DESPRE UTILIZAREA GRILELOR POLIMERICE LA STRUCTURILE DIN ZIDĂRIE
ABOUT USING POLYMERIC GRIDS FOR MASONRY STRUCTURES

NICOLAE DANIEL STOICA* , **MIRCEA BARNAURE**
Universitatea Tehnică de Construcţii Bucureşti, Bd. Lacul Tei 122-124, 020396, Bucureşti, România

Around the world there is a significant number of masonry buildings. Owing to the structural degradation during their existence, many of these structures require retrofitting interventions, especially those located in seismic areas. If masonry buildings have religious or cultural value, then the interventions should have a wider scope that aims to conserve the historical heritage. The Venice Charter of 1964 [1] includes two key principles guiding how this work should be carried out: the first principle is that structural interventions must be as less visible as possible, in order not to modify the aspect of the building; the second principle is that the action must be reversible, offering the possibility of dismantling should the interventions have poor efficiency. For this type of retrofitting works composite materials might offer several advantages. In particular, polymeric grids can ensure an enhanced resistance to the unreinforced masonry structures while not modifying their architectural aspect. The grids can be used for new buildings also, as they have some advantages with regard to the traditional solutions with steel reinforcement.

În lume există un număr semnificativ de clădiri cu structura din zidărie. Multe dintre acestea necesită lucrări de intervenţie în vederea consolidării, datorită degradărilor suferite de-a lungul timpului, în special în cazul celor situate în zone seismice. Unele dintre aceste clădiri fac parte din patrimoniul cultural sau religios, iar intervenţiile asupra lor trebuie să se facă în baza unor principii care să asigure menţinerea caracterului lor istoric. Carta de la Veneţia din 1964 [1] include două principii cheie: primul principiu este ca intervenţiile structurale să fie cât mai puţin vizibile, astfel încât să nu modifice aspectul clădirii; al doilea principiu este ca acţiunea să fie reversibilă, cu posibilitatea de demontare stabilită încă de la început în caz de non-performanţă. Pentru acest tip de intervenţii sunt interesante produsele din materiale compozite. În particular, grilele polimerice pot asigura o rezistenţă sporită a structurilor din zidărie simplă, fără modificarea aspectului arhitectural al acestora. Grilele pot fi utilizate şi în cazul clădirilor noi, prezentând anumite avantaje faţă de soluţiile tradiţionale cu armături din oţel.

Keywords: *d. Masonry, d. Construction, c. Mechanical properties, FRP, Polymeric grid, strength*

1. Introduction

Given that all of its structural components are, in essence, heterogeneous, masonry is not a continuous and isotropic material. Moreover, masonry has clear discontinuities in the connecting areas between the bricks. From the point of view of the Theory of Dislocation, the joints between the bricks are structural geometric imperfections, and this is important because stress concentrations occur around geometrical faults [2].

For long-term actions (such as gravitational loads, for example), the ductility of the lime mortar protects the bricks against dislocation by the phenomenon known as adaptation. For short-term actions (such as those occurring during earthquakes), there is not enough time for local stress concentrations to be redistributed through plastic deformations to the adjacent sections [3].

The traditional way of building masonry walls, with alternating bricks (weaving) allows changing the position of the vertical joints, leading to an almost constant and uniform distribution of the areas of stress concentration. This is harder to obtain for hollow bricks, where, due to their thin walls, an increase of the maximum tension stresses appears. Cement mortar worsens the situation. Because it is fragile, the mortar between bricks easily cracks and the redistributed internal forces focus around any existing structural defects including cracks.

The equilibrium and stability of cracks are studied in detail by the Theory of Dislocation using Burgers vectors. For the particular case of a symmetrical crack with a length equal to 2D developed in a continuous and isotropic medium with a Young modulus E under a uniform distributed pressure p_o, we have

$$2D = \frac{4\alpha E}{\pi\left(1-\nu^2\right)p_0^2} \tag{1}$$

where ν is the Poisson ratio and α is the surface tension force (N/m) defined by

$$\alpha = \frac{Eh^3}{24\left(1-\nu^2\right)}k^2 \tag{2}$$

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* Autor corespondent/*Corresponding author,*
E-mail: stoica@utcb.ro

where h is the buckling layer thickness and κ is curvature. For extreme values of p_o, equation (1) contains the geometric instability of the crack. This instability is due to the fact that the material elasticity and fragility were considered perfect. In fact, plastic deformations that develop at the edges of the crack reduce its extension.

