorize the materials of low tensile strength in the construction (ordinary concrete, fibrous concrete, lime concrete, cemented earth) and allow us to develop techniques of covering which will replace the reinforced concrete and the wood; the materials classically used for the floors. The arched slabs are supported by bracing walls that will transmit the loads of the building to the floors and guarantee the overall stability of the structure.

In this article we will describe the construction method chosen for this approach; materials, equipment and operating mode. Then we will verify the stability of the model through numerical simulations, to conclude on advantages, disadvantages and socio-economic impact of this technique.

2. Description of Procedure

The objective of monolithic structure technology is the mass production of low-rise green buildings through the design of a monolithic formwork for the bonding of the building's load-bearing structure. The forms suitable for this construction approach are based on structures generated from arched frames (Fig. 1) such as the vaulted structure supported on bearing walls. The choice of this type of structure is justified by the will to mobilize traditional or artificial concretes of low tensile strength for the covering with the objective of bonding a single monolithic load-bearing structure of the building by the adapted formworks with an almost infinite rate of reuse. This will allow us to eliminate the use of reinforcement steel and wood for the roofing while gaining on the ecological and economical plans. The openings will have an arched shape (Fig. 2) and will be made as a reservation in the monolithic formwork. Counterforts elements must be dimensioned to take up the thrust forces at the right of the supports of the arches to avoid building thick walls.

Fig. 1 - Perspective of the model showing the structure generated from the arched frames

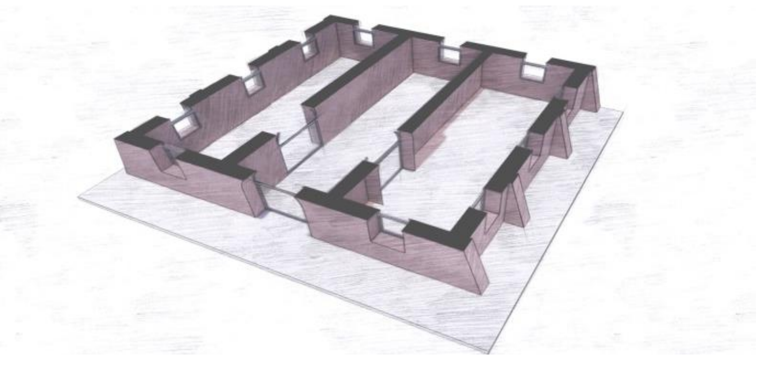

Fig. 2 - A plan view showing the insertion of the arched bays in the load-bearing walls

The model architectural design: we propose in this section the typical model of the hybrid building suitable for the villages (Fig. 3) based on the monolithic structure technology. Unlike the traditional approach to construction, the architectural design and the supporting structure are studied simultaneously upstream from the design phase of the monolithic formwork, which is an essential part of this technology because the position of the partition walls impact the distribution of the building's parts. The partition walls are made after the formwork is removed. The roofs have the shape of a vault, which allows a perfect integration of the building (Fig. 4) in its environment. The arched openings are perfectly integrated into the structure. A bioclimatic, simple and monolithic architecture ensures an ideal and healthy living environment.

