SYSTEM DEFECTS OF EXTERNAL CLADDINGS FOR RESIDENTIAL HOUSING IMPLEMENTED IN THE AREA AFFECTED BY INDUSTRIAL ACTIVITIES

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Summary

This paper deals with systemic defects and failures in peripheral claddings in residential development constructed in the second half of the 20th century on territories affected by industrial activities, in particular, by underground mining and heavy industry. Such defects and failures occur not only in residential buildings built from the 1950s until the end of the century and in those buildings under reconstruction and remediation, but also in new apartment buildings. Heat parameters are among pressing issues there and industrial territories influence structures of the new and reconstructed buildings.

In case of the reconstructed buildings, the defects and failures in the peripheral cladding are often closely connected with additional contact overcladding of the building. The aim to make the buildings compliant with principles of sustainable development is then often more complex and more costly. Decisions should to be made then which alternative is the best one for remediation. A possibility is to use a multi-criterion analyses which optimises the result, making the investment more efficient.

Keywords: building, undermining, peripheral cladding, systemic failures

1 Industrial territory in the Ostrava and Karviná regions

1.1 Undermined territories

The area of the Ostrava and Karvina regions is about 170 km^2 [1]. This is an undermined territory which is affected by mine excavation of raw materials [2] (bituminous coal, in this case).

Facilities constructed on the territory are exposed throughout their service lives to undermining effects, namely to deformation of landscape. Such influences are present for many years even after the mines are abandoned. These are disappearing effects of mining activities. In line with ČSN 73 0035 [3] deformation results from random long-lasting load of building structures by uneven deformation of foundation soil (in case of continuous deformation of landscape) or as random extraordinary loads (in case of discontinuous deformation of landscape). Structural measures and underpinning of the buildings depend on a specific location within the industrial territory of the Ostrava and Karvina regions which, in turn, depend on magnitude of mine excavation effects. It follows from experience in the underpinning of the buildings on the undermined territories that the design should be based on rather wide aspects of soil deformation dynamics and the structural solution should be sensitive enough and should provide reasonable protection against such effects.

(**Fig.1**) shows some defects and failures resulting from the mine excavation: subsidence of a building and, in turn cracks. Such defects and failures occur in historic buildings, brick buildings and in buildings made from panel blocks.

Fig. 1 *Buildings influenced by undermining*

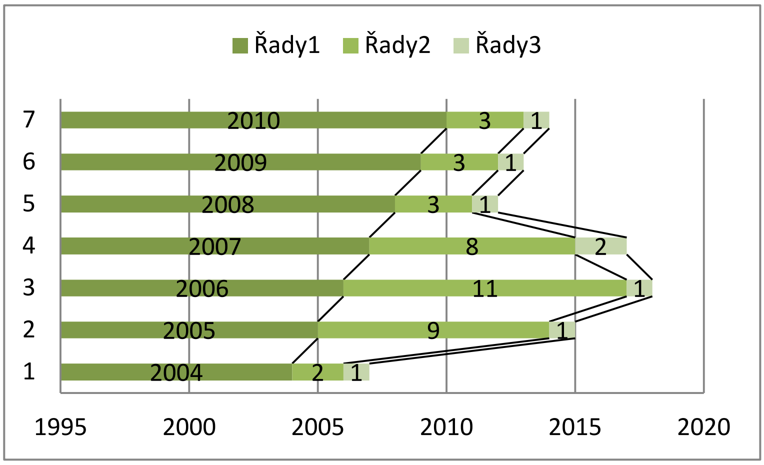
1.2 Monitoring of residential buildings made from panel blocks

From 2004 to 2010, residential buildings made from panel blocks were monitored in Havirov and Orlova. Those two cities are located on fully/partly undermined territories. The main goal of the monitoring was to make technical and structural assessment of the panel block buildings which should be used as an accompanying document for application for a subsidy for improvement of heat, energy and technology parameters of the buildings (the name of the subsidy is "Green Light for Savings"). The monitoring should also reveal failures and defects resulting from mine excavation and heavy industry [4]. More than 32 panel block residential buildings with 4 up to 6 floors were monitored. These were the panel block buildings, type T02B-OS, T03B-OS, BP-70-OS or VOS.