To avoid this failure mechanism, a possible solution is to use polymeric grids embedded in mortar covering the potential geometric imperfections of the masonry. These grids have a regular geometry and an important tensile strength and can take over masonry stresses and uniformly redistribute them to the adjacent sections, eliminating the risk of dislocation or fracture. Experimental shaking table tests on large scale models [4-6] showed a significant increase in the resistance of masonry buildings reinforced with polymer grids.

2. Polymeric grids for masonry

There are several strengthening techniques for the unreinforced masonry structures. The conventional techniques are reinforced concrete jacketing, grout injections and internal or external prestressing of the walls. Modern techniques involve the use of composite material meshes, made of strips or grids, that can be either externally bonded or embedded in mortar layers. With regard to the composite materials, there are several types currently used for structural strengthening, namely FRP (fiber-reinforced polymer), SRG/P (steel reinforced grouts/polymer) and TRM (textile reinforced mortars) [7-9]. This paper analyses Tensar Richtergard grids [10] which are particularly reliable for the strengthening of masonry structures [11].

2.1. Manufacturing technology

The grids are made of polyethylene and polypropylene by hot wiredrawing and have the configuration and physical-mechanical characteristics guaranteed by the manufacturer. The mixture of polyethylene and polypropylene is then dosed as by hot rolling to produce a high density membrane. The membrane is then perforated by punching and an orthogonal network of circular voids with constant diameters and distances between them is obtained. This perforated membrane is then subjected to uniform longitudinal tensile stresses on its width under controlled speed and temperature. The unidirectional wiredrawing makes the initially circular voids to become curved rectangles. In this way the unidirectional polymer grid with well defined geometry and strength is obtained. By continuing the same technological process, with uniform wiredrawing in the transverse direction, the bidirectional polymeric grid with square mesh curves is obtained.

The main advantage of the manufacturing process is due to the macromolecular structure of the linear polymers chosen as base material. By rolling between two cylindrical steel drums, the polyethylene and polypropylene membrane is compacted in thickness until a high density is obtained. During the hot rolling process, the long macromolecules are not oriented, and the directions of the cuneiform molecules remain random, as in the original mixture. But by the wiredrawing process the orientation of the macromolecules begins and is produced. They are oriented in the wiredrawing direction and thus the intermolecular spaces dramatically decrease.

The orientation of the polymer molecules, which occurs during the manufacturing of grids, provides several advantages. Firstly, the grids joints are rigid, unlike for other grid systems, where the joints are glued or sewn. Second, the high Young modulus ensures that a high tensile strength is obtained for small deformations. Also, the polymers trend to deform in time under long-term loads is greatly reduced. The choice of a grid system for masonry strengthening should be based on these three criteria: high tensile strength at low strain, low long-term deformations and rigid grid joints [12].

2.2. Geometry of the grids

The polymer grids are composed of flexible ribs and rigid joints. The ribs are variable in their plane geometry but they have constant thickness. They are narrower in the middle and become progressively wider in the proximity of joints. The geometry of the joints between the ribs is made of


a. Grile monoetirate / *mono-wiredrawing grids* b. Grile bietirate / bi-wiredrawing grids

Fig. 1 - Geometria grilelor / *Grid geometry.*

continuous curves. The joints are integrated in the grids and their thickness is up to four times the thickness of the ribs. The mono-wiredrawing grids have two axes of symmetry, parallel to the ribs (Fig.1.a). The bi-wiredrawing grids have four axes of symmetry, two parallel to the ribs and two parallel with the diagonal of the meshes (Fig. 1.b).

