20 YEARS EXPERIENCE WITH BED JOINT REINFORCED MASONRY IN BELGIUM AND EUROPE

by

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ABSTRACT

A practical survey done by the "Centre Scientifique et Technique de la Construction" in the sixties showed that cracking was by far the most important cause for damage in constructions. As an answer to this problem Murfor bed joint reinforcement has been developed by the authors of this paper.

Between 1970 and 1980 a very important research program has been conducted in Belgium, with the cooperation of the already mentioned C.S.T.C., the "Katholieke Universiteit Leuven" (KUL), the "Rijks Universiteit Gent" (RUG) and the Bekaert company.

Mechanical testing included centric and eccentric compression, horizontal bending and vertical bending. Physical testing included shrinkage and corrosion tests (with inside and outside exposure). About this testing program, executed on clay brick, dense and light weight concrete block and aerated concrete block, is extensively reported.

In a second part a market survey about the market penetration and about the type of application used in different markets is discussed.

In the third part the invention and the development of a new masonry reinforcement, combining horizontal and vertical reinforcement is announced. The first test results are mentioned.

1. INTRODUCTION

In the period from 1964 to 1966 the "Centre Scientifique et Technique de la Construction" made a practical survey in order to establish the causes of damage in constructions. This survey carried out with technicians, architects, engineers, contractors and also with laboratories and housing and building developers showed that the cracking in masonry was by far the most noticed damage.

Different causes lead to this cracking:

Causes of physical origin: expansion of the roof or of the reinforced concrete structure, shrinkage and dilatation of walls....
Causes of mechanical origin: excessive loads on walls, deflection of bearing slabs or beams of partition walls....
Accidental causes: settlement of foundations, vibrations...

In all these examples the limited tensile- and shear- resistance of masonry has been brought to evidence, hence, the idea of reinforcing masonry just like concrete being also reinforced in order to increase its load bearing capacity.
From there the idea of MURFOR, a reinforcement specially adapted to masonry. In order to determine its characteristics and its effectiveness a huge testing program has been conducted and numerous studies have been undertaken. Murfor has been developed at a moment when reinforced masonry was almost unknown on continental Europe.

This lecture also has an historical value, it is its objective to determine one of the poles of development in Europe. The authors of this paper have bared an important part of the burden of the development of this type of reinforcements it is with a certain proud that they evoke almost 25 years of service to reinforced masonry.

2. EXPERIMENTAL STUDY.
In the period between 1970 and 1980 a very important research program on reinforced masonry has been conducted in Belgium. The test program has been conducted by the already mentioned C S T C in collaboration with
The "Katholieke Universiteit Leuven "(K U L) doing mechanical and shrinkage tests
The "Rijksuniversiteit Gent "(R U G) for the fire tests.
The Bekaert company for in situ corrosion tests in Hemiksem near Antwerpen.
The experimental station of the C S T C at Limelette for accelerated corrosion tests.

2.1. Mechanical Tests. See table 1 on next page.
2.1.1 The materials used for testing include:
- Concrete block, clay brick, expanded clay block, aerated concrete block.
- Mortars adapted to block material in accordance with Belgian specifications, for the aerated concrete an admixture was used.
- Prefabricated bed joint reinforcement type Murfor.

2.1.2 The tests include:
- Centric and eccentric compression.
- Horizontal bending.
- Vertical bending.

2.1.3 Test results and conclusions:
- Compression: The reinforcement absorbs longitudinal ($\sigma_1$) and transversal ($\sigma_2$) tensile stresses which appear in masonry under compression due to the Poisson effect (fig.1.), hence reinforced masonry has its compressive strength increased with 5 to 20% compared to unreinforced reinforced masonry.
- Thanks to the trusses of the reinforcement the load bearing capacity of both leaves of cavity walls can be taken into account. Supplementary reinforcement in both leaves absorb the shear stresses(fig.2.) This positive result has also been observed for eccentric loading.
- Bending: Horizontal and vertical bending tests have proven the validity of the hypotheses of the theory of elasticity; the bilinear behavior of the deflection in function of the moment was brought to evidence.
<table>
<thead>
<tr>
<th>Type of Masonry</th>
<th>D</th>
<th>DE</th>
<th>HV</th>
<th>HH</th>
<th>V</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollow concrete blocks 39x19x19</td>
<td>D3a et D3b</td>
<td>D1</td>
<td>HV1</td>
<td>HV1</td>
<td>V2</td>
<td>C1</td>
</tr>
<tr>
<td>39x14x19 mortar C300</td>
<td></td>
<td>DE2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29x14x14</td>
<td>DE1</td>
<td></td>
<td></td>
<td></td>
<td>V1</td>
<td>V5</td>
</tr>
<tr>
<td>29x14x14 mortar C300</td>
<td>D4a et D4b</td>
<td>D2</td>
<td>HV2</td>
<td>HV3</td>
<td>V6</td>
<td>V9</td>
</tr>
<tr>
<td>Perforated clay blocks 29x14x9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29x14x9 mortar C300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perforated brick 29x14x9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29x14x9 mortar C300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain blocks expanded clay 39x14x19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39x14x19 mortar C200 + G100</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
The reinforcement has also increased the cracking moment of reinforced walls compared to the unreinforced ones.
In the case of deep beams (\(l/h = 1.75\)) made out of concrete block or clay brick the hypotheses of Navier have been proven to be correct. The diagram of the stresses in the median section is different from the diagram of reinforced concrete (fig.3).