From 2004 to 2010, new houses in some parts of Ostrava and Karviná were also monitored. Attention was paid to eight new residential buildings made from wall/skeleton structural systems with bricks in external walls.

(**Fig.2**) shows the panel block buildings, while the chart in (**Fig.3)** shows parameters and numbers of the panel block buildings. Systemic failures and defects in peripheral cladding have been identified on the basis of the monitoring. The buildings included those built in the second half of the 20th century as well new buildings which have been built since 2004.

Fig. 2 *Types of apartment houses built from panel blocks – monitoring from 2004 to 2010*



Comments: Line 1: period under monitoring;
Line 2: number of panel block buildings which have been monitored;
Line 3: the number of new buildings made from panel blocks

Fig. 3 *Number of apartment houses built from panel blocks – monitoring from 2004 to 2010*

2 Systemic defects and failures in peripheral cladding

2.1 Residential housing from panel blocks

Systemic failures and defects in the peripheral cladding in residential houses made from panel blocks are structures and structural sections with cracks in the peripheral cladding and/or with heat defects /typically, thermal bridges and links). Namely:

- Offsetting structures of balconies and loggias,
- Rejected floors,
- Sills,
- Attics.

The monitoring has proved that the mining has not resulted in failures and defects, this means, the cracks, in T02B-OS, T03B-OS and BP-70-OS. Such as cracks have been, however present, in rather tall panel block buildings which were identified as the type ID VOS in the Ostrava and Karvina Regions. (**Fig.4**) shows basic parameters of those buildings. Regarding T02B-OS, T03B-OS and BP-70-OS, certain degradation has been witness on the peripheral cladding. In Orlova, joints in the peripheral cladding started degrading.

- *This is a skeleton structural system made from reinforced concrete. There is a reinforcing monolithical core in panels. 6,00 m modules were used.*
- *The multi-family houses have got 12, 14 up to 17 floors. One experimental building with 21 floors was built.*
- *Load-carrying walls inside the building are made from reinforced concrete. Thickness: 200 mm.*
- *Peripheral cladding is made from window-sill belts from gas silicate, thickness: 240 mm, combined with spandrels. $U_N = 0.80\ Wm^{-2}K^{-1}$.*
- *Partition walls inside the building are made from reinforced concrete, thickness: 60 mm.*
- *The roof consists of one layer – some types can be loaded and resist the weight of walking persons. $U_N = 0.78\ Wm^{-2}K^{-1}$.*
- *The ceiling consists of hollow pre-stressed panels made from reinforced concrete. Thickness: 200 mm and 300 mm.*

Fig. 4 *Parameters of a tall panel block building*

It is clear from the analysis of the structures and structural sections in the residential buildings made from panel blocks that much attention was paid to static aspects of the panel block buildings during the second half of the 20th century and that almost all panel block buildings were protected against undermining effects – even in territories out of such effect.

It follows from the structural and static parameter analyses pursuant to ČSN 73 0039 [5] that panel block wall and load-carrying systems made from panel blocks are rather rigid. This, in turn, results in higher internal forces in case of forced deformation (such as landscape curvature). Much attention was paid to horizontal loading of panel block buildings – it concentrated either on collar beams or complete ceiling plates. This was in line with general structural principles for structures built on undermined territories pursuant to ČSN 73 0039. The prefabricated panel ceilings were reinforced by reinforcement which was installed between panel joints or cast-on-site concrete layer (at least 30 mm thick).

This was a continuous additional reinforcement. Joints were often overlapping. The additional reinforcement along the perimeter of the wall and ceiling segments co-acted with reinforcing collars similarly as in the case of cast-on-site concrete.

Joints between the wall panels and ceiling panels were assessed in terms of statics and created continuous vertical and horizontal panes. Joints were transferring normal and stress tension. In order to increase shear capacity, concrete dowel pints, reinforcement or offsetting were used. Dimensions were chosen in accordance with provisions of ČSN 73 1201 [6] which were valid then for concrete elements. In case of horizontal head joints, it was possible to resist shear forces even in a flat joint, if vertical load was sufficient. Proper shape, perfect concreting and permanent anti-corrosion protection of the connecting reinforcement was necessary for the joints. Same requirements applied to the joining of vertical and horizontal segments. It was not allowed to make openings in vertical edges of the wall segments. Peripheral walls of basements could have been designed from panel blocks for class III or worse classes pursuant to Table 4 in ČSN 73 0039 only if it had been proved that such walls would resist landscape deformation. If basements were deeper than 2.5 m, it was recommended to use cast-on-site wall structures. As few openings as possible were made in basement walls in order not to weaken them too much. The basement walls were perfectly connected with ceiling structures over the basement.

