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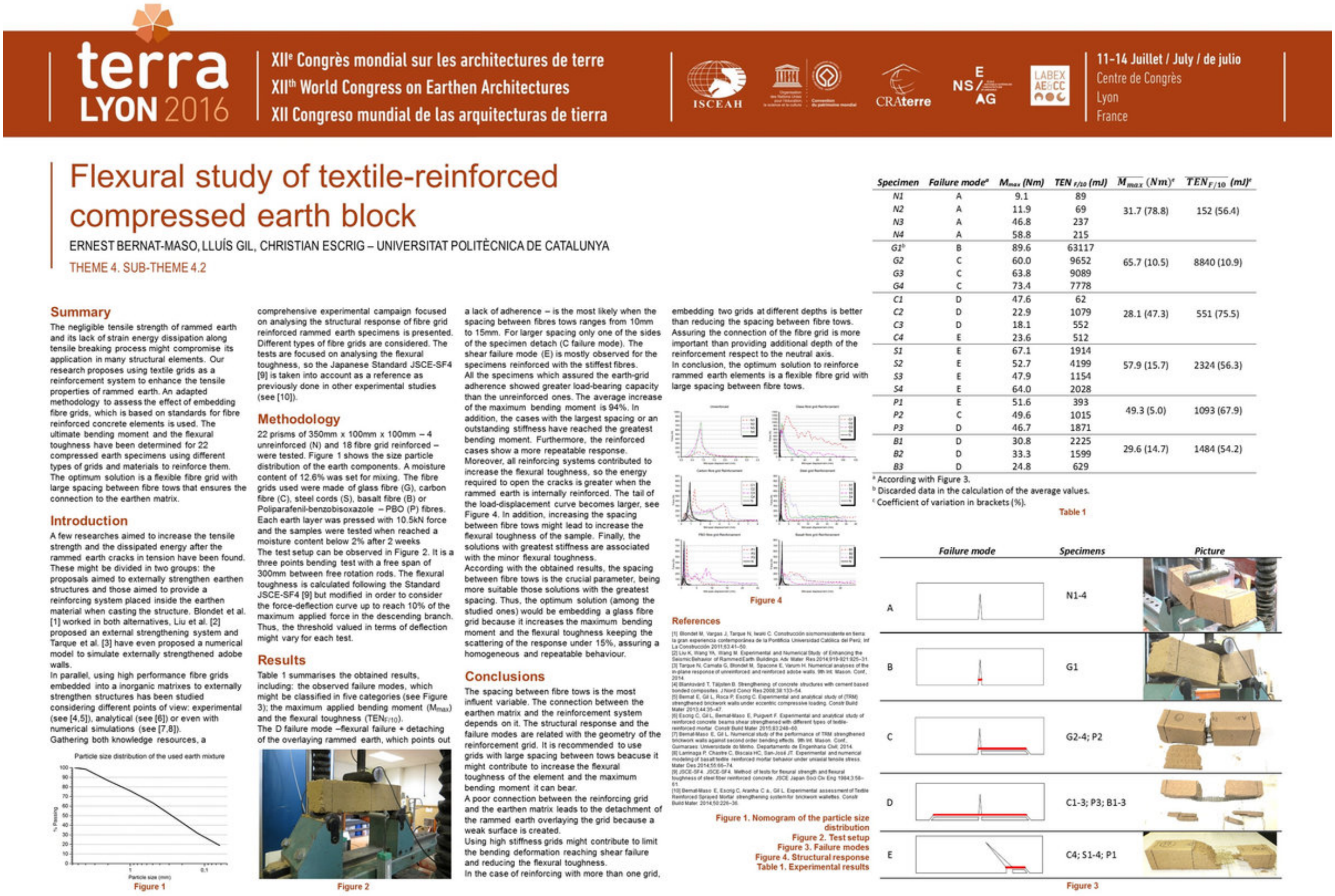

terra LYON 2016

XIIe Congrès mondial sur les architectures de terre
XIIth World Congress on Earthen Architectures
XII Congreso mundial de las arquitecturas de tierra

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11-14 Juillet / July / de julio
Centre de Congrès
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Flexural study of textile-reinforced compressed earth block

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THEME 4. SUB-THEME 4.2

Summary

The negligible tensile strength of rammed earth and its lack of strain energy dissipation along tensile breaking process might compromise its application in many structural elements. Our research proposes using textile grids as a reinforcement system to enhance the tensile properties of rammed earth. An adapted methodology to assess the effect of embedding fibre grids, which is based on standards for fibre reinforced concrete elements is used. The ultimate bending moment and the flexural toughness have been determined for 22 compressed earth specimens using different types of grids and materials to reinforce them. The optimum solution is a flexible fibre grid with large spacing between fibre tows that ensures the connection to the earthen matrix.

Introduction

A few researches aimed to increase the tensile strength and the dissipated energy after the rammed earth cracks in tension have been found. These might be divided in two groups: the proposals aimed to externally strengthen earthen structures and those aimed to provide a reinforcing system placed inside the earthen material when casting the structure. Blondet et al. [1] worked in both alternatives, Liu et al. [2] proposed an external strengthening system and Tarque et al. [3] have even proposed a numerical model to simulate externally strengthened adobe walls.

In parallel, using high performance fibre grids embedded into a inorganic matrixes to externally strengthen structures has been studied considering different points of view: experimental (see [4,5]), analytical (see [6]) or even with numerical simulations (see [7,8]).

