RECONSTRUCTION OF GROUND SUPPORTED FLOORS - BUILDING PHYSICAL ASPECTS

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UDK: 69.059.25:699.822
DOI:10.14415/konferencijaGFS2017.009
Summary: *Building renovation means urgent tasks for engineers over Europe. Reconstruction of floors laying on ground raises questions not only from thermal insulation and waterproofing, but also from technological and covering point of view. The article summarizes the theory of moisture transport and several hygrothermal analyses offer solutions to floor reconstruction using up-to-date posterior waterproofing materials and to connection to other building constructions.*

Keywords: *moisture transport, reconstruction of floors, posterior insulation*

1. INTRODUCTION

During the reconstruction of the buildings subsequent utilization of attics and basements, which had only been used for storage, are highlighted. Before the design process detailed diagnostic analysis of the structures must be implemented, which describes the real state of the building elements. In Central Europe a significant part of the city cores was built at the eclecticism architectural period, or later. Only exceptional buildings were equipped with water insulation during construction, thereafter only horizontal wall insulation was applied in the bottom level of the cellar slab to protect the facade walls.
From 1910 onwards, waterproofing was made more often for basement elements, however the paper- and cloth reinforced bituminous membranes are putrefied by now, so they have not been able to fulfill their function. It can be stated that a large part of the basements and ground supported floors are burdened with significant amounts of moisture. A lot of theoretical work deals with determining of amount and movement of the presenting moisture. This article is a summary of some of these theories, as well as presentation of practical and properly working examples. The moisture that traverses through structures impresses not only in the structures of buildings, but also other civil engineering structures as well as settling basins, tunnels, retaining walls.

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2. THEORETICAL PHYSICS OF THE MOISTURE TRANSPORT

A significant part of building materials is permeable to vapour and liquid moisture. In brick, stone and concrete structures in the soil the moisture is present in vapour and liquid state. In most cases, both moisture phases appears in the pores: the water vapour above the liquid, on the surface of the pore in form of molecular water layer and water vapour. Presence of moisture depends on the structure and pore size of the material. The effect of moisture on the material should be analysedseparately for solid, closed and open pore structure. The solid materials react chemically with water or absorbs moisture by osmosis. In the closed-pore materials the moisture uptakes realized by surface adsorption, while in the open-pore materials it occurs by diffusion, capillary water uptaking and adsorption.

Water vapour mechanisms

Water vapour from the soil passes into the inner space in two ways: effusion or diffusion. During effusion the vapour transmits coincidently to the walls of very small connected pores. During diffusion the water molecules mix with air and the vapour is transmitted by the effect of the concentration difference. In this case water molecules are encountered. In porous solid materials various types of diffusion are taking place.

Molecular diffusion happens in the wide pores which have larger diameter than the free path of molecules. This diffusion is mostly the same than the diffusion in homogeneous medium, but the cross section of the pores are smaller, thus it is called as effective diffusion.

The so-called Knudsen transport is the characteristic of the narrow pores, wherein the pore diameter is less or equal than the free pore-length. The gas molecules collide with each other and the wall of pore. The diffusing material, so the water vapor mass flow is describe by Fick's I^{st} law. The temporal changes in the concentration of water vapour are calculated on the basis of Fick's 2^{nd} law.

One of the diffusion mechanism also should be mentioned, that is the dissolution diffusion. This is a typical process of certain organic polymers. Contrary to mineral building materials, the water is linked to macromolecules of the polymer, and there the plastic swells. Concerning water vapour solubility of the polymer is determined by the macromolecular chain and the polar or apolar characteristic of the plasticizer. (Fig.1., 2.)

Water transport

In liquid phase the water is carried by capillary movement and flow. The limit of expanse of water has a minimum surface. In the pores, as very thin capillaries, the water rises due to the surface tension. Therefore between the fluid and wall of the pore, as well as the wall of the pore and air, cohesion and adhesion are different.

The flow is water movement occurring due to the pressure difference. Condition of flow is that the capillaries and pores are saturated, so the adsorption forces do not impede water movement. The surface diffusion always occurs in the presence of liquid. The surface diffusion is the movement of those water molecules, which form a thin film of water on the surfaces of pores and of microcapillaries of hygroscopic materials, therefore the wall of the pores absorbs the water vapour molecules. Surface diffusion is determined by the relative humidity and the surface roughness.

