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Analysis of damp in the substructure of a multi-family residential building – case study

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Abstract: This paper discusses dampness in an underground garage of a multi-family residential building on the basis of a case study. Due to high groundwater levels, the building substructure was constructed using W8 watertight concrete. This applies to both the foundation slab and substructure walls. However, leaks have occurred even though the used solutions were in theory designed to protect the building substructure from rainwater ingress. Macroscopic in situ tests, boreholes in the garage hall floor and foundation slab as well as laboratory test to determine the watertightness of the concrete were carried out to determine the cause of this construction defect, manifesting itself as damp in the structural elements in question.

Keywords: groundwater, damp, watertight concrete, damp proofing.

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1. Introduction

The problem of dampness in a building substructure's structural partitions is a current one, frequently discussed in scientific papers [1-3] and, in particular, in technical structural surveys [4-6]. This issue applies to structures at different stages of their life cycles encompassing historic structures, as exemplified by wall damp in a Gothic-Renaissance town hall [7], and relatively recently built structures, as exemplified by damp in a new terraced house [8].

A contemporary method for damp proofing building substructures entails the incorporation of W8 watertight concrete in "coat-free damp proofing" technology otherwise referred to as "non-bituminous proofing" [9]. The use of this technology eliminates the need for additional insulation layers, such as torching membrane. If technological requirements are met and the construction work is executed correctly W8 watertight concrete should provide sufficient protection against groundwater ingression into a building.

This case study details a process, which starts with identifying the causes of the problem (i.e. the appearance of damp in a building substructure) and ends with proposing an effective remedial programme.

2. Building substructure technical condition assessment

In the first place, even before the team decided to carry out a structural survey, a site visit took place. It was noted that despite the use of watertight concrete technology, known as "non-bituminous proofing", signs of damp were visible in the building substructure. Both the garage walls and the stairwell walls were affected. Troughs filled with aggregate were constructed around the garage floor near the walls to allow groundwater to evaporate, but also to assess the presence of groundwater ingress into the building. Figures 1 a) – 1 h) show damp on the walls of the building substructure.

