

Lusitanian timber framed masonry via FINE Ltd. civil engineering software

Author Pavel Kuklík

CTU in Prague, Faculty of Civil Engineering,
Department of mechanics, Thákurova 7, 166 29, Czech Republic
e-mail: kuklikpa@fsv.cvut.cz



Education: CSc. (Ph.D.) CTU in Prague, Faculty of Civil Engineering, 1984.
Thesis title: Solving of the Layered Subsoil.
Ing. CTU in Prague, Faculty of Civil Engineering, Department of Geotechnics, 1975. *Thesis title: Stiffness Matrix of the Plate foundation.*
Individual course focused on the theory of structures, CTU in Prague, Faculty of Civil Engineering, (1973-1975)

Professional qualification:

Teaching assistant, CTU in Prague, Faculty of Civil. Eng., Dept. of Struc. Mech. (1975-78}
Assistant professor, CTU in Prague, Faculty of Civil. Eng., Dept. of Struc. Mech. (1978-95)
Associated professor, CTU in Prague, Faculty of Civil. Eng., Dept. of Mech. (1995-)
Assistant professor, CTU in Prague, Faculty of Architecture, Institute of Exact Theories (1992-95)

Fields of research interest:

Constitutive relations of soils
Foundation on piles, interaction structure-fundaments
Stress measurements in site
Theory and application of the FEM
Theory and application of non-linear problems

Activity:

Member of IACMAG
Member of Society for Experimental Mechanics
Member of WTA CZ, head of the static section
Member of WTA Inter

Short summary

Das haupte Ziel von diesem Fachartikel ist den Leser mit der Modellierung des Lausitzeres Hauses mit der Holzzimmerung bekannt zu machen, vor allem mit der Kalkulation von der Tragfähigkeit von der Holzgezimmerten Wand. Das Finiteelementeverfahren erlaubt den Verwender den Holzrahmen mit dem Holzgezimmerten Mauerwerk zu kombinieren. Weil das füllende Material auf der Basis der Mischung von dem Stroh und dem Lehm erzeugt wurde, wurde GEO FEM ausgewählt. Der Resultat von der Analyse von den wirklichen Konstruktionen ist in einem guten Einklang mit der Empfehlung, die in dem alten Deutschen Büchern präsentiert wurde.

Keywords: timber framed masonry, FEM, Cottage of the Lusitanian type, culture heritage, influence zone

Abstract

The main objective of the paper is to introduce the reader to the FEM modeling of the Lusitanian timber framed house, mainly to calculation of the bearing capacity of the timber framed wall. The finite element method allows the user to combine the timber frame with the filling masonry. As the filling material is based on the clay straw mixture the GEO FEM was chosen. The result of the real structure analysis is in a good agreement with the recommendation presented in the ancient German books.

Key words: *timber framed masonry, FEM, Cottage of the Lusitanian type, culture heritage, influence zone*

Introduction

The present contribution deals with Lusitanian timber framed walls and their stiffness and bearing capacities. The investigation was founded on the house which was erected in 18th century, then reconstructed, enlarged, at the end of 19th century to the nowadays image. The face was also modified during this reconstruction according to village baroque requirements. The object is situated