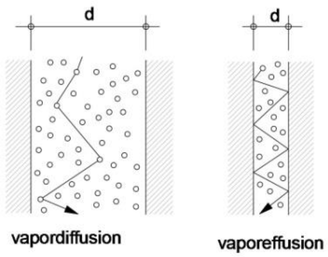

Figure 1. Mechanisms of diffusion and effusion

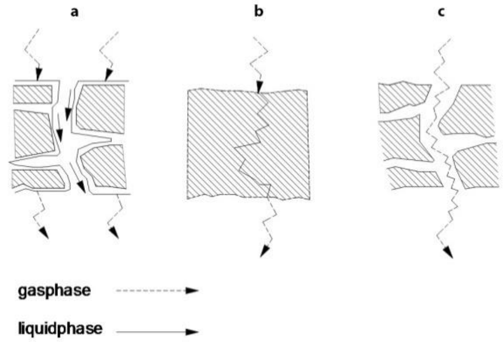

Figure 2. Surface (a), dissolution (b) and water wapour diffusion (c)

Another phenomenon should be noted in which in cement plasters, fine concrete, solid or sandy soils and water-content polymers a voltage change eventuates, and the water moves into cathode direction. This phenomenon is the electro-osmosis, which occurs always on the border of the two media of fine pore structure.

Mechanisms of moisture transport are determined by:

- water content of the pores,
- the size of the pores.

Table 1: Comparison of various moisture transport processes according to Klopfer [1]

Mechanism	Typical property, describing law	Example
water vapour diffusion	gaseous form of water in pores open pores; Fick's laws, gas laws	gaseous state, relative dry porous material
surface diffusion	movement of absorbed water molecules on wall of pores; open pores	materials with high pore-rate moderate water content
dissolution diffusion	water solubility; Fick's lows	organic polymers
capillarity	liquid water in open pores, surface-tension	porous materials
flow	water flow due to pressure differentials Darcy's law	at coarse pore sizes partly or totally, at fine pore-sizes totally saturated
electrokinetic phenomena electro-osmosis	water flow in pores due to electrical fields modified Darcy's law	materials with fine pore structure, clay, sandstone, organic polymers

In Figure 3. the humidity increasing in the pores of building materials is illustrated (on the basis of Fechner's works [2]).

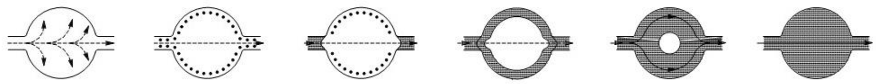

Figure 3. Capillary condensation and pore saturation due to ascending water vapour

On the pore walls of dry materials the water vapour is absorbed, then there is not moisture transport. The pore walls are covered with the water in some molecules thickness, so with the termination of adsorption forces water vapour is diffusible, and surface diffusion is also significant. As a result of the rising water vapour the capillary driving starts. The water vapour condense on capillary walls, finally the pore is saturated with water. In structure with high moisture content the moisture transport is determined by the capillary forces and flow. However, for a certain moisture content can not be assigned a form of moisture transport because it is affected by also the temperature and the size of the pores.

The calculation methods of moisture transport

The moisture transport is a relatively slowly ongoing process in time. Therefore, many of the methods of calculation assumes stationary state. According to Kießl, moisture transport of building structure is determined by the moisture content of building material, the temperature and the pressure (gradient) changes as well as the pore size and distribution [3]. According to Klopfer inside of the structure in contact with water drying process takes place [1]. Fluid transport occurs on water attacked side. Here, the water content is higher than the equilibrum moisture content in the building material at 95% relative humidity. Close to the inner side the moisture escapes by diffusion, at this side the moisture content is lower than equilibrium moisture. Figure 4 shows the cross section of the structure with the moisture distribution in one water-side load.