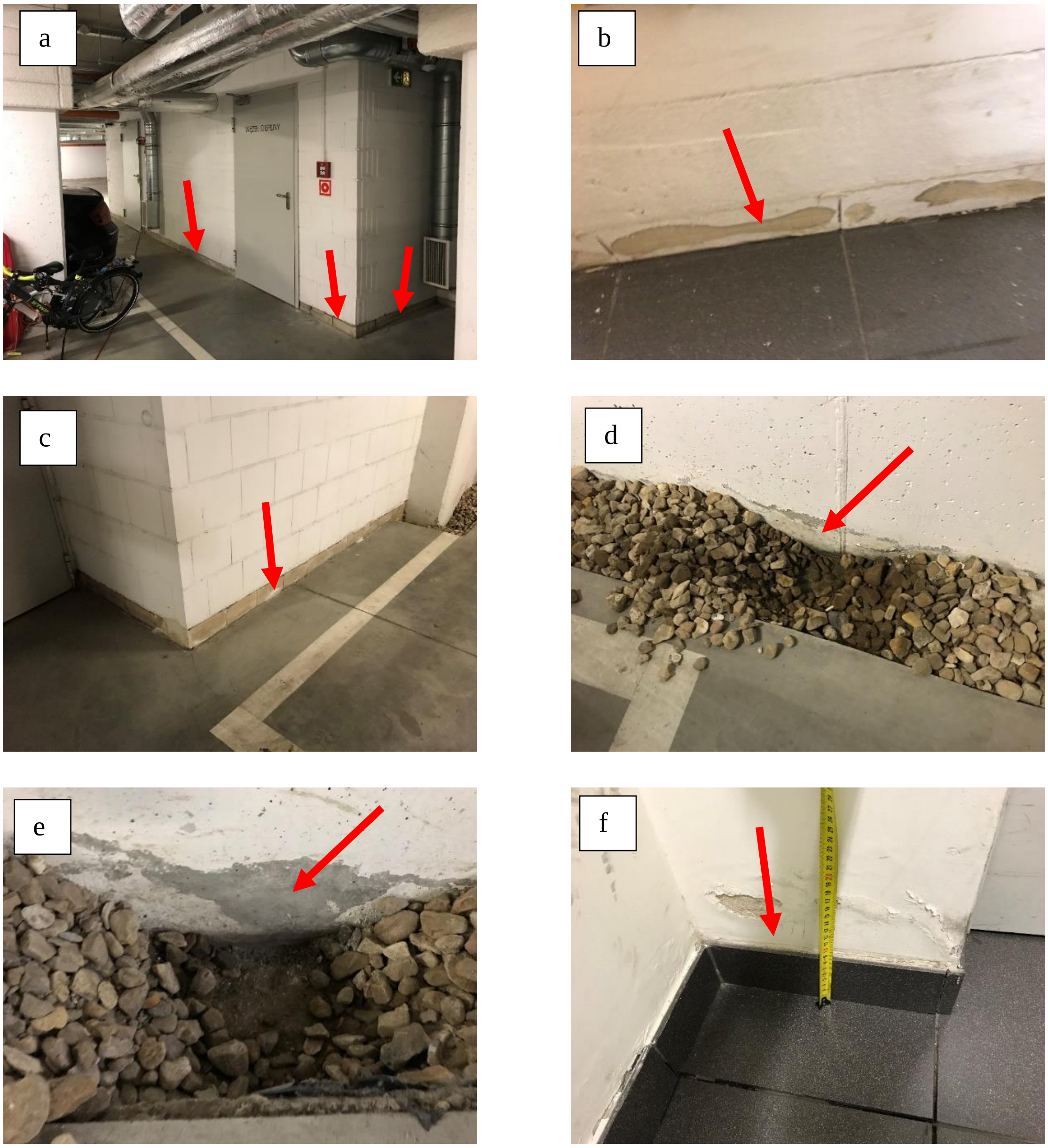

Fig. 1. Damp in the building substructure: a), b), c) walls of infrastructure rooms and resident's storage rooms; d), e) external walls of the underground garage; f), g), h) stairwell walls.

Analysing the as-built documentation on site, it was found that the following changes had been made to the drainage of the building substructure during the construction works:

- a gravel band was laid along the external walls of the building instead of trench drainage,
- inside the underground garage floor point drainage solutions were changed to trench drainage,
- a gravel band was laid in the floor along the internal faces of underground garage external walls.

3. Applied diagnostic methods

The following diagnostic tasks were carried out within the scope of the structural survey:

- site visit which entailed locating and thoroughly inspecting any existing damp;
- macroscopic organoleptic "in situ" tests;
- required excavations at the joint of the garage hall walls and floor;
- borehole in the garage hall floor and foundation slab;
- laboratory test to determine the watertightness class of the foundation slab concrete below the underground garage floor;
- moisture tests of the underground garage walls;
- soil compaction tests adjacent to the building using an SD 10 dynamic probe;
- borehole in the soil next to the building to determine the current groundwater level.

4. Test results

a) Borehole in the underground garage floor and foundation slab below the floor

A borehole (Figure 2.1) was performed to check compliance of the constructed layers with the design and to take a sample for watertightness testing of concrete from the underground garage floor and foundation slab. The borehole made it possible to determine that the foundation slab below an approximately 10 cm thick floor (Figure 2.2 and Figure 2.3) was 27.7 cm thick (Figure 2.4 and Figure 2.5). According to the design documentation, the foundation slab should be 40–60 cm thick. At the borehole there was no separation layer (made of black construction film for example) between the floor and the foundation slab.

The boreholes revealed the presence of groundwater between the underground garage floor and foundation slab. It was also found that, under dynamic loads applied to the top floor surface, the water between the floor and the foundation slab was pumped into the boreholes (Figure 2.6). The water level did not rise during the course of a 24 hours of observation.

A watertightness test was carried out on a sample from a borehole (Figure 2.5) drilled into the underground garage foundation slab under laboratory conditions. As a result of the test, the watertightness class was found to be W8 and is in accordance with the as-built documentation.

Fig. 2.1. Overall view of boreholes in the underground garage floor and foundation slab.

Fig. 2.2. Overall view of the borehole in the underground garage floor.

Fig. 2.3. Measuring the thickness of the borehole in the underground garage floor: 9.5 cm.

Fig. 2.4. Overall view of the borehole in the underground garage foundation slab.

Fig. 2.5. Measuring the thickness of the borehole in the underground garage foundation slab: 27.7 cm.

Fig. 2.6. The red arrow indicates water between the floor and the foundation slab.

b) Moisture tests of the underground garage external walls

Moisture tests of the underground garage external walls were carried out using a TANEL HGR – 9 moisture meter. Locations of moisture measurement points on the underground garage external walls are shown in Figure 3. The results for given measurement points are shown in the Table 1. Two wall moisture tests were carried out for each measurement point:

- right by the bottom of the gravel trough – shown in orange in Table 1;

- at approximately 10 cm above the bottom of the gravel trough – shown in green in Table 1.

The highest moisture levels were found at measurement points 1, 10 and 11 – readings taken right by the bottom of the gravel trough. The locations of these points may indicate areas where leaks are occurring at the joint between the foundation slab and the walls.