The polymeric grids for masonry, SS20, SS30 and SS40 are bi-wiredrawing grids, with the meshes of the grid in the shape of rounded squares. In their plane, these grids show two remarkable geometric qualities. Firstly, they appear as multiple areas connected together. All the stitches are separated only by a continuous closed curve. These geometric contours ensure the uniform continuity of the stresses. All the connections around the perimeter mesh seamlessly thus avoiding concentration of flaws or efforts, phenomena known in mathematics as catastrophes. Secondly, all the meshes of the grids are small, only a few centimetres wide and equally spaced between them. The distances between the axes of the meshes are 39x39 mm for SS20 and SS30 and 33x33 mm for SS40. This allows them to redistribute and level the stresses, by reducing the frequency of the local concentrations of efforts. Mathematically, this means that the input vector quantities are transformed into tensor effects [13].

Table 1

Caracteristici mecanice ale grilelor polimerice / *Mechanical characteristics of polymeric grids*

Tipul grilei / *Grid type*	Rezistență de control / *Control strength* (kN/m)	Raport tensiune – deformație specifică / *Strength – strain ratio*		Greutate specifică / *Unit weight* (daN)	Dimensiunea rolei / Roll size (m)
		2%	5%		
	Long./Trans.	Long./Trans.	Long./Trans.		
SS20	20	7.0	14	0.20	50x4
SS30	30	10.5	21	0.30	50x4
SS40	40	14.0	28	0.40	30x4

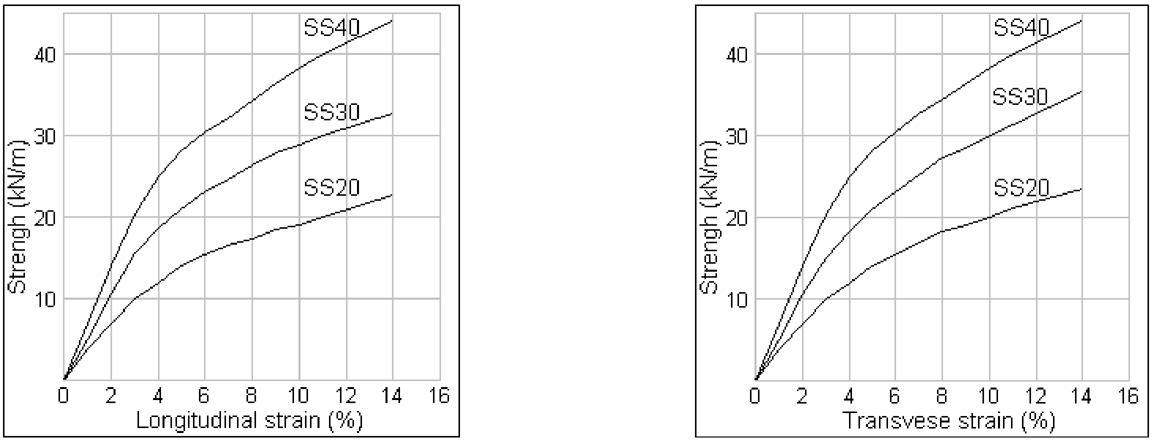


Fig. 2 - Curbe caracteristice pentru grilele polimerice / *Characteristic curves for the polymer grids*

Table 2

Rezistențe secționale ale grilelor polimerice / *Sectional strength of polymeric grids*

Tipul grilei *Grid type*	Fibre longitudinale *Longitudinal ribs* (MPa)	Fibre transversale *Transverse ribs* (MPa)	Noduri rigide Rigid joints (MPa)
SS20	306	386	44
SS30	220	293	44
SS40	267	369	38

2.3. Mechanical characteristics of the grids

For the three types of polymer grids meeting the requirements for masonry, SS20, SS30 and SS40, the numbers in the name are the control strengths in kN/m. The mechanical characteristics of these grids are given in Table 1, and the characteristic curves are shown in Figure 2.

The strengths of the ribs for the three types of grids are shown in Table 2 and highlight that they are superior to those of the steel bars usually used in reinforced concrete. The strength of the joints is about nine times smaller than that of the ribs, but their surface is correspondingly larger.