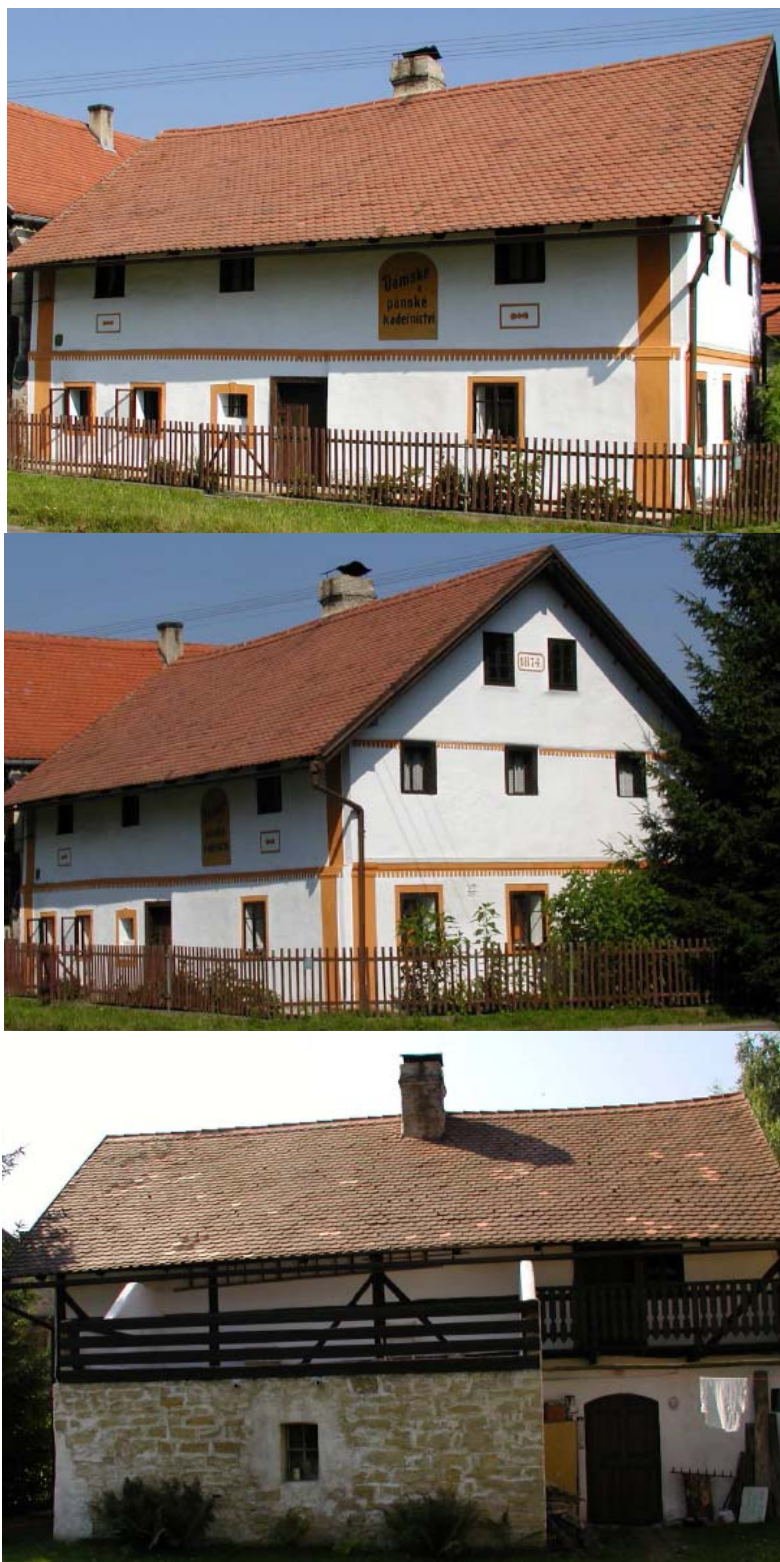


Fig. 1 The cottage of Lusitanian type, south, east and north view

in the north part of the Czech Republic in Radouň (Radaun). The house was built in the locality of ancient citadel. A famous owner of the citadel was Albrecht from Vallenstein. At the end of 17th century the citadel fell into disrepair as it was not in use any more. In 1981 the house started to be used as a weekend house (cottage) and present face was finished in 1995. The face should be close to the image from 1874 as it is written on the façade of the gable.

Fine Ltd. GEO 4 modulo was chosen for the numerical modeling. It is geotechnical finite element software enabling this kind of calculation. We assume that the behavior of masonry is similar to soil as it can be considered a straw mud (clay) timber composite. FINE Ltd. Geotechnical FEM modulus solves arbitrary reinforced soil structure in 2D [1]. The basic advantage of all geotechnical software is also the arbitrary activation of the partial parts of soil reinforcement composite. The calculation was proceeded small strain small, displacement, physical non linear. Also the contact elements should be employed, but it was not used in this contribution.

The house of our interest and the types of walls are introduced in following pictures Fig. 1, Fig. 2.



Fig. 2 Room on the first and the second floor.