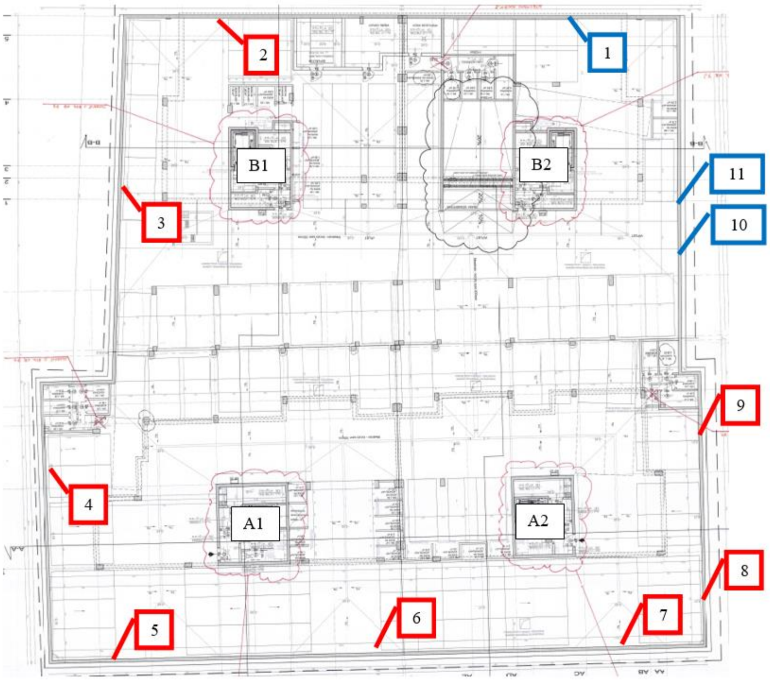

Fig. 3. Locations of moisture measurement points on the underground garage external walls are shown in red and blue. Measurement points with the highest moisture levels are shown in blue. For the purposes of this study stairwells are marked with the A1, A2, B1 and B2 symbols.

Table 1. Results of moisture measurement tests on the underground garage external walls in accordance with Figure 3 for given measurement points. Test results for measurements taken right by the bottom of the gravel trough are shown in orange; test results for measurements taken at approximately 10 cm above the bottom of the gravel trough are shown in green.

Measurement point number (according to Figure 3)	Test result [%]	Dry / Moist
1	2.1	Dry
	HI – off the scale	**Moist**
2	0.9	Dry
	2.0	Dry
3	1.6	Dry
	2.0	Dry
4	1.2	Dry
	1.6	Dry
5	1.4	Dry
	0.9	Dry

6	1.4	Dry
	2.3	Dry
7	1.3	Dry
	1.4	Dry
8	1.1	Dry
	1.9	Dry
9	1.4	Dry
	2.2	Dry
10	0.8	Dry
	HI – off the scale	**Moist**
11	2.6	Dry
	5.9	**Moist**

To verify the current subsurface and hydrological conditions and the condition of the compacted foundation backfill by the building, dynamic probing tests using a light DPL probe were performed (Figure 4) and a control borehole was drilled using a hand auger.

Up to a depth of 80 cm in the test soil the soil compaction index I_S was ≥ 0.98, and the compaction degree I_D of ≥ 0.55 was determined up to a depth of 90 cm. Highly compacted, compacted and moderately compacted soils were found from a depth of 220 cm. There were no reservations as to the compaction index and compaction degree in the tested soil.

Fig. 4. Overall view of a DPL dynamic probing soil compaction test.

A borehole in the subsoil was made next to the building, on the side of intense damp in the substructure. The borehole revealed the following strata:

- sand-gravel mix up to a depth of 60 cm below ground level;
- loamy sand between 60 and 100 cm below ground level;
- sandy loam between 100 and 350 cm below ground level;
- groundwater level at a depth of 290 cm below ground level.

The subsurface and hydrological conditions showed no significant deviations from those described in the as-built documentation.

Fig. 5. Overall view of the soil borehole made using a hand auger.

5. Occurrence of defects: a cause-and-effect analysis

The tests and visual inspections led to the following findings:

- on the basis of boreholes in the underground garage floor and watertightness test performed on the concrete from the foundation slab:
  - presence of groundwater between the underground garage floor and foundation slab;
  - under variable loads applied to the slab (thermal and use-associated), the water between the floor and the foundation slab is pumped into the boreholes;
  - the watertightness class of the foundation slab concrete at the borehole is W8;
- on the basis of moisture tests of the underground garage external walls:
  - the highest moisture levels were found at measurement points 1, 10 and 11 – readings taken right by the bottom of the gravel trough;
- on the basis of soil compaction tests adjacent to the building using a DPL dynamic probe:
  - no reservations as to the soil compaction levels;
- on the basis of a borehole in the substrate next to the building:
  - the subsurface and hydrological conditions showed no significant deviations from those described in the as-built documentation;
  - groundwater level was found at a depth of 290 cm below ground level.

