PREFABRICATED LOAD BEARING WALL PANELS – EFFECTIVE TECHNOLOGIES FOR EARTH STRUCTURES

Jan Růžíčka

Summary

The paper outlines first results and experience of using prefabricated load bearing wall panels with wooden frame and rammed earth core. The aim of the project was to verify possibilities of manufacturing prefabricated earth structures and their behaviour leading to higher efficiency of using earth as a modern building material.

They are no practical experience in the branch of using contemporary pre-formed or prefabricated earthen structures in the Czech conditions. To date, prefabrication has been used by only a very small number of examples. Realized foreign pilot projects used prefabricated earthen structures [1], [2], [3] show large potential and number of benefits.

Keywords: Sustainable building, renewable building materials, earth structures, rammed earth, timber structures, prefabrication

1 Introduction

This pilot project is achieved in cooperation with the member of CIDEAS "Centre of Integrated DEsign of Advanced Structures" – Construction Company Alterstav Ltd. The technological process will be verified within the construction of a private family house in the village Kozmice near Prague (architect J. Makovec, studio A91). The building has been designed as a timber structure with load bearing timber columns. Two parallel diaphragm interior walls are creating cavity for distribution of heating air and are also creating heat accumulator and are designed as pre-formed wall panels with wooden frame and rammed earth core.

The fabric of the family house was built in November 2006 (**Fig. 1**), wooden frame of prefabricated wall panels was ready in November 2007, laboratory tests of earthen material were made in March/April 2007 and ramming of earthen core started in May 2007.

Fig. 1 Timber structure of the family house in Kozmice (12/2006). Two parallel diaphragm interior walls creating cavity for distribution of heating air will be built from prefabricated wall panels

2 Environmental aspects of earth structures

Advantages of using earth as a building material are from the environmental point of view especially: (i) use of renewable sources, (ii) use of material with low value of embodied energy, embodied CO_2, and embodied SO_2, (iii) use of recycled and easily recyclable material, (iv) use of local sources.

Typically utilization of soil for structural materials is production of various types of unburned bricks (adobe, stabilized blocks...) or in situ rammed earth structures. These means of technology are demanding on man power, construction time and technological discipline.

Prefabrication as one of basic structural principles of sustainable building could potentially allow (i) minimizing of on-site construction time, (ii) decreasing of technological faults and (iii) decreasing of negative impacts of site works on environment.

3 Methodological and conceptual approach

In comparison with most conventional usage of soil for building structures prefabricated elements offer a number of advantages for earth structures:

- stable source of basic components for the mixture, their constant properties and possibility to use one prescription,
- higher quality-factor and decreasing of technology risks on the building site,
- prefabrication of panels or other elements in off-season time,
- better condition for earth manufacturing including exact batching of basic components, admixtures, stabilizers and batching water,
- sufficient ageing time for shrinkage restriction.

The project is focused on the following key issues:

- structural design of the panel according to structural analysis in various cases,
- design of the basic mixture and of admixtures for earthen core,
- production process assessment – verification of the technological process of prefabricated wall panels, impact of the transport on the quality, possibilities of building-site handling,
- in-situ tests – long term monitoring of drying curve of earthen core of panels placed in the structure in correlation with air humidity,

- laboratory tests – behaviour of the prefabricated wall panels under stress cycles, strain curve and its distribution between earthen core and wooden frame, transverse voltage determining on diagonal bracing of wall panel.

4 Structural design of the panels

Prefabricated wall panel (**Fig. 2**) of the size 2400×910×150 mm has been designed according to floor high and modulus of interior load bearing wall. Structural joints of the wooden frame are made with steel binder BOVA and diagonal bracing is created with steel threaded pipe. Diagonal bracing is also used for decreasing of shrinkage impact between wooden frame and earthen core and also for preload transfer into earthen core for better behaviour during transportation of the element.

Structural analysis of the prefabricated wall panels has been performed according to following load cases:

- production case – ramming of earthen core is performed into sliding form placed around the wooden frame without upper frame cross beam. Diagonal steel bracing is carrying the loads of transverse voltage of earth ramming,
- transportation case - proportioning of the lower frame cross beam bearing self-weight of earthen core, designing of structural joint lower frame cross beam-vertical post and designing of transport fixtures in the upper part of wooden vertical posts,
- structural case – load bearing prefabricated wall panel is placed in the structure and is carrying all steady and imposed loads. Transverse tension caused by load distribution in the earthen core is determined by calculations under acting soil.

Fig. 2 Wooden frame of the prefabricated wall panel and structural details.