3. Integrated joints kinematics

3.1. Analytical approach

The relative displacement of a rigid joint to the neighbouring fixed joints is considered. To simplify calculations, a bi-wiredrawing grid is chosen with all ribs having the same length *l*. The displacement occurs by elastic deformation of the ribs. For comparison in calculation a network of free ribs, without joints is also considered. In the first scenario it is recognized that through a perturbation the integrated joint has a vertical displacement Δ from O to O' (Fig.3.a). This displacement leads the horizontal ribs O1 and O3 to lengthen.

The following notation is made:

$$\delta = \Delta \sin \alpha \tag{3}$$

Then, as $tg\alpha = \dfrac{\Delta}{l}$ and $\sin\alpha \approx tg\alpha$,

it results:

$$\delta = \frac{\Delta^2}{l} \tag{4}$$

The forces in the ribs become:

$$N_1 = N_3 = \frac{EA}{l^2}\Delta \tag{5}$$

and:

$$N_2 = |N_4| = \frac{EA}{l}\Delta \tag{6}$$

The virtual work of the integrated joint is:

$$L_i = \frac{1}{2}N_1\delta + \frac{1}{2}N_2\Delta + \frac{1}{2}N_3\delta + \frac{1}{2}(-N_4)(-\Delta) = \frac{EA}{l}\Delta^2\left(1+\frac{\Delta^2}{l^2}\right) \tag{7}$$

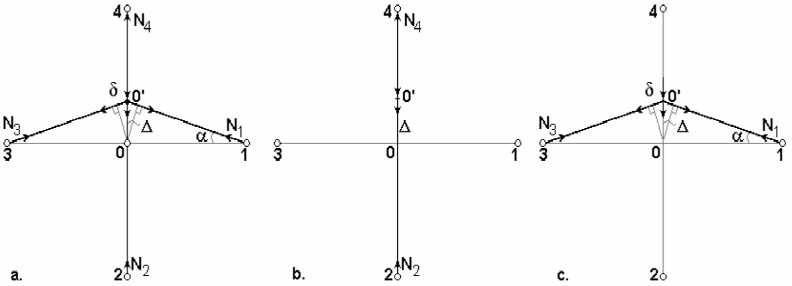


Fig. 3. – Deplasare verticală Δ / *Vertical displacement Δ.*

On the other hand, if the same perturbation deforms only the vertical ribs O2 and O4 with Δ (Fig.3.b) then the virtual work is:

$$L_{24} = \frac{1}{2}N_2\Delta + \frac{1}{2}(-N_4)(-\Delta) = \frac{EA}{l}\Delta^2 \tag{8}$$

Alternatively, if only the horizontal ribs O1 and O3 are freely deformed with δ, (Fig.3.c), then the virtual work is:

$$L_{13} = \frac{1}{2}N_1\delta + \frac{1}{2}N_3\delta = \frac{EA}{l^3}\Delta^4 \tag{9}$$

By comparing equations (8) and (9) with (7), the following ratios can be obtained:

$$\frac{L_{24}}{L_i} = \frac{1}{1+\dfrac{\Delta^2}{l^2}} \tag{10}$$

$$\frac{L_{13}}{L_i} = \frac{\dfrac{\Delta^2}{l^2}}{1+\dfrac{\Delta^2}{l^2}} \tag{11}$$

which show the decrease in elastic strain energy of the free ribbed networks with regard to the grids with integrated joints. The decrease depends on the strain level, and it reaches 50% for Δ = l (Fig. 4).