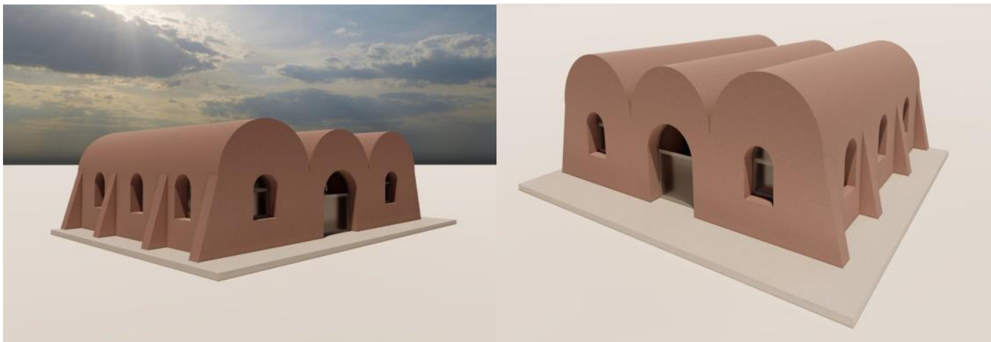

Fig. 3 - Perspective of a monolithic building designed with arched frames

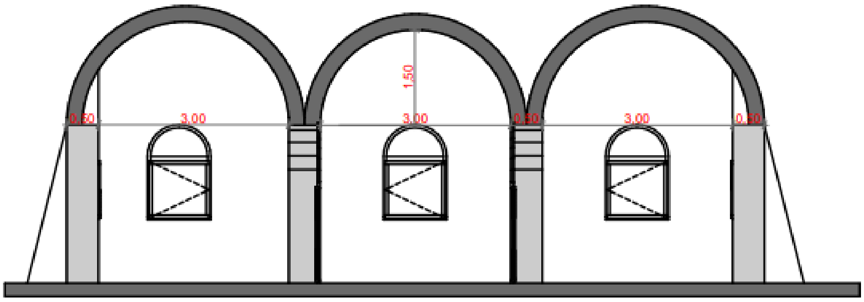

Fig. 4 - Cross section of the arched frames showing the vaulted roof of the model

Steps and construction method:

- The design and realization of the monolithic structure of the metal formwork with an almost infinite rate of reuse.
- Layout of the building and installation of the metal formwork.
- The manufacture of the fiber-reinforced concrete and the pouring of the monolithic structure simultaneously, concreting pockets can be created in the formwork to ensure the total filling of the structure (Fig. 5).
- Removes formwork and completion of the finishing work.
- The reuse of the same formwork for the mass production of other similar housing units.

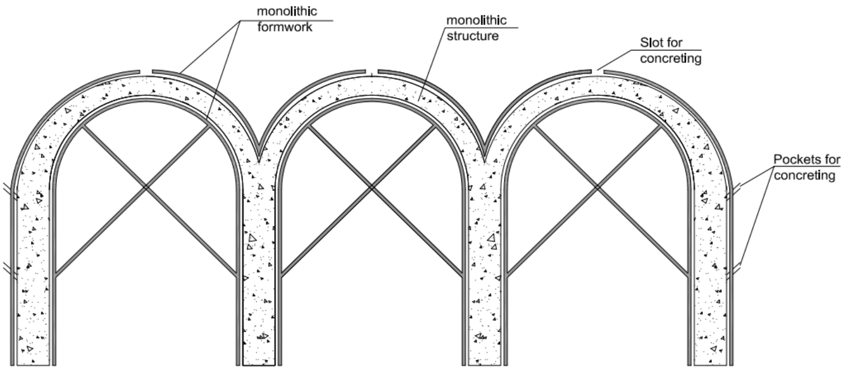

Fig. 5 - Cross section of the monolithic formwork with slots and concreting pockets

3. Stability of Arches and Vaults

The arches and vaults are among the oldest techniques used to realize the elements of coverings (floors and lintels) largely abandoned in the construction for the difficulty of implementation to the detriment of modern materials and techniques. The design of the arches aims to find a geometry for which the material works mainly only in compression, limiting the cutting forces and the bending moments that must be zero (the funicular polygon). The ideal shape to support a uniformly distributed load for an arch of deflection H and length L is a parabola of equation $y(x)= (4H/L^2).x.(L-x)$, this shape allows to cancel the bending moments all along the arc. For a point load we find a piecewise affine curve of equation $y(x) = (-2H/L) x+ 2H$. For an arch supporting the combination of a uniformly distributed load and a point load, the shape is a shape whose equation is the sum of the two equations previously mentioned (Equation of parabola+ Equation of an affine curve); this is the shape of pointed arches (Gothic Art) (Antonelli, 2017). In our study and for architectural reasons we adopt a form of the round arch. The bearing capacity of arches and vaults vary considerably depending on the quality of materials used, the construction method, shape, thickness and type of loading. According to Akbarzadeh & Taghi (2020) the bearing capacity of masonry vaults of small span is estimated at 30KN (order of size).

The minimum thickness to contain the thrust line for a semi-circular arch is the span/18 (Huerta, 2006) which gives for our example 300/18 and if we adopt a geometrical factor of 3 for the stability approach we find a thickness of 50 cm which well justifies the pre-dimensioning value set for our design example.

In order to assimilate the mechanical behavior of the vaults of our model and to have orders of magnitude of mechanical moments, shear forces and stresses. We have performed a linear combination analysis at the ultimate limit state with finite elements of the vaults using the Robot software. The roof is considered inaccessible supporting an operating load of $100daN/m^2$ combined with the self-weight during the analysis of the structure at the ultimate limit state according to the BAEL91 regulation. The walls are modeled by linear roller supports.