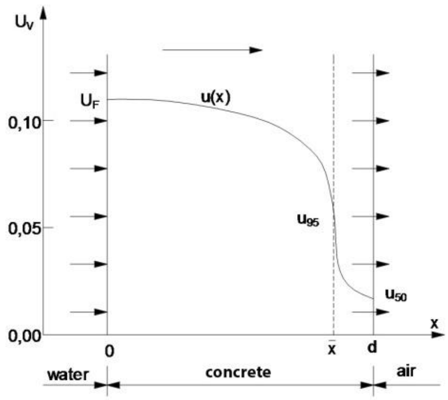

Figure 4. Water evaporation reduction in the internal side of a structure with outer side water load (according to Klopfer [1])

On the inner side of the structure water vapour diffusion takes place. This has a great significance in watertight concrete structures, as moisture coming from the soil evaporates into the interior. This moisture must be driven by natural ventilation or air technique.
The time-dependent processes can be tested with the Fraunhofer Institut für Bauphysik WUFI programs. These multi-layer structures can be analyzed by combined heat and moisture transport in parallel layers. At the vapour transport calculation the vapour diffusion and dissolution diffusion, while at the liquid transport the capillarity and surface diffusion are taken into account. As boundary condition meteorological and climatic data of interiors are needed. The results show the temporal variations of relative moisture, the heat flow density, the average moisture content of structural sections and thetotal moisture content of the entire structure. The temperature distribution, relative humidity and moisture content of the sections in any point at any time can be determined [4]. The program can not handle the flow of water, for example leakage and hydraulic flow, electro-osmotic and kinetic effects. There is a suitable program for consideration of the above mentioned effects. The Dresden University of Technology has developed Delphin [5]. This also examines coupled heat and moisture transport in materials at instacioner state. The simulation is used to determine the temperature, the humidity and the vapor pressure distribution of the structure. As boundary conditions air temperature, air pressure, direct and diffuse short-wave and long-wave radiation, wind speed and direction, precipitation and air pressure are taken into account. At the structures in the soil the program can handle the effect of hydrostatic water pressure and the transport of dissolved salts. The procedures for the calculation of the moisture transports were compared by O. Fechner (Institut für Bauingenieurwesen Berlin). During comparison watertight concrete structure was tested in the soil with different thicknesses under the same conditions in stationary state. The aim of the study was to determine the overall throughput of moisture for a period of 5 years. Fechner found that the results for the moisture supplied show strong correlation for structures in the soil. This establishes that with steady-state analysis, as an easier method suitable results can be detected. [2] According ot Fechner the moisture which is passing through the structure that the inner surface of the air takes on [2]:

$$Q_v = n \cdot m_s \cdot [(100-p_{hi})/100] \cdot V \cdot 24 \text{ [g/m}^2\text{d]} \quad (1)$$

where,

Q_v quantity of humidity that air can take up [g/m^{2}d]
n number of air changes [1/h], average basement window n = 0,2, ventilated space n≥0,5
V room volume relation to external surface [m^3/m^2]
m_s maximum water content of air [g/m^3]
p_{hi} relative humidity [%].

A safety factor is required for sufficient moisture equatation:

$$Q_v > 1,75 \cdot Q \quad (2)$$

The process can take place if the surface is not closed with a vapour barrier layer. To avoid moisture damage it should be ensure that the traversed moisture can evaporate freely from the basement walls and floors. The furnishings of the room do not impede moisture path, the covering must be designed to let the air flow in front of the walls and floors.