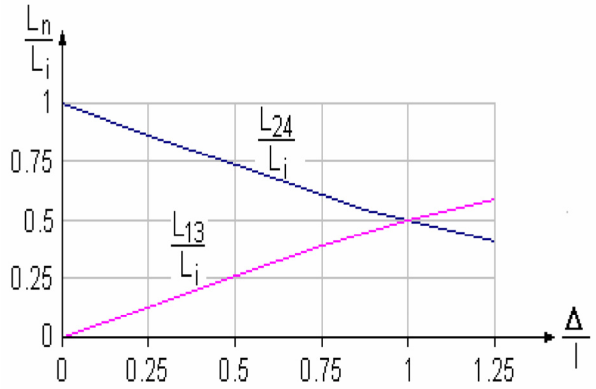


Fig. 4 - Reducerea energiei elastice de deformare / *Decrease in elastic strain energy.*

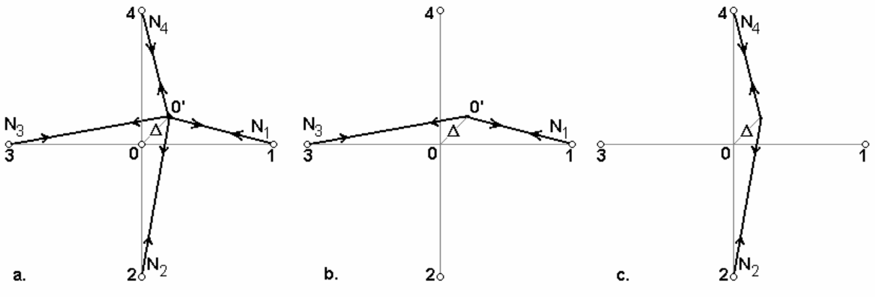


Fig. 5 - Deformație Δ inclinată la 45° / *Δ deformation inclined by 45°*

In the second calculation scenario it is assumed that by another perturbation the integrated joint receives a Δ deformation inclined by 45° to the ribs axis, from O to O' (Fig. 5a).

This deformation makes the ribs lengthen with the same value:

$$\delta = \frac{\Delta}{\sqrt{2}} \tag{12}$$

The forces in the ribs become:

$$N_1 = N_4 = -\frac{EA}{l\sqrt{2}}\Delta \tag{13}$$

$$N_2 = N_3 = \frac{EA}{l\sqrt{2}}\Delta \tag{14}$$

The virtual work of the integrated joint grid is:

$$\begin{aligned} L_i &= \frac{1}{2}(-N_1)(-\delta) + \frac{1}{2}N_2\delta + \frac{1}{2}N_3\delta + \\ &+ \frac{1}{2}(-N_4)(-\delta) = \frac{EA}{l}\Delta^2 \end{aligned} \tag{15}$$

On the other hand, if from the same perturbation the ribs freely deform in pairs, for the same Δ strain (Fig. 5.b, c), the virtual work is:

$$\begin{aligned} L_l &= \frac{1}{2}(-N_1)(-\delta) + \frac{1}{2}N_3\delta = \\ &= \frac{1}{2}N_2\delta + \frac{1}{2}(-N_4)(-\delta) = \frac{EA}{2l}\Delta^2 \end{aligned} \tag{16}$$

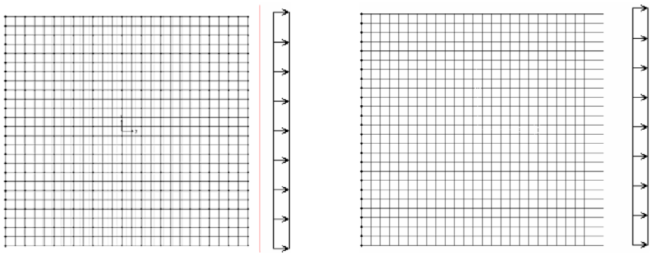
The ratio between equations (16) and (15)

$$\frac{L_l}{L_i} = \frac{1}{2} \tag{17}$$

is constant and independent of the size of the displacement Δ and of the ribs deformations respectively. This leads to the conclusion that the grids with integrated nodes have a double strain capacity in comparison with the free ribs networks. The capacity of energy dissipation for the grids with integrated nodes with regard to the free ribs grids is also doubled.