5 Experimental part of the project

5.1 Design of the basic mixture

The samples of basic components for the mixture were taken from 3 locations near to the manufactory in Vysoké Mýto: sand pit Světlá, sand pit Běskovice, brickworks Hrabčuk Vysoké Mýto. Grain size distribution curve has been determined for each sample according to ČSN 72 1017 „ Determination of grain size distribution of soils for geotechnical purposes“. The final mixture for earthen core was created by 75 % sand from sand pit Běskovice + 25 % clay from brickworks Hrabčuk (**Fig. 3**). This ratio of basic components accords with recommended grain size distribution curve as per [4] a [5].

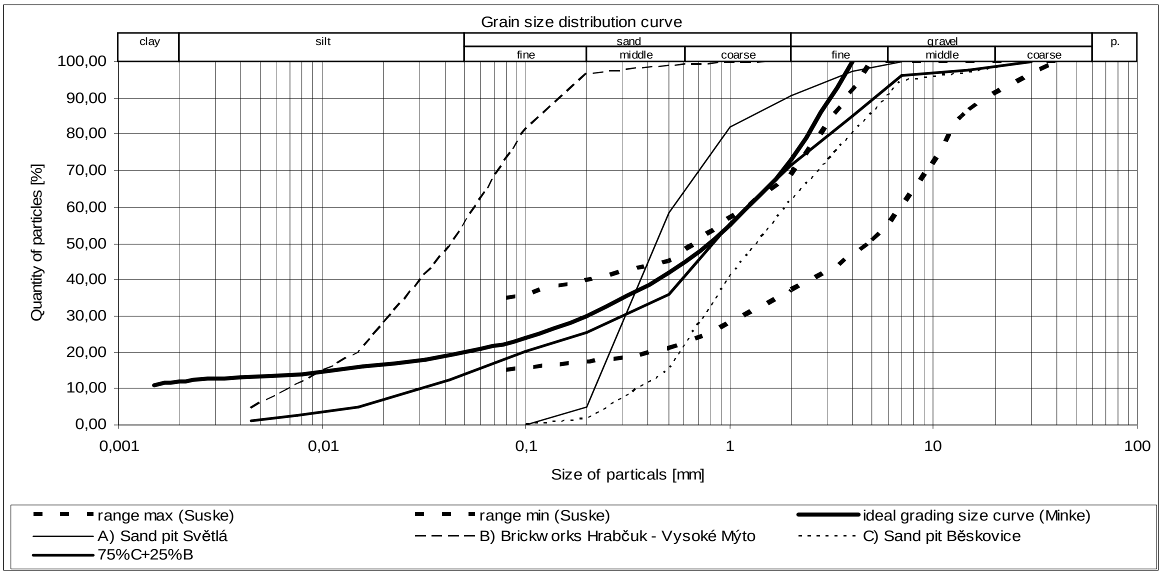

Fig. 3 Grain size distribution curves for basic components, for basic mixture (75 % of sand from sand pit Běskovice + 25 % clay from brickworks Hrabčuk) and its comparison with recommended mixtures according to [4] a [5].

5.2 Design of admixtures

Final decision of stabilizers and admixtures has been made according to results of preliminary tests of compressive strength. Hand-rammed test specimens of the size 100×100×100 mm have been produced in steel forms in various means of stabilization: (i) without admixture, (ii) 5 % of lime CS, (iii) 5 % of cement 32,5R III/A, (iv) 5 % of hydraulic binder MULTIBAT. Compressive strength and static modulus of elasticity in compression were undertaken in accordance with the Czech standards ČSN EN 12390-3 „Testing hardened concrete – Part 3: Compressive strength of test specimens” and ČSN ISO 6784 „Concrete – Determination of static modulus of elasticity in compression”.

Tab. 1 Compressive strength and static modulus of elasticity in compression of test specimens

Stabilization	Size	Production density	Time of ripening								
			7 days			**14 days**			**28 days**		
			Density	Compressive strength	Static modulus of elasticity	Density	Compressive strength	Static modulus of elasticity	Density	Compressive strength	Static modulus of elasticity
	d x l x h	ρ_v	ρ_7	$f_{c,7}$	$E_{c,7}$	ρ_{14}	$f_{c,14}$	$E_{c,14}$	ρ_{28}	$f_{c,28}$	$E_{c,28}$
	[mm]	[kg/m^3]	[kg/m^3]	[N/mm^2]	[N/mm^2]	[kg/m^3]	[N/mm^2]	[N/mm^2]	[kg/m^3]	[N/mm^2]	[N/mm^2]
without admixture	100 x 100 x 100	2364	2164	**3,36**	103,58	2122	**2,61**	107,63	2044	**4,23**	131,22
5% lime CS		2276	1994	**1,10**	36,07	2079	**0,73**	35,22	1986	**1,95**	55,03
5% cement 32,5R III/A		2236	2098	**3,61**	100,35	2044	**2,54**	81,17	2053	**4,58**	105,83
5% hydraulic binder Multibat		2219	2093	**3,32**	83,41	2080	**2,96**	103,58	2043	**4,72**	111,42