There are three types of bearing walls introduced in the set of pictures. Timber framed masonry wall, typical for the second floor, German element of the Lusitanian house; for the first floor an arenaceous marl quarry or timbered wall is typical. The arenaceous marl quarry can be seen from the north point view; timber wall can be seen in the first floor room and it is, on the contrary, a Czech element of this style mixture. We decided to carry out numerical investigation on a combination of timber framed masonry walls supported by arenaceous marl quarry. The cross section of timber bars is in good agreement with the recommendation presented in [2].

Parameters modification

The solution is 2D plane strain. In our case it calls for several improvements. When solving the stress state inside the wall it is evident that it is plain stress. The first improvement is parameter modification changing the wall material parameters (plain stress) to the computer code parameters (plain strain). The following equation describing plain stress state is valid for the stress strain situation in the wall, real known parameters.

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \frac{1}{E_{wall}} \begin{bmatrix} 1 & -\nu_{wall} & 0 \\ -\nu_{wall} & 1 & 0 \\ 0 & 0 & 2(1+\nu_{wall}) \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}. \quad (1)$$

The computer code calculation is based on the plain strain state, computational input data. This situation is described by relation

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \frac{1-\nu_{comp}^2}{E_{comp}} \begin{bmatrix} 1 & -\frac{\nu_{comp}}{1-\nu_{comp}} & 0 \\ -\frac{\nu_{comp}}{1-\nu_{comp}} & 1 & 0 \\ 0 & 0 & \frac{2}{1-\nu_{comp}} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} =$$

$$= \frac{1}{\bar{E}} \begin{bmatrix} 1 & -\bar{\nu} & 0 \\ -\bar{\nu} & 1 & 0 \\ 0 & 0 & 2(1+\bar{\nu}) \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}. \quad (2)$$

Combining statement (1) and (2) yields

$$\nu_{wall} = \frac{\nu_{comp}}{1-\nu_{comp}} \rightarrow \nu_{comp} = \frac{\nu_{wall}}{1+\nu_{wall}}; \quad \frac{1}{E_{wall}} = \frac{1-\nu_{comp}^2}{E_{comp}} \rightarrow E_{comp} = E_{wall} \left[1 - \left(\frac{\nu_{wall}}{1+\nu_{wall}} \right)^2 \right]. \quad (3)$$

No we are able to transform the known wall material parameters to computational program input data as it is expressed in the relations (3).

Secondly, it is necessary to solve the problem of different thickness of the timber framed wall members. Let us choose the masonry thickness as the referential one and let us divide, normalize all thicknesses of timber bars by this value. The load must also be spread by this referential value. Normalized thicknesses, which will be used for the computation, are nominated with prime and they are calculated in the following way.

$$\bar{b}_{masonry} = \frac{b_{masonry}}{b_{masonry}} = 1(m), \quad \bar{b}_{i\ bar} = \frac{b_{i\ bar}}{b_{masonry}} (m). \quad (4)$$

Homogenization of the filling masonry

The simple averaging process is introduced for the homogenization of the ancient building filling masonry.

The approach describes parallel coupling of the bearing elements, which means superposition of the stress effects. We assume that corresponding strain is the same for both two parts. This statement is expressed by following relation

$$\begin{aligned} \sigma_{1part} &= E_{1part} \varepsilon, \sigma_{2part} = E_{2part} \varepsilon; F_{1part} = \sigma_{1part} A_{1part}, F_{2part} = \sigma_{2part} A_{2part} \\ \sigma_{\phi} &= E_{\phi} \varepsilon = \frac{F_{1part} + F_{2part}}{A} = \left[E_{1part} \frac{A_{1part}}{A} + E_{2part} \frac{A_{2part}}{A} \right] \varepsilon \Rightarrow \\ &\Rightarrow E_{\phi} = \left[E_{1part} \frac{A_{1part}}{A} + E_{2part} \frac{A_{2part}}{A} \right]. \end{aligned} \quad (5)$$

Here we denote σ_{ipart} stress, A_{ipart} representative area of the i -th constituent, E_{ipart} Young's modulus and ε common strain.