Fig. 1

- \(N\): compressive load
- \(\sigma_l\): longitudinal tensile stress
- \(\sigma_t\): transversal tensile stress

\[\sigma_t = \text{Transversal tensile stress}\]

The additional reinforcement in each wall is taking over the shear stresses.

Fig. 2

Flexural stress distribution at middle height in a deep beam made of reinforced concrete for \(l/h_u = 1.175\)

Flexural stress distribution at middle height of a deep beam made of reinforced masonry for \(l/h_u = 1.75\)
2.2. Physical tests. (see table 2.)

2.2.1. Shrinkage:

Four walls of aerated concrete measuring 3.4 by 1 meter have been tested. The shrinkage was prevented by collating the walls against a steel frame, and in order to simulate reality a uniform vertical load has been applied. Only the unreinforced wall showed cracking, the others stayed uncracked.

<table>
<thead>
<tr>
<th>Wall composition</th>
<th>Shrinkage</th>
<th>Corrosion (all the walls with reinforcement type A1)</th>
<th>Thermal Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity wall, clay bricks 19 x 9 x 6.5</td>
<td></td>
<td>Test A: mortar C 300 + 2% CaCl2, Test C: mortar C 300</td>
<td></td>
</tr>
<tr>
<td>Plain wall clay blocks 29 x 19 x 14</td>
<td></td>
<td>Test B</td>
<td></td>
</tr>
<tr>
<td>mortar C 300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity wall: bricks 19 x 9 x 6.5</td>
<td></td>
<td></td>
<td>Test on reinforced wall</td>
</tr>
<tr>
<td>5 cm cavity hollow block of dense</td>
<td></td>
<td></td>
<td>Test on unreinforced wall</td>
</tr>
<tr>
<td>concrete 39 x 14 x 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mortar C 300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain wall hollow concrete block</td>
<td></td>
<td>Test D</td>
<td></td>
</tr>
<tr>
<td>39 x 19 x 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mortar C 300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity wall dense concrete block</td>
<td></td>
<td>Test E</td>
<td></td>
</tr>
<tr>
<td>39 x 9 x 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mortar C 300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerated concrete block 49 x 24 x 24</td>
<td>R1 reinforced (Type A1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mortar C 300 + Aditong</td>
<td>R2 reinforced R3 unreinforced R4 reinforced (Type A1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Physical tests
2.2 Corrosion:

Accelerated laboratory corrosion tests.

Wallettes (1.25 by 1.25 meter) have been exposed as follows:
- One side to the normal laboratory conditions (20°C and 60% RH)
- The other side in a box with extreme conditions (40°C and 100% RH)

After 8 months, walls made with perforated clay brick showed starting corrosion of the reinforcement, walls made of Besser concrete block didn’t show any trace of corrosion of the reinforcement.

In cavity walls, the diagonals of the reinforcement which cross the cavity corrode if no additional protective coating is applied.

A minimal cover of 15mm of good compacted dense mortar is necessary.

2.2.3. Outside corrosion exposure of walls to industrial environment.

Five types of walls have been erected in 1976 in Hemiksem near Antwerpen on an industrial site close to a pickling facility.

The following types of reinforcement were put in every wall:
- Commercial hot dipped galvanized (min. 60 g/m²)
- Heavily hot dipped galvanized (min. 275 g/m²)
- Galvalume coated (55% Al, 40% Zn, 5% Si)
- Epoxy coated on galvanized (min 80 U epoxy on 60 g/m² Zn)
- Stainless steel (AISI 304)

The five types of walls were composed as follows:
- Plain wall made of perforated brick (snelbouw)
- Plain wall made of concrete block (type Besser)
- Plain wall made of expanded clay block (Leca)
- Plain wall made of thin jointed aerated concrete
- Cavity wall made of concrete block and concrete facing brick

Five specimens of every type of wall were constructed in 1976.


Observations lead to the following conclusions:
- Duplex coated reinforcement (zinc + epoxy) stayed intact.
- Stainless steel reinforcement also stayed intact.
- Highly exposed walls in a corrosive environment are to be reinforced with corrosion resistant reinforcement, this means stainless steel or duplex epoxy coated reinforcement.
- The Murfor EXF in the thin bed joints was so good protected by the special mortar that almost no corrosion was noticed even after 10 years of severe exposure.

3. BED JOINT REINFORCEMENT IN PRACTICE.

3.1 Most common types of bed joint reinforcement.

Based on large scale tests and on many years of experience e.g. in the USA, the use of bed joint reinforcement has become well known and widely accepted in many European countries. Several manufacturers developed different shapes of bed joint reinforcement.