3. MOISTURE INSULATION IN BUILDING CONSTRUCTION PRACTICE

During the reconstruction of residential buildings improving the living conditions of the residents is often neglected, the owners just concentrate on building energy modernization. Characteristically thermal insulation of the facade, window replacement and possibly building services renovation is being done, but to improve the interiors are not part of the plans. This is especially a growing problem in the structures of buildings in contact with the soil, where wetting of building parts is caused by insufficient waterproofing, the residents' health is at risk. The impermissibly high humidity of structures can lead to spoilage, weathering, efflorescence and also to mold. The durability of building construction and compliance for user requirements can be solved by posterior waterproofing and by new order of layers. The first step of reconstruction works should be the prevention and the reduction of the wetting processes, which were described by the above-mentioned physical phenomena. The average age of domestic building stock is much more than the estimated average life of waterproofing materials, so probably the waterproofings already do not perform their duties properly. Waterproofing materials of the previous decades, such as bituminous membranes on paper, tar membranes, pitch, etc., on the basis of diagnostic experience, they have been aged. Against groundwater, soil moisture and water vapour a number of technologies are available, in addition the traditional membranes state of the art insulation coatings also can be useful. There are dozens of years of experience in application of bituminous and PVC waterproofing, water-tight concretes and drainage systems. However at renovations the building characteristics, the construction conditions or the economic issues narrow the scope of applicable technologies. Thus use of such novel group of techniques and materials are required, in which case of reconstruction tasks collectively implement by the complex protection mechanism against moisture. Regarding the lack or insufficient waterproofing the tasks of the floor reconstruction should be basically treated from waterproofing perspective. The solution for that has an effect on the durabiliy of the layers of floor, moreover affects the placement of the thermal insulation.

If waterproofing under the floor is no longer able to serve, presumably the waterproofing under the wall either. Then generally the capillary moisture rising causes the damages, which is further intensified by the water vapour diffusion. Renovating or rebuilding of ground supported floor structures is closely related to posterior waterproofing of walls both by the stoppage of wetting of capillary action and by keeping away rainwater from the skirting wall and soil moisture from the building structure. Applying these together formes a complex system: a continuous waterproofing with the horizontal floor, the layer through the cross section of wall, and the vertical wall insulation. For the masonry through boreholes chemical injection materials forms a watertight layer in the wall cross section. The surfaces of pores of the masonry become hydrophobic for example with silane-based creams, further narrowing of capillaries is achieved with alkali-silicate agents.

Advanced materials of posterior waterproofing

The effective resolution of posterior surface waterproofing is given by cement-based mortar smeared insulations. Favorable characteristics can be listed as rapid

implementation, low labor requirement and simple application. Two-component variations form a thin film layer (~2 mm) flexible coating and the surface cladding could be strictly built. Compared to conventional waterproofing material the water vapour diffusion resistance coefficient is relatively low (μ~1000). [6] This property allows the slow escape of the water vapour from the wet structure after waterproofing, so the drying process.
The rigid insulating cement-based mortars, as novel solution for engineering structure are performing crystalline mechanism that closes the path of the water with filling the capillaries of the concrete surface in few mm thickness. With this, impermeability is achieved, but the adhesion of a next layer is obstructed because of the complete closure of surface porosity. If a new concrete structure is operating during the reconstruction, the crystalline waterproofing admixture can be used, thus the total concrete structures can be made watertight. With the crystallization the forming concrete cracks can filled up, so it works as "self-healing" waterproofing up to 0.4 mm width.
At the watertight reinforced concrete structures in the connections the working joints are the weakest points of the waterproofing. In addition to the bentonite tapes and the so-called roundabout tapes, thermoplastic elastomer swelling tapes are spreading. This material operating on the physical principle of dissolution diffusion can increase 10 times of its volume under continuous load of water, and at dry state it shrinks back. [6] As the water vapour resistance of watertight concrete structures due to the waterproofing additive does not increase significantly, so this change can not be separately analyzed in this research.

Building constructional considerations related to floor reconstruction

The structural solutions may be varied in comparison to the reconstruction possibilities (Fig. 5). Several aspects need to be considered after the structural and building physical diagnosis of the existing layers (eg. Fig. 5.A, B, C).
With the deliberation of possibility of the finished floor level changing, basically three group of solutions are possible: "heightening" on the existing floor (Fig. 5.D, E); termination of floor layers under the bottom of original cover plane then building new layers (Fig. 5.F); even the entire removing of existing floor (Fig. 5.G, H, I) and build a completely new.
When a waterproofing layer and the new covering are the target, and the former bonded cladding is ceramic tile, it is possible to maintain it and build the new layers on special bonding primer. In this case thermal insulating capacity development is not possible (Fig. 5.D). The addition of thermal insulation layer system, with the feasible increased finished floor level, requires the construction of additional layers: technological insulation, screed, new covering (Fig. 5.E). If the original floor covering (e.g. parquet) dissassembly is necessary due to its material or defective condition, but the waterproofing is appropriate, it is possible to built a new order of layer design.
Then increasing the finished floor level with a few cms, on the thermal insulation layer with a thin fiber-reinforced cement screed load distribution layer any new covering could be constructed (Fig. 5.F). Depending on the rate of reconstruction and the existing order of layers of the floor, the entire rebuilding of the floor order of layers (Fig. 5.G,H,I) gives the most effective solution from structural, waterproofing and vapour barrier point of view.