Estimation of the influence zone depth calculation

Following approach was used for the influence zone depth calculation. Assuming cottage foundation as a rigid strip footing, the depth of influence zone can be estimated from the formula

$$H = \frac{\pi a}{2} \sqrt{\frac{2-2\nu}{1-2\nu}} \frac{1}{\sinh^{-1}\left(\tan \frac{\pi \gamma h}{2f_z}\right)} \quad (m), \quad (6)$$

where a is the width of the strip (information about the shape), ν is Poisson ratio (description of the soil behavior), h is the depth of footing excavation, γ specific weight of the excavated soil (γh describes preconsolidation), f_z the level of uniform foundation surcharge. The basic idea of influence zone depth calculation is briefly introduce in Fig. 3.

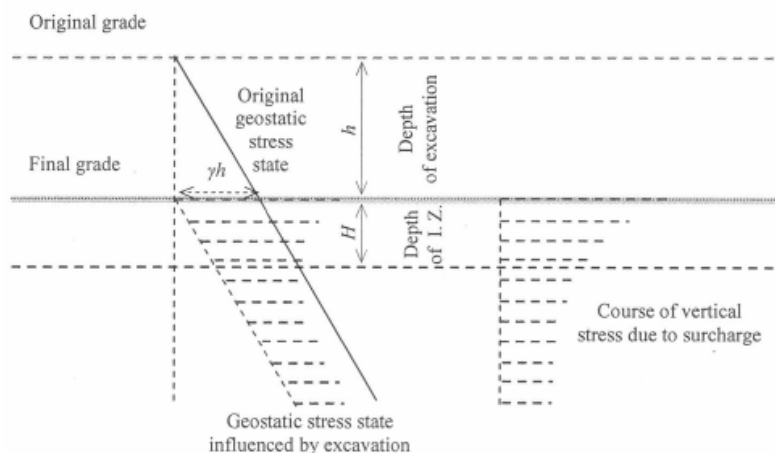


Fig. 3 Influence of excavation on the geostatic stress state course

The level of foundation surcharge can be estimated from 50 kPa, fair value, to the 100 kPa, over estimated value. Responding depth of the influence zone is in the range from 2 to 4(m). Real depth of ancient excavation could be around 1 (m) for this type of ancient house, Poisson ration of subsoil is estimated around $\nu = 0.35$, specific weight $\gamma = 20 \text{ kNm}^{-3}$. More details of influence zone depth calculation can be seen in [3], [4].

Passing all these steps of modifications and estimations the FINE GEO FEM modulo can be adopted for stress strain state calculation in the timber framed walls and others supporting elements.

Input data

A room segment was investigated by FINE GEO 4 program. The segment of the house is introduced together with the static scheme in the following Fig. 4. Timbered frame is seen on the top, zig zag line. Advantage of the program is in activation of all regions, beams, support arbitrary in the current stage. Three stages of calculation were passed. In the first stage the subsoil region was activated. In the second stage the walls of the first and second floor and at least the structure were loaded by the action of roof.

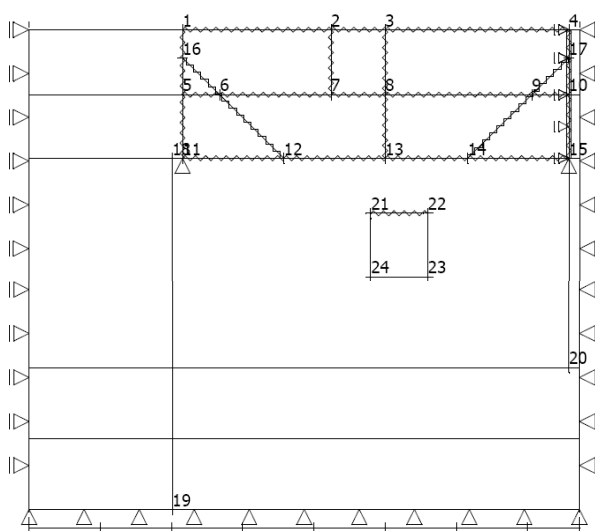


Fig. 4 Investigated one room segment of the house

Soil number 1 describes the filling masonry on the second floor timber frame; soil describes the first floor quarry masonry. Plasticity was derived by Mohr Coulomb.

