PREFABRICATED RAMMED EARTH ELEMENTS FOR LOAD BEARING VERTICAL STRUCTURES – MECHANICAL PROPERTIES AND ENVIRONMENTAL BENEFITS

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Summary

They are many ways how to asses environmental benefits of earthen structures and benefits from the point of view of wider criteria of sustainable building – lower values of embodied CO_2 and SO_2 emissions and embodied energy, using earth as fully and easy recyclable material enabling design of structures of higher environmental quality etc.. Advanced technologies as prefabrication enable wider using of those materials and decreasing of technological risks. On the other hand low-tech approach and self-made technologies enable taking advantage of wide range of social issues.

The paper summarizes those benefits and gives relevant examples. Also experimental results of mechanical behavior of load bearing wall based on rammed earth panels developed at CTU in Prague are presented.

Keywords: rammed earth, prefabricated structures, sustainable building

1 Introduction

One of the approaches towards sustainable building [1] is increasing of usage of raw natural materials. Natural materials have a high potential of environmental quality for example in following criteria: embodied CO_2 and SO_2 emissions, embodied energy, using renewable sources, easy recycling, etc.

Earth and earthen structures belong to the materials and structures with high environmental potential. One of the main disadvantages of using earth in modern building structures are long construction time, high risks of technological faults, limited on-season time and volume changes during the ageing time. Prefabrication, as one of the basic structural principles, could eliminate those disadvantages and could also bring environmental benefits in decreasing of negative impact of site works on the environment.

2 Technical properties and technological approach for modern earth structures

2.1 Mechanical properties

One of the problem of using earth in building structures are shrinkage properties during the curing time and volume changes under the influence of relative humidity. Also rheological changes under the influence of RH changes could be significant. On the other hand mechanical properties of earth like bending tension strength and compressive strength are for all types of clays quite obvious and move between 3–12 N/mm^2 for compressive strength and 0,75–4 N/mm^2 for bending tension strength according to used clay and way of stabilization [2]. One of the main problems is that those properties depend on local material characteristics, chemical and grain composition of specific material and also on technological process. For that reason it is very complicated to draw generalized conclusion.

2.2 Environmental properties

Environmental impact connected with the construction of the buildings is valuated mostly by following ecological criterions: embodied CO_2 [gCO_2/kg] as a global environmental load, embodied SO_2 [gSO_2/kg] as a local environmental load, embodied energy E [MJ/kg] or total weight of the constructions [t].

Calculation of embodied emissions and energy for prefabricated panels compared to other clay materials and concrete (Tab. 1) is based on data for "clay at mine" and "sand at mine" sourced from Ecoinvent database [3]. To this basic data energy and emissions produced during the manufacturing process were added. According to whole life cycle this calculation considers only cradle to gate part, it means period from the obtaining of the basic material to the production of the structural element. The technological process of manufacturing prefabricated elements includes three phases (i) transportation from mines to the workshop, (ii) drying and grinding, (iii) mixing and ramming.

Tab. 1 *Environmental parameters for prefabricated rammed earth panels*

Parameters	Units	Prefab rammed earth	Clay at mine	Clay plaster, at plant	Concrete, normal, at plant	Brick, at plant
PEI	MJ/kg	0,1963	0,0439	0,4819	0,5749	2,5737
GWP	$kgCO_{2,\ ekv.}/kg$	0,2391	0,0029	0,0191	0,1099	0,2386
AP	$gSO_{2,\ ekv.}/kg$	0,0217	0,0224	0,0716	0,1849	0,5456
EP	$g(PO_4)^{3-}{}_{ekv.}/kg$	0,005	0,005	0,023	0,046	0,172
ODP	$gCFC_{2,ekv.}/kg$	$3{,}56.10^{-7}$	$3{,}64.10^{-7}$	$27{,}47.10^{-7}$	$37{,}06.10^{-7}$	$178{,}02.10^{-7}$
POCP	$gC_2H_{4,\ ekv.}/kg$	$5{,}72.10^{-4}$	$5{,}75.10^{-4}$	$29{,}66.10^{-4}$	$67{,}78.10^{-4}$	$397{,}15.10^{-4}$
Volume weight	kg/m^3	2000	2000	1815	2380	600

2.3 Technological approach

2.3.1 Low tech

Contemporary low technologies based on earth and straw enable today also their using within special projects with wider social or social-economic impact. Those projects can be divided into following groups: (i) social programmes for developing countries, (ii) special programmes in disaster areas, (iii) social programmes for unprivileged and social eliminated people. From this point of view “green”, low-cost and low-tech approach could contribute to solve specific social problems. They are some experimental projects in Europe and all around the world using simple earth structures to meet specific social needs [4], [5]. The main reason to use the simplest technologies in those cases is to reduce dramatically direct investments costs and to offer job and retraining opportunity.

2.3.2 High tech application

Prefabrication, as one of the basic structural principles, could eliminate disadvantages of demanding technology, high risk of technological faults, limited on-season time etc. and could also bring environmental benefits in decreasing of negative impact of site works on the environment [6].

Positive experience from the first pilot project realized in 2008 in Pilsen, CZ dealing with prefabricated earthen elements [2] led to the development of the second generation of prefabricated rammed earth structures. Load bearing elements of the size 600 x 1000 x x 200 mm were designed and manufactured by using pneumatic rammer with electric air pump and system formwork in the Experimental Centre of FCE of CTU in Prague in 2012. After the drying period of 8 weeks compressive strength and static modulus of elasticity were determined. Final tests were carried out on full scale wall structure in March 2013 and final results will be present.

Fig. 1 *Left: Building up process of sheltered workshop for disturbed and disabled clients of the Diakonie in Caslav, CZ (2005). Middle: Prefabricated rammed earth panels [7]. Right: Production and testing of experimental panels in the Experimental Centre of FCE of CTU in Prague.*

3 Environmental potential of earthen structures in modern buildings – case study

This case study which is currently being processed is aiming to illustrate a benefit which wider usage of earth construction can bring to the environment. The crucial question at the beginning is how significant could be the benefit by substituting part of the common brickwork made from hollow ceramic blocks by advanced earth structures used as load bearing and partition structures.

3.1 Residential buildings in the Czech Republic in overall numbers

According to the data of the Czech Statistical Office [7] there was at average 13 860 family houses built in the period from 2000 till 2010. 92,8 % of them was built from masonry and only 3,5 % was based on timber structures. Within this case study structural design of several types of family houses and residential buildings was analyzed and statistical data were used for determination of environmental potential of modern earth structures.

3.2 Residential building analysis from the point of view of earthen structures potential usage

In average about 12,3 % to the floor area of the residential building is area of circumferential walls and 4,5 % are inner walls both load bearing and partition walls. Average floor area of the residential building according to [7], average number of houses built per year, environmental data mentioned above, several scenarios of ratio of earthen structure usage were taking into account. If inner constructions of all masonry were built from earthen structures embodied energy and SO_2 emissions would be decreased more than 20 % comparing to common technology based on ceramic blocks. Decreasing in CO_2 emissions is not so significant due to higher value of volume weight of earthen structures but partial improvement is also obvious.

4 Conclusions

The topic of sustainable building covers wide range of issues including environmental, socio-cultural and economic criteria. Earthen structures represent one of possible approaches to meet the needs of sustainable building not only from the environmental point of view but also from the point of view of positive social economic impact of building sector.

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