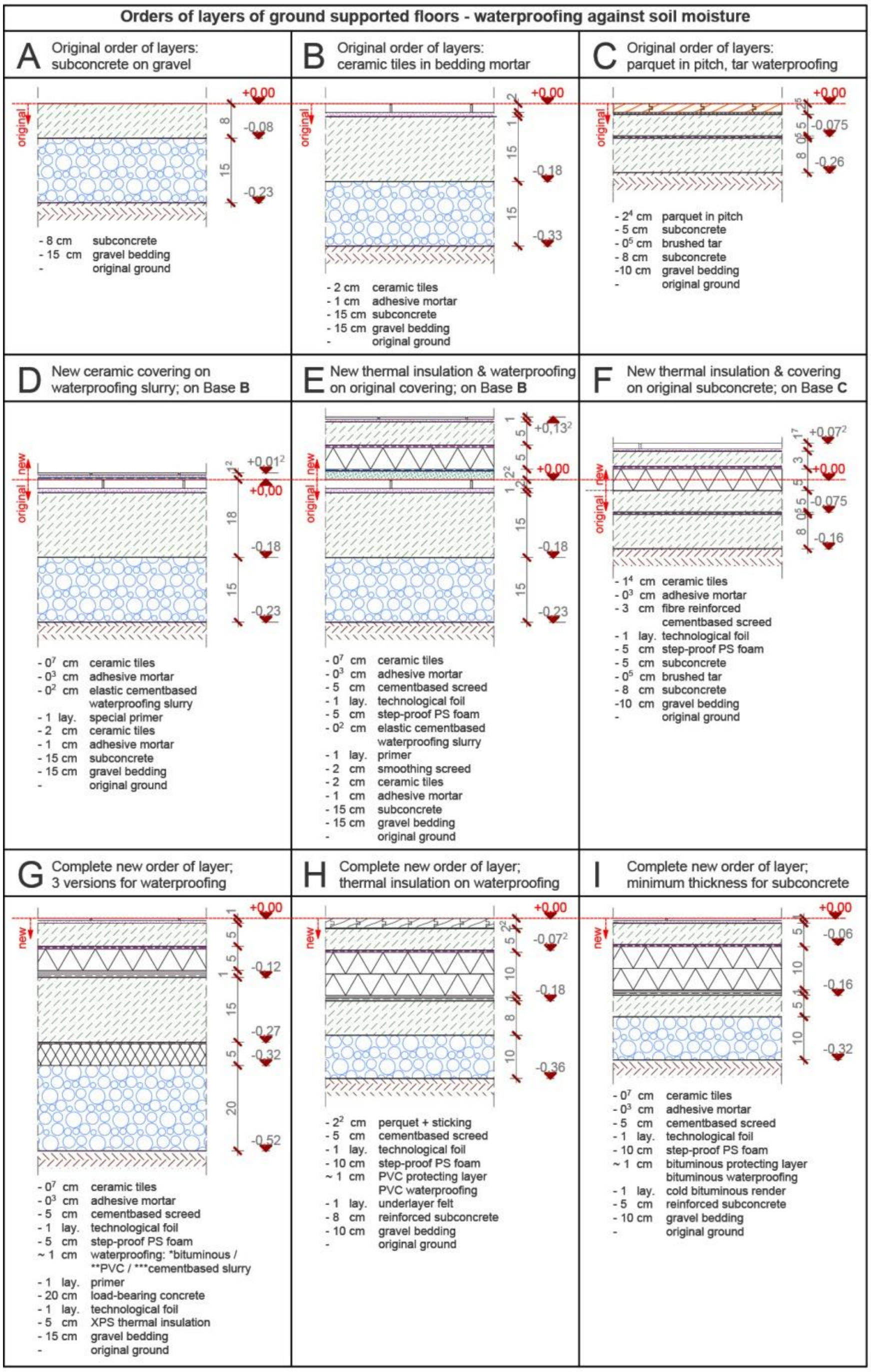

Figure 5. Reconstruction versions on ground supported floors

Technology rules proposed for further consideration for the increasing of water vapour resistance are the use of a stepped-jointed XPS insulation boards, and the use of technological foils in room-width-wide, otherwise stick of laying connections. It is essential that the interior divider structures join to the wall and floor with waterproofing membrane interposing.