Soil parameters

Material model: Mohr-Coulomb

Name	gamma [kN/m ³]	E [MPa]	nu [-]	With Ko	Ko [-]
Soil number: 1	20.00	45.92	0.29	NO	
Soil number: 2	20.00	991.74	0.09	NO	
Subsoil	17.50	63.00	0.30	NO	
Name	phi [dgr.]	c [kPa]	psi [dgr.]		
Soil number: 1	25.00	30.00	0.00		
Soil number: 2	40.00	30.00	0.00		
Subsoil	31.50	5.00	0.00		

Parameters of two selected beams are listed below. The width of the beam correspond the idea introduced in relation (4). The load was also spread in the same idea.

Beam parameters

Beam number: 1

Beam type: rectangle
 Cross-section height = 0.20m
 Cross-section width = 1.00 m
 Material: timber

Beam supports: hinge - fixed

The beam self-weight is considered in the analysis.

Cross-section area A = 2.0000E-01 m²/m
 Moment of inertia I = 6.6667E-04 m⁴/m
 Young modulus E = 10000.00 MPa
 Shear modulus G = 900.00 MPa
 Self weight = 10.00 kN/m³

Beam number: 9

Beam type: Reinforced concrete rectangle

Cross-section height = 0.16m

Cross-section width = 1.00 m

Material: timber

Surcharge

Type	Name	Mag.1 [kN/m]	Mag.2 [kN/m]	x1 [m]	x2 [m]
Line[kN/m]		60.00		0.89	
Line[kN/m]		60.00		-1.09	
Line[kN/m]		10.00		-2.84	
Line[kN/m]		10.00		2.58	

Results of calculation

Results of performed analysis are presented in the following pictures. The standard level loadings are presented from Fig.6 to Fig.9 correspond; Fig. 10 and Fig. 11 describe the state near the collapse; more than two and half time overloaded.

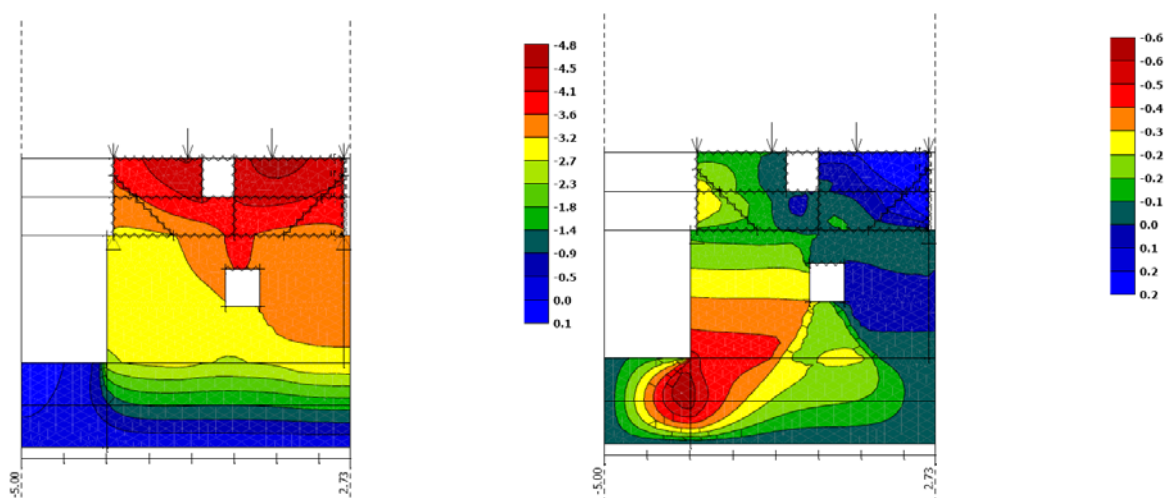


Fig. 6 Distribution of the vertical and horizontal displacements in the wall (mm)