Gathering both knowledge resources, a comprehensive experimental campaign focused on analysing the structural response of fibre grid reinforced rammed earth specimens is presented. Different types of fibre grids are considered. The tests are focused on analysing the flexural toughness, so the Japanese Standard JSCE-SF4 [9] is taken into account as a reference as previously done in other experimental studies (see [10]).

Particle size distribution of the used earth mixture

% Passing

Particle size (mm)

Figure 1

Methodology

22 prisms of 350mm x 100mm x 100mm – 4 unreinforced (N) and 18 fibre grid reinforced – were tested. Figure 1 shows the size particle distribution of the earth components. A moisture content of 12.6% was set for mixing. The fibre grids used were made of glass fibre (G), carbon fibre (C), steel cords (S), basalt fibre (B) or Poliparafenil-benzobisoxazole – PBO (P) fibres. Each earth layer was pressed with 10.5kN force and the samples were tested when reached a moisture content below 2% after 2 weeks

The test setup can be observed in Figure 2. It is a three points bending test with a free span of 300mm between free rotation rods. The flexural toughness is calculated following the Standard JSCE-SF4 [9] but modified in order to consider the force-deflection curve up to reach 10% of the maximum applied force in the descending branch. Thus, the threshold valued in terms of deflection might vary for each test.

Results

Table 1 summarises the obtained results, including: the observed failure modes, which might be classified in five categories (see Figure 3); the maximum applied bending moment (M_{max}) and the flexural toughness ($TEN_{F/10}$).

The D failure mode –flexural failure + detaching of the overlaying rammed earth, which points out a lack of adherence – is the most likely when the spacing between fibres tows ranges from 10mm to 15mm. For larger spacing only one of the sides of the specimen detach (C failure mode). The shear failure mode (E) is mostly observed for the specimens reinforced with the stiffest fibres.

Figure 2

All the specimens which assured the earth-grid adherence showed greater load-bearing capacity than the unreinforced ones. The average increase of the maximum bending moment is 94%. In addition, the cases with the largest spacing or an outstanding stiffness have reached the greatest bending moment. Furthermore, the reinforced cases show a more repeatable response.

Moreover, all reinforcing systems contributed to increase the flexural toughness, so the energy required to open the cracks is greater when the rammed earth is internally reinforced. The tail of the load-displacement curve becomes larger, see Figure 4. In addition, increasing the spacing between fibre tows might lead to increase the flexural toughness of the sample. Finally, the solutions with greatest stiffness are associated with the minor flexural toughness.

According with the obtained results, the spacing between fibre tows is the crucial parameter, being more suitable those solutions with the greatest spacing. Thus, the optimum solution (among the studied ones) would be embedding a glass fibre grid because it increases the maximum bending moment and the flexural toughness keeping the scattering of the response under 15%, assuring a homogeneous and repeatable behaviour.

Conclusions

The spacing between fibre tows is the most influent variable. The connection between the earthen matrix and the reinforcement system depends on it. The structural response and the failure modes are related with the geometry of the reinforcement grid. It is recommended to use grids with large spacing between tows beacuse it might contribute to increase the flexural toughness of the element and the maximum bending moment it can bear.

A poor connection between the reinforcing grid and the earthen matrix leads to the detachment of the rammed earth overlaying the grid because a weak surface is created.

Using high stiffness grids might contribute to limit the bending deformation reaching shear failure and reducing the flexural toughness.

In the case of reinforcing with more than one grid, embedding two grids at different depths is better than reducing the spacing between fibre tows. Assuring the connection of the fibre grid is more important than providing additional depth of the reinforcement respect to the neutral axis.

In conclusion, the optimum solution to reinforce rammed earth elements is a flexible fibre grid with large spacing between fibre tows.

Figure 4

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Figure 1. Nomogram of the particle size distribution
Figure 2. Test setup
Figure 3. Failure modes
Figure 4. Structural response
Table 1. Experimental results

Specimen	Failure mode[a]	M_{max} (Nm)	$TEN_{F/10}$ (mJ)	$\overline{M_{max}}$ (Nm)[c]	$\overline{TEN_{F/10}}$ (mJ)[c]
N1	A	9.1	89	31.7 (78.8)	152 (56.4)
N2	A	11.9	69		
N3	A	46.8	237		
N4	A	58.8	215		
G1[b]	B	89.6	63117	65.7 (10.5)	8840 (10.9)
G2	C	60.0	9652		
G3	C	63.8	9089		
G4	C	73.4	7778		
C1	D	47.6	62	28.1 (47.3)	551 (75.5)
C2	D	22.9	1079		
C3	D	18.1	552		
C4	E	23.6	512		
S1	E	67.1	1914	57.9 (15.7)	2324 (56.3)
S2	E	52.7	4199		
S3	E	47.9	1154		
S4	E	64.0	2028		
P1	E	51.6	393	49.3 (5.0)	1093 (67.9)
P2	C	49.6	1015		
P3	D	46.7	1871		
B1	D	30.8	2225	29.6 (14.7)	1484 (54.2)
B2	D	33.3	1599		
B3	D	24.8	629		

[a] According with Figure 3.
[b] Discarded data in the calculation of the average values.
[c] Coefficient of variation in brackets (%).

Table 1

Failure mode		Specimens	Picture
A		N1-4	
B		G1	
C		G2-4; P2	
D		C1-3; P3; B1-3	
E		C4; S1-4; P1	

Figure 3


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