In Figure 5 represented orders of layers were examined concerning vapour diffusion, from which the cumulative vapour diffusion resistance values are shown in Figure 6. (data sources: [6-9]). The order of layers of Table 5. cumulative vapor diffusion resistance ΣR_v [$m^2 \cdot h \cdot Pa/kg$] is greater at all renovated order of layer than the minimum value of vapour barrier characteristic, as the estimate limit value $R_v > 6{,}67 \cdot 10^6$ [9].

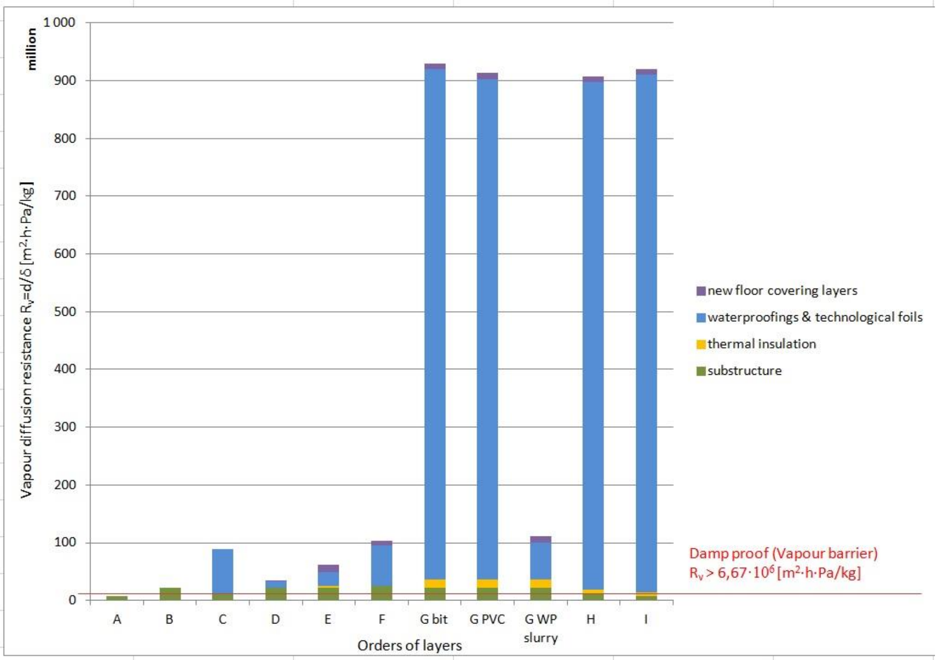

Figure 6: The cumulative vapor diffusion resistances of orders of layers visible in Table 5.

In vapour diffusion terms traditional bituminous and PVC waterproofing dominate, but there are no limitations in renovations in applicability of the waterproofing slurry insulation regarding the choice of flooring or the function of room. It would be considered that between water vapour resistance of the floor and the wall should not be a big difference, thus the resistance of the masonry does not increase significantly because of injection. For the reduction of capillary moisture - if this is possible - an outer side gravel bedding drainage system is suggested, but specifically without plastic surface drainage boards. Through the gaps of gravel bedding likely the saturation vapor pressure of the soil can equalize into the level for the vapor pressure of free air, thus helping the masonry to dry.

4. SUMMARY

Based on the presented detailed analysis, it can be seen that wetting of building structures is a complex physical phenomena. Identification of the causes of dampness must be the first step in the reconstruction, then the design of the technologies and realization of posterior waterproofing system. For the moisture protection of building structures several advanced material are available, with which the renovation of old buildings can be achieved according to nowadays requirements.

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