3.2. Numerical analysis

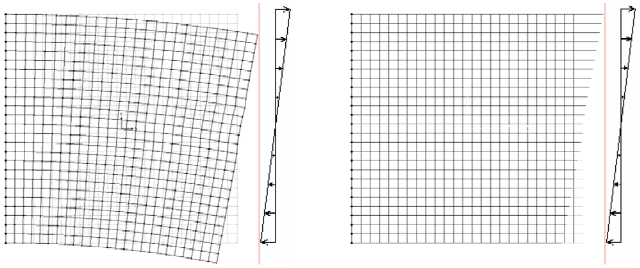
The behaviour of mortar matrix with embedded polymeric grids was numerically modelled using SAP2000 software both for a free ribs network as well as for a grid with integrated joints. The mortar matrix was modelled as a bidirectional network of bars with the same geometry as the polymeric grid, with equivalent strength and equivalent elastic properties. Both models were successively submitted to one and two directional forces systems. The small strain situation was considered, with uncracked mortar withstanding both tension and compression forces. As the compression strength of the ribs is very low, they were only accounted for in the tension areas. The resulting elastic deformations were compared to the original orthogonal configurations and clearly highlight the different behaviour between the two types of products used as reinforcement. Deformations are shown in Figures 6-11. The differences in behaviour between the two types of reinforcements are more obvious under biaxial actions. The deformations in the two directions are cumulative and reach a maximum value at the point where the axial forces are applied. Unlike for the free ribs networks, the ribs of the grids with integrated joints collaborate in withstanding the shear forces.



a. Rețea cu noduri integrate / *Integrated joint grid*

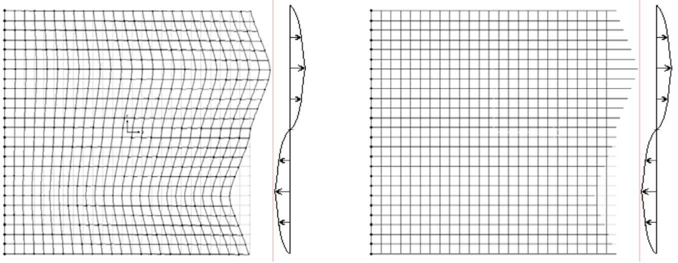
b. Rețea de nervuri libere /*Network of free ribs*

Fig. 6 - Deformații din întindere uniformă unidirecțională / *Deformations for uniaxial uniform tension.*



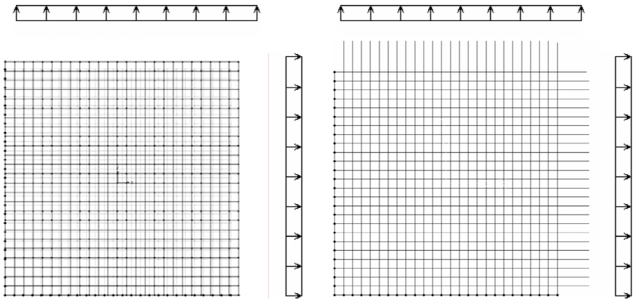
a. Rețea cu noduri integrate / *Integrated joint grid* b. Rețea de nervuri libere /*Network of free ribs*

Fig. 7 - Deformații din încovoiere pură unidirecțională / *Deformations for uniaxial pure bending*



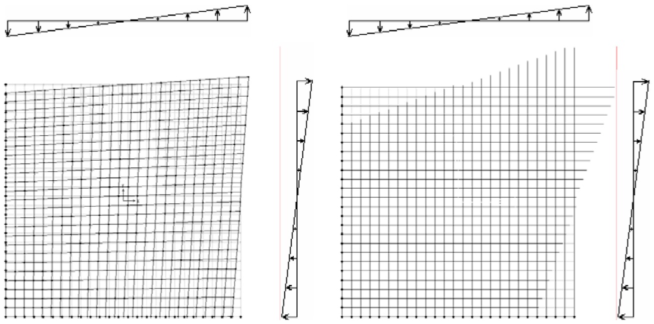
a. Rețea cu noduri integrate / *Integrated joint grid* b. Rețea de nervuri libere /*Network of free ribs*

Fig. 8 - Deformații din acțiune sinusoidală unidirecțională / *Deformations for uniaxial sinusoidal action*