The laboratory tests have been made for each mean of stabilization after 7, 14 and 28 days of ripening. Each series of testing elements contained 3 specimens. Considering the results of compressive strength (**Tab. 1**, **Fig. 4**) hydraulic binder Multibat was used as an admixture to increase static parameters of earth core.

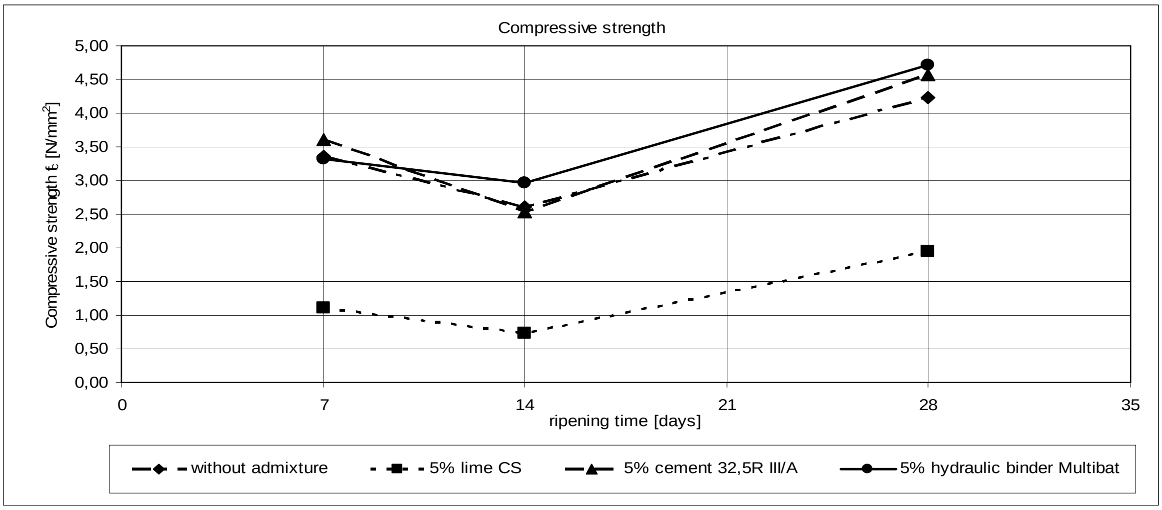

Fig. 4 Production of prefabricated wall panel

5.3 Production of prefabricated wall panel

First prefabricated wall panel with wooden frame and earthen core was produced in May 2007 (**Fig. 5**). Two approaches to ramming of the earth core have been used: (i) hand ramming, (ii) machine ramming (**Fig. 6**). Simple wooden boards of the width 300 mm and fixed with hand screw have been used as a sliding form. Ramming of the earthen core has been performed in layers of the height 50-70 mm.

Fig. 5 Production of prefabricated wall panel

Fig. 6 Hand ramming with wooden rammer and technological equipment for machine ramming

Wooden rammer has been used for simple hand ramming. The quality of hand made ramming was sufficient but working efficiency was not so high and insufficient for large scale manufacturing. Technological equipment containing pneumatic rammer and electric air pump was used for machine ramming. Working efficiency and quality of structure has been increased. Also lower water content towards to lower shrinkage during ripening.

6 Conclusions

This project represents one of possible approaches to sustainable building using earth structures as a modern technology. The main benefit is not only in using earth as a natural and easy recyclable material but also in using prefabrication as an efficient technology decreasing negative impact of building on environment.

Combination of high efficient technologies on one hand and natural "low-tech" and "low-cost" materials on the other hand allows utilization of specific properties of each of them. From the global point of view the research in the branch of earth structures is important for development of civil engineering in developing countries where those technologies are still traditional parts of contemporary building culture.

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Ing. Jan Růžička, Ph.D.

✉ CTU in Prague
Faculty of Civil Engineering
Thákurova 7
166 29 Praha 6, Czech Republic

☎ +420 224 354 572

+420 223 339 987

☺ jan.ruzicka@fsv.cvut.cz

URL www.cideas.cz