Some heat and moisture defects which were revealed in the panel block buildings resulted from lack of verified experience in designing of panel block buildings in the second half of the 20th century, development of ČSN 73 0540 [7] and even more stringent standards. Originally, the standards for the heat insulation of cladding were derived from masonry walls lined with kiln bricks with the thickness of 450 mm. Those standards have become more restrictive in the course of time. (**Fig.5**) shows development of a heat transmission coefficient for peripheral claddings U_N [W/(m^2.K)] from 1955 to 2012. The reason for strict energy and heat performance has been the growth of energy prices and pressure of the company to decrease the energy demand and, in turn, to improve the quality of the environment, namely to reduce undesirable emissions of carbon dioxide CO_2 that gives rise to green house effects [8].

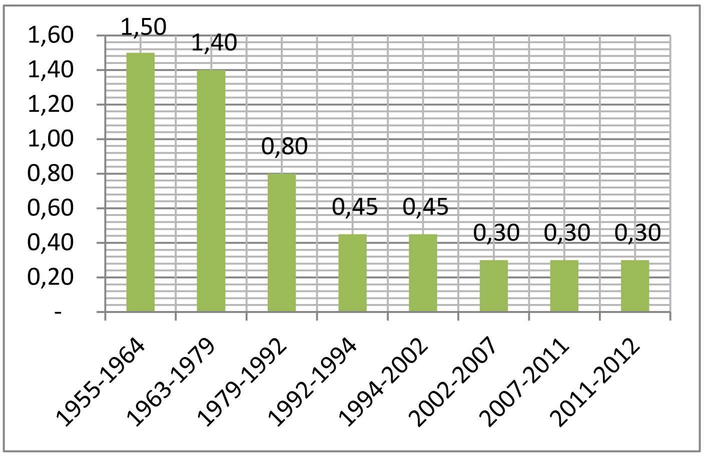


Fig. 5 *Development of the heat transmission coefficient in the peripheral cladding from 1955 to 2012 pursuant to ČSN 73 0540*

In the last decade, ETICS (External Thermal insulation Composite Systems [9]) have been used to remove systemic failures and defects during additional overcladding. This improves energy balance of the panel block buildings and removes heat and moisture defects [10].

2.2 New residential housing

It follows from the monitoring of the new residential housing from 2004 to 2010, that systemic failures and defects in the peripheral cladding have been occuring in same structures and structural sections as in the panel block buildings which were constructed in the second half of the 20th century.

In spite of much progress and innovations in heat performance which have been reached in last decades, there are many critical details in peripheral cladding. (**Fig.6**) shows typical current defects and failures. Reasons include:

- Design of the critical details pursuant to ČSN 73 0540,
- Technologies and speed of construction.

Fig. 6 *Failures relating in the peripheral cladding (lintels above doors and windows).*

There is also one special group of systemic failures and defects which have been occurring in multi-family houses built from panel blocks during the second half of the 20th century as well as in new houses built since 2005: these are failures and defects in overcladding of the buildings.

2.3 Overcladding

When applying ETICS, attention should be paid to substrate where the ETICS are applied.

Both the panel block buildings from the second half of the 20th century and new houses have revealed problems resulting from poor treatment of the substrate.

An example is a remediated panel-block building with apartments. See (**Fig.7**). The paint on the overcladded façade changes its colour – from the attic along the peripheral cladding to the bottom.