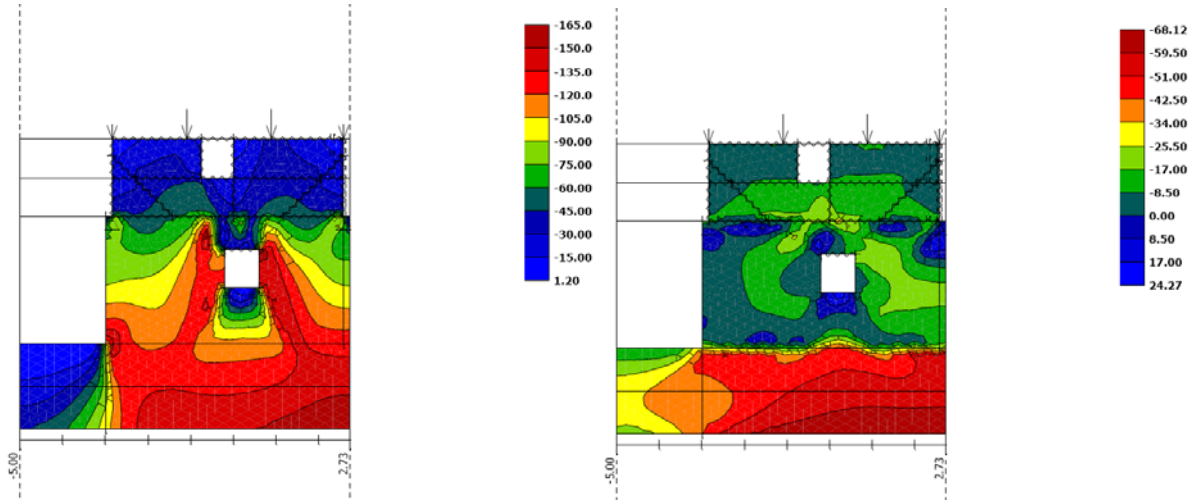


Fig. 7 Distribution of the vertical and horizontal stress in the wall (kPa)

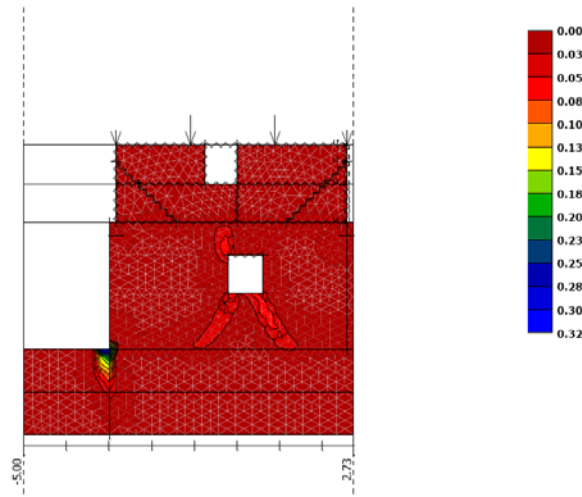


Fig. 8 Equivalent plastic deformation (%)

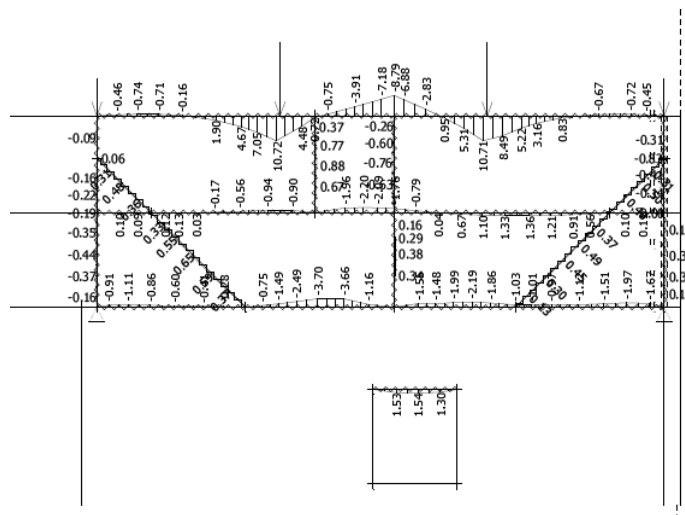


Fig. 9 Course of the bending moments (kNm)