In the CEN Task group 3 of Working group 3 of CEN TC 125 has listed the best known types in Europe (fig.4.)
Fig. 4: Most common types of bed joint reinforcement

Remarks:
Replacement of one type of bed joint reinforcement by another one is possible but only if it has at least the same cross sectional area, for it is the amount of steel that brings the expected result.

Both reinforced and prestressed concrete have suffered severe damage due to corrosion of the reinforcement. The porosity of mortar and bricks makes masonry reinforcement even more endangered. In masonry exposed to rain, to marine atmosphere or to an aggressive environment epoxy coated or stainless steel reinforcement has to be used.

3.2. Application fields.
3.2.1. The main application fields are:
- Structural reinforcement, only for crack control
- Designed reinforced masonry, designed according accepted rules in order to increase the resistance of the masonry structure to horizontal or vertical loading.
3.2.2 Some of the most common applications are presented on fig. 5

- A. Differential settlement of soil
- B. Stress concentrations at door and window openings
- C. Longer wall sections between movement joints
- D. Large wall sections exposed to wind pressure
- E. Masonry lintels
- F. Walls on deflecting slabs or beams
- G. Ring beams - Roof tie beams
- H. Stack bonded masonry

**Fig. 5: Main application fields**

A. Bed joint reinforcement in the first 3 to 5 joints prevents cracking due to eventual differential settlement of subsoil.
B. Concentrated stresses at the angles of door- and window-openings, a well known cause of cracks, are neutralized by the incorporation of bed joint reinforcement above and or under those openings.
C. Shrinkage and dilatation limit the length wall sections between expansion joints may have. Bed joint reinforcement controls cracking, making an increase of this length with 50 to 100% possible.
D. In our countries wind loads are serious matters and every designer has to comply with severe specifications for design loads. Reinforcing bed joints of masonry is the better alternative for thicker walls or additional supports.
E. Facing brickwork is visually and physically affected by the incorporation of lintels made of foreign materials (e.g. concrete or steel). Bed joint reinforced masonry lintels have now become a well-known way to solve this problem.
F. Non bearing partition walls very often crack, due to bending of their supporting beam or floor. Reinforcing a number of joints in the lower part of the wall and leaving some space above it avoid cracking here.

G. Ring-beams or ring ties are needed in order to stiffen walls and to connect them. Concrete ring beams need expensive and time consuming shuttering and disturb the physical homogeneity of the masonry. Bed joint reinforcement perfectly does this job.

H. Architects loving masonry valorize the possibilities of this marvelous material. Bed joint reinforcement often offers them new possibilities: Stack bonded masonry and even mixed masonry are now feasible if strengthened by bed joint reinforcement.

3.3. Market penetration.
A survey of the global market penetration and of the main application fields are brought together in table 4. This table gives an idea of the general acceptance of a market for bed joint reinforcement and it also lists the most common applications in the considered countries.

<table>
<thead>
<tr>
<th>General market accept.</th>
<th>Most used applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>BELGIUM</td>
<td>A B C D E F G H</td>
</tr>
<tr>
<td>SWITZERLAND</td>
<td>* * * * * * *</td>
</tr>
<tr>
<td>THE NETHERL</td>
<td>* * * * * *</td>
</tr>
<tr>
<td>GREAT BRITT</td>
<td>* * * * *</td>
</tr>
<tr>
<td>SCANDINAVIA</td>
<td>* * * * *</td>
</tr>
<tr>
<td>GERMANY</td>
<td>* * * * *</td>
</tr>
<tr>
<td>FRANCE</td>
<td>* * * * *</td>
</tr>
<tr>
<td>SPAIN/ITALY</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

Table 3. Market penetration / Main application fields.

The latest evolution in the field of masonry reinforcement is based on an idea of Erwin Reinle from Switzerland, who invented a three-dimensional reinforcement. After further development this idea has been patented by Bekaert.

The reinforcement (fig. 6.) consists of two longitudinal wires, to be laid in the bed joint, welded orthogonally to stirrups. These stirrups lap each other in the holes in bricks or blocks. The stirrups are anchored in order to form a continuous chain of reinforcement by filling the holes, in which they lap, with mortar or micro concrete.
Fig. 6: Three dimensional reinforcement

First testing at E. T. H. of Zuerich has been done on clay brick piers reinforced with Murfor Re under the guidance of Prof. Thurlimann and Mr. Schwartz. proved the feasibility of the system. For results see the paper of Mr. Schwartz. More tests are under way. First field applications in Switzerland with this reinforcement technique have been done on gable ends. Further testing, this time on concrete block, has been conducted at the University of Liege in Belgium by Mr. Oliveira for his Doctorate. Promoter is Prof. Dotreppe. In this work the new reinforcement is compared with standard rebar, results will be known by the end of the year.

5. CONCLUSIONS.
Bed joint reinforcement is in Europe a well accepted complement for masonry, it enhances its strength, building confidence for OWNER CONTRACTOR AND ARCHITECT.

The new three-dimensional reinforcement system Murfor Re seems to be very promising. Further test programs are will follow. We keep you informed of the progress.