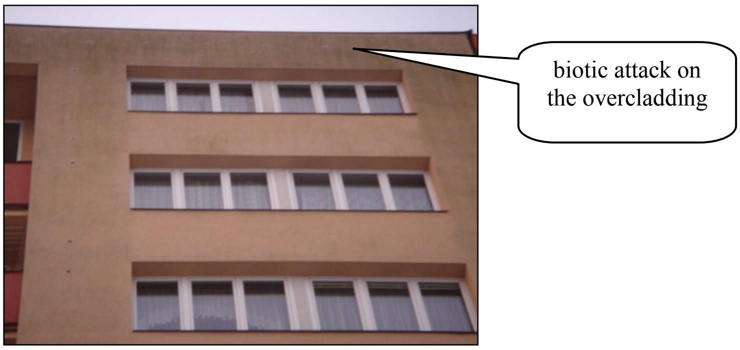


Fig. 7 *Overcladding of a panel-block multi-apartment building*

Biotic attack has been revealed in a sample of the overcladding. The samples were analysed in laboratories using a confocal microscope [11]. (**Fig.8**) shows photos taken in the confocal microscope – see cells and cell clusters (chains). A water extract of plaster samples was observed in a light steaming microscope. Microimages (**Fig.9**) prove growth of algae, fungi and cyanobacteria in the sample. Chroococcidiopsis sp. is the species of cyanobacteria. Green terrestrical algae (Chlorophycae) are definitely present there. In some places, colonies occur in the sample. Considering the type of the sample, it was not however possible to identify a particular species. Fungus hyphae and spores were also witnessed in the sample. Because the sample was rather small, it was not possible to identify the type of fungus/mould. This has proved presence of living organisms (algae, cyanobacteria and fungi) in a sample of plaster.

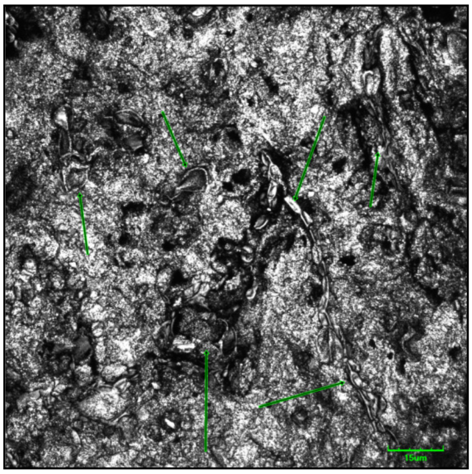


Fig. 8 *Analysing the sample in a confocal microscope and algae in the sample*

Fig. 9 *Presence of cyanobacteria, fungi*

Occurrence of living organisms, moss and algae in peripheral overcladding is a rather pressing issue. R. Büchli and P. Raschle [12] mention than secondary effects of biotic attack on overcladded facades were not expected, the reason being phenomena typical of construction physics. Research and innovations are often based on traditional approaches to the building industry – this is a try and error method which has been used in past for other building elements and structures.

All peripheral claddings in the regions of Ostrava and Karvina have been exposed to frequent emission and air pollution – this is an industrial territory and many industrial plants are located there. Those negative effects change the colour of the overcladded facade (the facades become dirty) and carbonate concrete in peripheral cladding consisting of panel blocks made from reinforced concrete, slag pumice and gas silicate concrete.

Carbonatation is more frequent in Karvina and Orlova where reinforcement of the panel block is often exposed in the peripheral cladding.

In spite of the fact that coal mines and some heavy industry plants were shut down in the 1980s and 1990s, air is still being polluted in the Moravia and Silesia (Note: there are four sources of air pollution in the region of Ostrava: industrial plants, local furnaces, transport and air emission from Poland). According to the Health Institute Study, two third of air pollution is caused by sources in Poland during heavily polluted days/smog days. In the Ostrava region, there are more than 2,100 sources of air pollution (400 of them are in Ostrava). Major producers of emission in Ostrava are (in case of all pollutants) big sources – the industry and energy business. In Ostrava, the sources are concentrated in ArcelorMittal's premises in Kuncice (where solid pollutants reach 425 g/m^2 per year) and in industrial sites in Marianske Hory-Vitkovice (where solid pollutants reach 51 to 185 g/m^2; www.dychamproostravu.cz [13]). (**Fig.10**) shows the map of pollution in the Czech Republic in January 2013 with 24 hour average values of solid dust particles PM_{10} (the PM10 particles). The figure proves clearly that the concentration of PM10 particles is rather high in the regions of Ostrava and Karvina. (The air quality index takes into consideration effects of emission on health of people. It uses 1 hour concentration of SO_2, NO_2, suspended particles of PM_{10}, 8 hour sliding concentration of of CO and, in summer from 1 April to 30 September, 1 hour concentration of ground ozone O_3) [14].