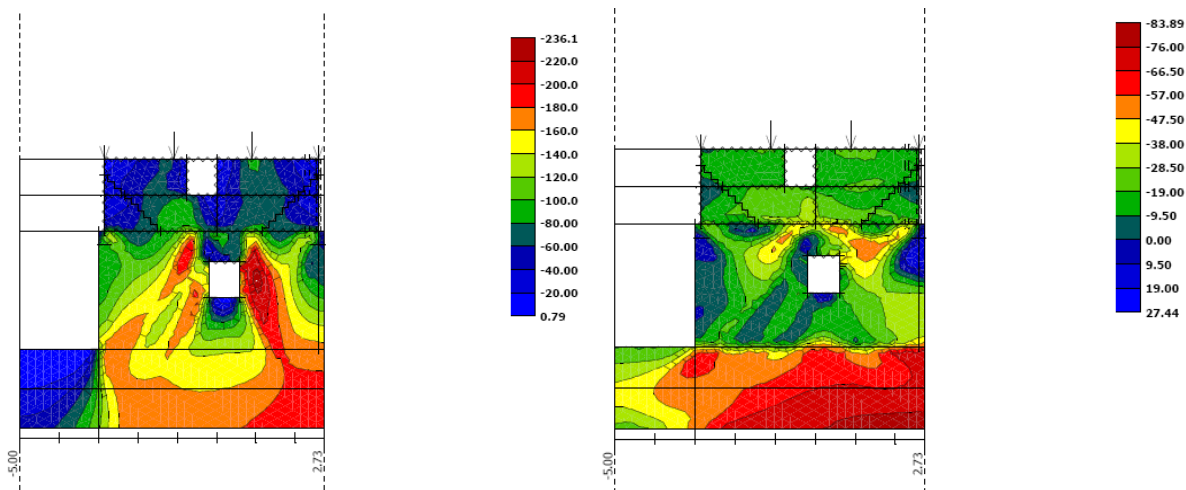


Fig. 10 Distribution of the vertical and horizontal stress in the wall (kPa)

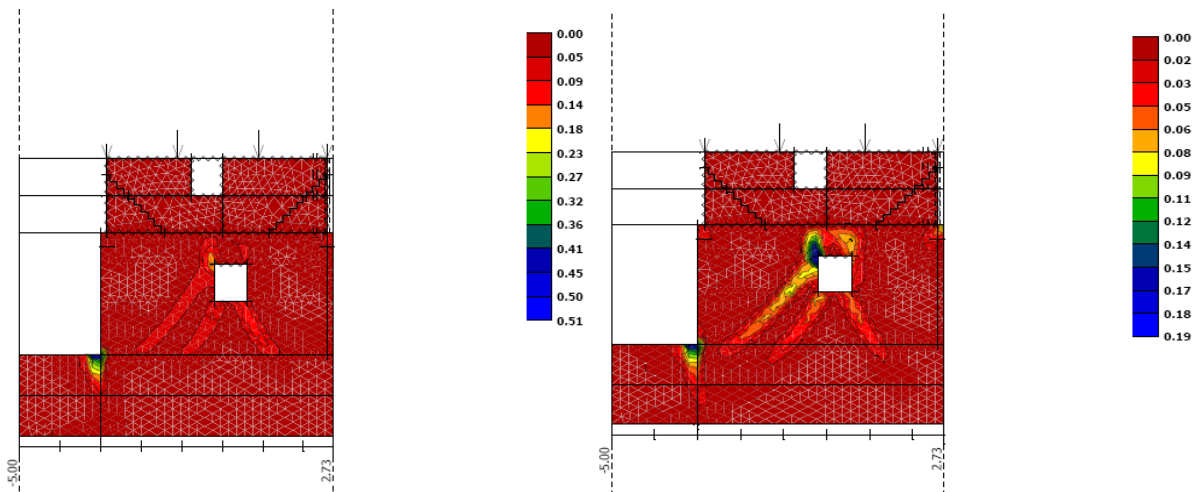


Fig. 11 Equivalent plastic deformation and potential crack propagation for two types of subsoil (%)

Timber framed wall spanning whole distance 5.5 m was calculated at. The results are presented in following Fig. 12 and Fig. 13.