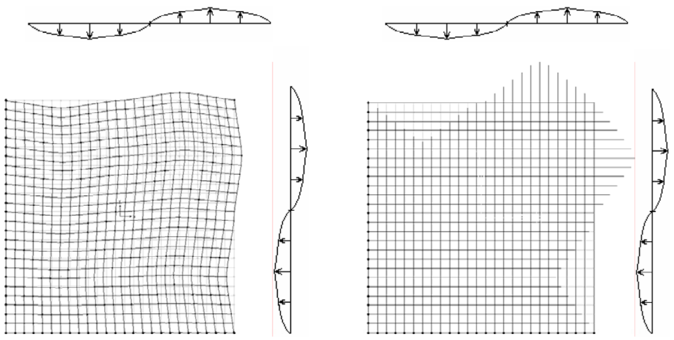
a. Rețea cu noduri integrate / *Integrated joint grid* b. Rețea de nervuri libere /*Network of free ribs*

Fig. 9 - Deformații din întindere uniformă bidirecțională / *Deformations for biaxial uniform tension*



a. Rețea cu noduri integrate / *Integrated joint grid* b. Rețea de nervuri libere /*Network of free ribs*

Fig. 10 - Deformații din încovoiere pură bidirecțională / *Deformations for biaxial pure bending*



a. Rețea cu noduri integrate / *Integrated joint grid* b. Rețea de nervuri libere /*Network of free ribs*

Fig. 11 - Deformații din acțiune sinusoidală bidirecțională / *Deformations for biaxial sinusoidal action.*

4. The stress transfer mechanism

Reinforcement appeared for strengthening a weaker material by using a stronger one. Thus reinforced concrete, prestressed concrete, reinforced earth and recently a range of composite materials were successively developed. There are two main types of reinforcement and stress transfer mechanisms from the material to the reinforcement. Passive reinforcements, as for reinforced concrete, correspond to a transfer mechanism through bonding, based on the development of tangential stresses on the contact surface. For the unbounded post-tensioned concrete, the reinforcement is active and the transfer of stresses is based on the normal stresses locally applied on limited surfaces. In the case of composite materials, strengthening is based on the Saint Venant's principle of continuity of geometric deformations and there are several technological procedures for the implementation of this principle. The stress transfer mechanism for the analyzed polymeric grids is based on the anchoring of the embedded joints. In the joints, the localised forces are transformed into sectional stresses. These are mainly tensile forces which the ribs then transmit to the neighbouring joints (Fig. 12.). Due to their slenderness the ribs never charge with compression forces. The rigid joints redistribute the efforts to be taken only by stretching ribs. But the ribs, with their variables cross sections, can also withstand in their plane shear and flexural efforts (Fig. 13.).

Of course that in the ribs submitted to bending, tension and shear deformations occur, both elastic and plastic. The elastic deformations together with the corresponding stresses lead to elastic strain energy, which is conserved as potential energy and which will be converted into mechanical work at the end of the action. The plastic deformations with their corresponding stresses lead to dissipated energy by converting part of the induced energy into heat.

This limits the amount of potential energy gained. Through this stress redistribution mechanism based on the ductility of the reinforcement a self-protection of the reinforced materials appears [14]. If the reinforcement is perfectly elastic, without ductility qualities, the dissipation of induced energy can no longer happen and the high accumulation of potential energy can cause sudden rupture in brittle materials and even dislocations. For the polymeric reinforcement the strength increases by deformation and its variable geometry allows the mobilization of its reserves of strength. Finally, as shown above, the grids with integrated joints have lower deformations and a more favourable distribution of forces than the free ribs networks.