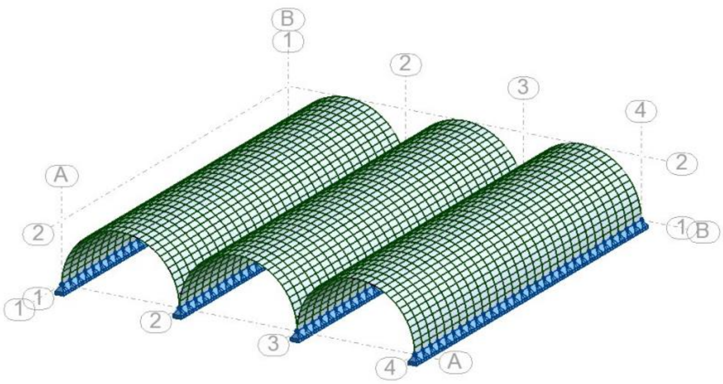

Fig. 6 - Perspective of vaults modeled on roller supports with mesh

4. Results and Discussion

The values of the bending moments (Fig. 7) have progressive negative values approaching the center of the keystone of the arch. These moments will generate tensile stresses in the upper fiber and compressive stresses in the lower fiber of the arch, which will increase the bearing capacity of the structure due to the effect of the arch shape.

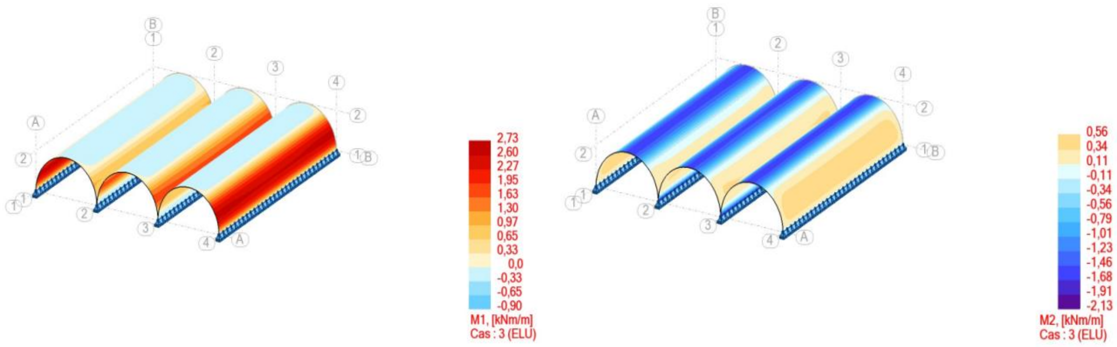

Fig. 7 - Principal values of the bending moments M1 and M2 at ultimate limit state

The shear stresses and shear forces (Fig. 8) are maximum as expected at the level of the supports with a maximum value of (t (1-2)max=0.08 MPa), this value can be taken with a concrete of compressive strength higher than 5MPa (ft28=0.6+0.06*fc28 : approximate formula BAEL91).

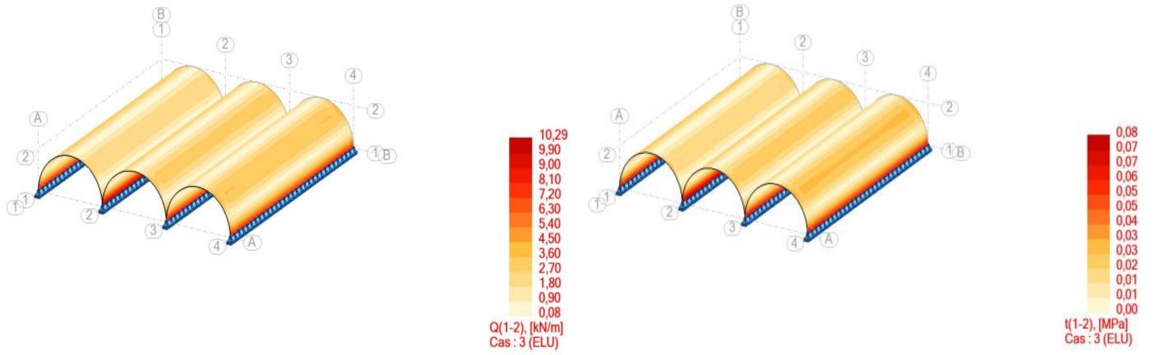

Fig. 8 - Principal values of shear forces Q (1-2) and shear stresses - t at ultimate limit state

The normal stress values (Fig. 9) show that the vaults work mostly as expected in compression. For our case, the stress values are very low (smax = -0.23 MPa at the supports) because it is an inaccessible floor with a load of 100 daN/m2. This value will be easily supported by low compressive strength concrete.