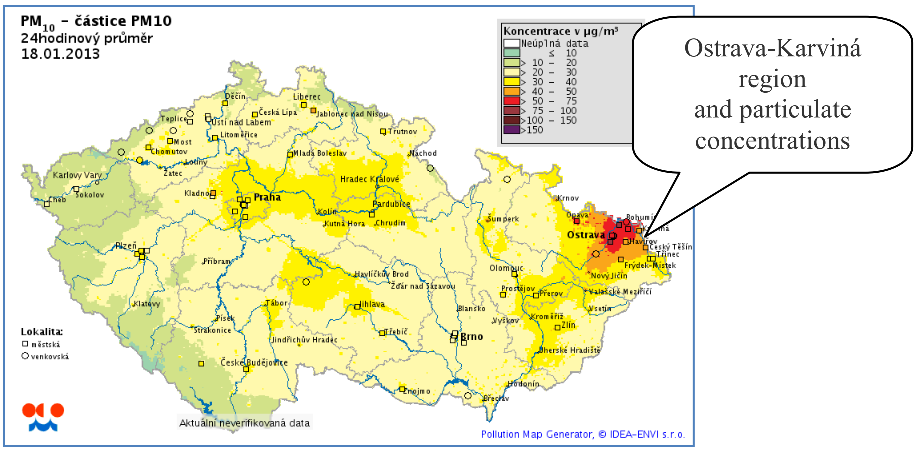


Fig. 10 *Air pollution in the Czech Republic (January 2013)*

3 Theory of decision-making and a multi-criterion analysis

If functions of a building on an industrial territory can be restored or if a building can be used for other purposes it is recommended to make decisions using a multi-criterion analysis. This tool makes it possible to choose the best solution which eliminates defects and failures/the best solution for complete remediation. The multi-criterion analysis can also minimise capital expenditure if renewable sources of energy are used and if energy demands of the building are as low as possible. There is not an only one solution. Therefore, the decision-making process should (1) include a multi-criterion analysis with certain criteria and sub-criteria which could assist future investors/decision-makers and could (2) help to find the best alternative for remediation of the building on the industrial site out of several possible remediation alternatives (3). The multi-criterion analysis has been used for preparation of an assessment model to be used for evaluation of the building and energy concept of buildings in brownfields. The assessment model has been prepared within CIDEAS (Centre for Integrated Design of Advanced Building Structures, 2005–2011), when dealing with the project named "Building and Energy Concept of Buildings in Brownfields"[15] [16]. A model situation for the multi-criterion analysis can be described in general as a set of permitted alternatives with a certain number of criteria (4), (5).

Alternative solutions

$$a_1, a_2 \ldots\ldots a_n \tag{1}$$

The number of decision-makers

$$e_1, e_2 \ldots\ldots\ldots e_n \tag{2}$$

A set of permissible alternatives

$$A = a_1 \ldots\ldots a_n \tag{3}$$

A number of assessment criteria

$$F = f_1 \ldots\ldots f_n\ , \rightarrow \max\ F = f_1 \ldots\ldots f_n \tag{4}$$

The decision-making situation

$$R = (e_1 \ldots.. e_n, a_1 \ldots.a_n, f_1 \ldots\ldots.f_n)$$
$$A \in (m, n) \rightarrow \max f_1 \ldots\ldots.f_n \qquad (5)$$

Using the multi-criterion analysis it is possible to choose the best alternative or the best remediation.

4 Conclusion

The monitoring of panel block buildings built in the second half of the 20th century has proved that there are not static cracks in vertical structures of the peripheral cladding (except for the VOS panel block system) which would jeopardise stability and of the building pursuant to [17]. Subsidence phenomena in foundation structures or cracks in the peripheral cladding have not been found in case of strip footing, foundation mats or foundation slabs. If neighbouring land subsided, the reason is poor or degraded drainage along the perimeter of the building. Reason for degradation and physical negligence of the peripheral cladding is the fact that no systemic care and maintenance has been performed in residential buildings which were built from panel blocks in the second half of the 20th century.

It follows from the monitoring of the new panel block apartment houses built since 2004, that defects and failures in the peripheral cladding are mostly heat defects.

In case of the ETICS cladding of the panel block buildings, the defects and failures were consequence of technology issues – for instance, poor preparation of the substrate, poor construction discipline, failure to keep consistent components or underestimation of weather.

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