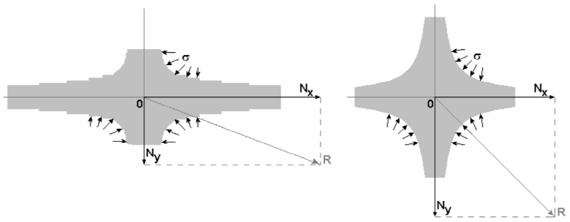


Fig. 12 – Mecanismul de transfer al eforturilor unitare în jurul nodurilor integrate / *Stress transfer mechanism around the integrated joints*

5. Use of polymer grids for masonry

There are two methods of masonry reinforcing using polymer grid: inserting the in horizontal mortar joints or reinforcing the mortar on the exterior surfaces of the walls. Inserting the grids in the horizontal beds (Fig. 14) can be used for the new buildings and ensures a high increase in resistance [15], while the additional cost is only 0,4 - 0,6% [12]. It is important that the grids are embedded in the mortar without them being in direct contact with the bricks, in order to avoid concentration of stresses around contact areas. As the grids have a much higher strength than the stresses potentially transmitted by the bricks, it is not necessarily to provide polymeric grids in each mortar bed, but it is sufficient to introduce reinforcement at every 5 rows of bricks.

Reinforcement of the mortar on the exterior masonry surfaces (Fig. 15) can be applied locally or on large areas both to existing or new buildings. This process increases the shear strength. When structural components are completely jacketed, a three-dimensional confinement effect and an increase in the masonry strength are obtained. The method is only effective if the reinforced plaster adheres well to the surface of masonry. To this end, before fixing the grids, the horizontal and vertical joints between bricks must be deepened. The operation is carried out carefully to avoid local cracks, manually - using a chisel and a hammer or mechanically. As for the solid bricks masonry the number of joints is almost three times higher, the adherence of the jackets is much better and therefore, the solution is more effective than for the hollow brick walls.

The fixing of the grids on the masonry walls is made using stainless steel nails fitted with polyethylene mounting rosettes (Fig. 15). The role of these nails ends after the mortar dries and they do not participate in the transfer of stresses. The

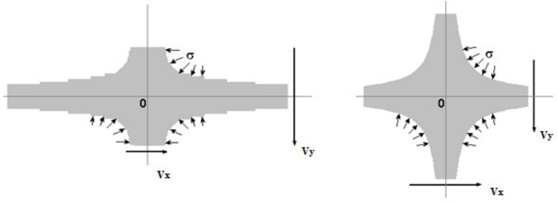


Fig. 13 – Forța tăietoare în jurul nodurilor integrate (V) / *Shear force around the integrated joints (V)*

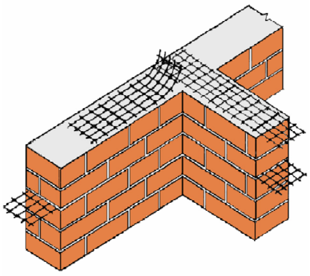


Fig. 14 Introducerea grilelor în rosturi orizontale / *Inserting grids in horizontal mortar beds*

mortar can be only with lime or lime-cement. It does not need to have much cement, as the mortar is only part of the matrix involved in the transfer of stresses from the masonry to the reinforcement (only the grid contributes to the resistance of the jacket). The solution leads to an increased in strength and in ductility and the masonry response to seismic actions is improved. The extra cost compared to the cost of simple masonry is only 6% [12].

6. Conclusions

The discontinuities that appear in masonry in the connecting areas between the bricks can lead to stress concentrations and local failures during earthquakes. To avoid this failure mechanism, a possible solution is to use polymeric grids embedded in mortar covering the potential geometric imperfections of the masonry. This solution is particularly useful for historic masonry buildings with religious or cultural value, where the interventions must be as less visible as possible and the retrofit must be reversible, offering the possibility of dismantling.

The polymer grids have a regular geometry and an important tensile strength and can take over masonry stresses and uniformly redistribute them to the adjacent sections, eliminating the risk of dislocation or fracture. This is confirmed by the results of the experimental tests on large scale models. Numerical simulations highlight that the grids with integrated joints have a much better behaviour than the bidirectional networks of independent ribs.

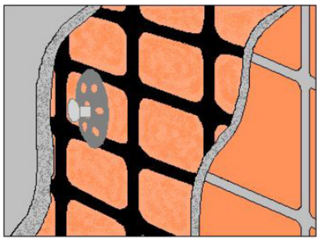


Fig. 15 Consolidarea mortarului pe fețele laterale / *Reinforcing the mortar on the exterior surfaces of the walls*

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