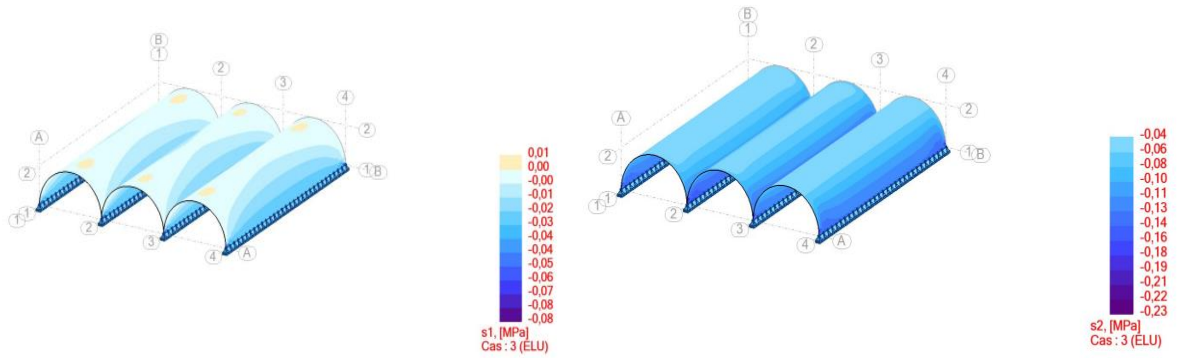

Fig. 9 - Principal values of normal stresses s1 and s2 at ultimate limit state

The calculations made confirm the human practice that has lasted for centuries, which consists in furnishing the form to use materials of low tensile strength for the covering. The values of the bending moments and shearing forces can be further reduced by adopting the funicular shape in order to reduce the thickness of the vaults and the thrust forces will be taken up by the counter-balance as already foreseen in the initial model design.

Advantages of monolithic structure technology:

This approach will make it possible to produce low-rise buildings with better ecological and technical performance at a very low cost. The advantages can be summarized as follows.

- A high production rate.
- A spectacular reduction of the cost price through the industrialization of the construction and an almost unlimited rate of reuse of the monolithic formworks.
- The cost-effectiveness of the traditional construction and the valorization of the local materials.
- The elimination of steel and the increase of the life span of buildings.
- A very good integration of the architectural design in its immediate environment.
- An ideal finish of the walls, an extraordinary power of insulation and a bioclimatic aspect.

Disadvantages of monolithic structure technology:

- Difficulties in overcoming heights, it is a technology generally suitable for low-rise buildings.
- The presence of partition walls that limit architectural creativity.
- Requires good soils with low deformations to avoid cracking by differential settlement.

Perspective of improving the technology of monolithic structures:

- Design monolithic formwork suitable for ground floor+1 building.
- Design more modular formworks for more freedom in the architectural design of buildings.
- Develop seismic solutions adapted to this technology based on the seismic fiber technology.

5. Conclusion

Through the application of the concept of hybrid technology, we have developed this practical approach to construction called the technology of monolithic structures, this approach will allow seeing the concept of construction differently with the objective of cohabiting the maximum of contradictory requirements in a single project: service, stability, aesthetics, economy and environment. Thanks to this technology we can put ecological buildings with better thermal, economic and technical performances at the service of a population that is looking for low cost buildings with better performances without severely impacting the environment.

The development of industrial processes for the mass production of traditional buildings will make the traditional more competitive with all the ecological and economic advantages that can be drawn. A wide range of structures and forms can be developed according to the needs, tastes and desires of the target population based on this approach which aims at the industrialization and the revalorization of this very old architecture. This trend must take its place in the field of buildings and public works to participate in limiting the pollution caused by construction and develop a constructive, ecological and social economy.

For steel and timber importing countries, the valorization of earth and stones to produce high performance buildings is an economic and ecological property at the same time, because with this technique it is possible to valorize the local materials and to decrease the imports this engineered materials.

Research work should be continued on this technology with the objective of developing commercial prototypes and developing seismic-resistant solutions through seismic fiber technology.

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