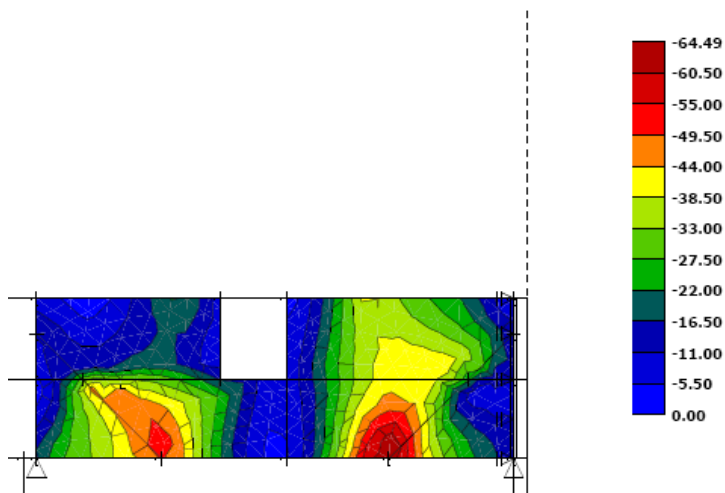


Fig. 12 Distribution of the vertical stress in the timber framed wall (kPa)

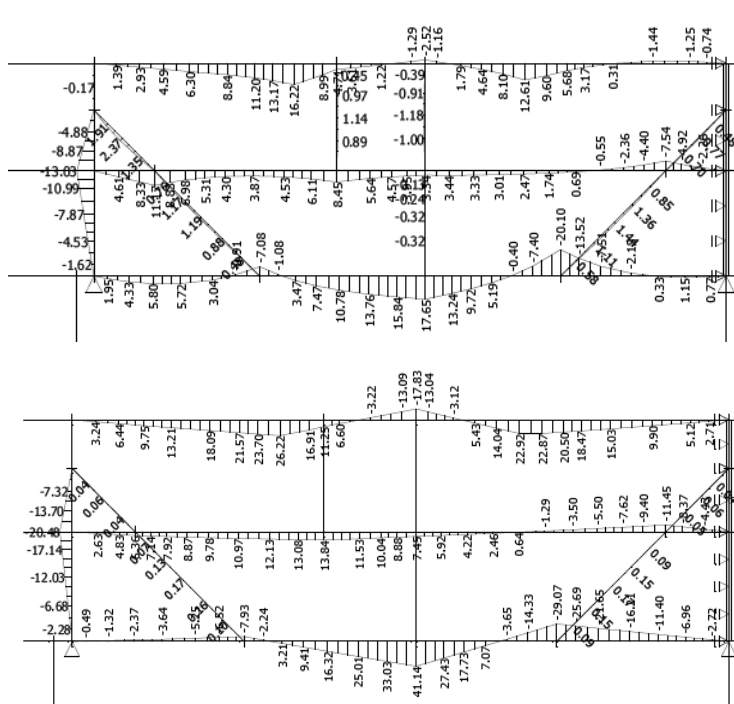


Fig. 13 Effect of filling masonry on the bending moment course (kNm); lower course of bending moment correspond all alone timber frame

Conclusion

The analysis shows great bearing capacity of the timber framed masonry. Definitely it is not a weak point of the house. The house Achilles heels, as it presented in the figures, are the places of stress concentration, e.g. the edges of window hole, the end of footing etc. Shallow footings are also problematical. In the stress distributions are seen absence of reinforcement. On the contrary, the timber framed masonry and its high bearing capacity show the construction sense of our ancestors.

Literature:

- [1] FINE, s.r.o. GEO MKP – Theoretical guide, www.fine.cz, 2002
- [2] Grebe W.: *Handbuch für das Bauen auf dem Lande*; Reichsnährstandsverlag G.M.B.H. Berlin 1943
- [3] Kuklík P., Kopáčková M.: *Comparison of elastic layer solution with Boussinesq half space solution*, (in Czech), Stavební Obzor, CTU in Prague, 2004, 6, pp.171-175.
- [4] Kuklík et al.: *Analytical and Numerical Calculation of the Influence Zone Inside the Subsoil*, [CD-ROM]. Beijing: Tsinghua University, 2004, s. 1-10.

Acknowledgements

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