In short, groundwater is seeping into the building despite the use of W8 watertight concrete, proper soil compaction around the building and groundwater levels not differing from those set forth at the time the design assumptions for this building were drafted.

Despite correct design assumptions and no evidence of obvious execution errors to date, the walls of the building remain damp, causing inconvenience to residents.

The highest moisture level was found at a measurement right by the bottom of the gravel trough and is shown in blue on Figure 3. As a result of the tests and visual inspection, it should be concluded that groundwater was penetrating into the underground garage at the junction between the external wall and the foundation slab at locations marked by a blue line in Figure 3. As the surface of the gravel trough along the external walls was not damp-proofed, groundwater was able to penetrate between the underground garage floor and foundation slab. Dynamic (generated by vehicle wheels) and thermal loads on the floor displaced the groundwater located between the underground garage floor and foundation slab.

At this point, one should note that according to expert experience, despite the use of W8 watertight concrete, the subsequent seepage of groundwater at the junction between structural elements – the walls and the foundation slab – is a common technical phenomenon. This is due to the fact that, in the vast majority of cases, construction contractors introduce a so-called “construction joint” to the concrete at this point, which impacts concrete watertightness at the junction of the structural elements.

As internal walls were not damp-proofed correctly (vertical damp insulation was not slotted between the internal walls and the floor) in resident’s storage rooms, infrastructure rooms, stairwell vestibules, lift vestibules and stairwells, groundwater (which is under the floor) causes the walls in these rooms to become damp.

6. Suggestion for renovation works’ remedial solutions

In view of the identified dampness in the building substructure’s structural partitions and with reference to the cause and effect relationship described above, we propose the following remedial works solutions:

- remove gravel from the trough in the floor along the internal faces of underground garage external walls;
- dry of the trough surfaces;
- perform damp-proof grouting at the joint between the underground garage external wall and foundation slab where leaks have become apparent;
- proof the joint between the floor and the foundation slab on the inside of the gravel trough in the garage,
- removal of scaling plaster on the internal walls of the substructure – lift shaft vestibules, stairwells and stairwell vestibules;
- removal of scaling plaster in stair runs;
- thorough drying of walls in lift shaft vestibules, stairwells and stairwell vestibules;
- thorough drying of walls in infrastructure rooms and resident’s storage rooms;
- thorough drying of stair runs’ side surfaces;
- gel grouting in walls of lift shaft vestibules, stairwells and stairwell vestibules as well as infrastructure rooms and resident’s storage rooms – injections should be performed as close as possible to the floor level;
- damp-proof grouting for stair runs structures – injections should be performed as close as possible to the floor level;
- layer based dpc in internal walls of lift shaft vestibules, stairwells and stairwell vestibules as well as walls of infrastructure rooms and resident’s storage rooms;
- remove the flooring layer around stairwells up to a width of approximately 20 cm;
- damp-proof the joint and additional insulation at the joint between stairwell walls and foundation slab;
- for walls in lift shaft vestibules, stairwells and stairwell vestibules the insulation should reach a height of 50 cm above the foundation slab;
- reconstruct the floor;
- for walls in infrastructure rooms and resident’s storage rooms the insulation should reach the applied film in the plinth area;

- reconstruct plasterwork (it is advisable to apply “breathable” restoration plasters) on the walls of stairwells, lift shaft vestibules, stairwell vestibules and the side surface of stair runs;

Once the construction repair works have been performed, ongoing checks should be carried out on the level of damp in the building substructure’s structural partitions. If new localised damp is found, the steps described above should be repeated.

Groundwater is also present between the underground garage floor and foundation slab. Complete drying of the garage foundation slab would require the floor layer to be removed which is not economically feasible. Thus, despite the implementation of the above remedial programme, localised damp in structural partitions may appear.

7. Conclusions

Based on the case study discussed in this article, it should be concluded that the use of W8 watertight concrete without thorough damp-proofing of the junction between the foundation slab and the external walls does not guarantee full protection against groundwater penetrating into the building. Such damp-proofing may entail the application of a special tape (rubber, steel or bentonite) that stops the flow of water into the building. It should be applied in accordance with the technological requirements for surface preparation and careful application, as carelessness on the part of contractors can lead to leaks [2].

It is difficult to determine the exact locations of groundwater seepage into building substructures when the upper floor layers have already been laid. In this case, it would be good practice to lay them out as late as possible so that locations of any leaks can be easily located. At that stage, damp-proofing and repairing them would be an easier and less expensive procedure than removing previously laid layers and then re-applying them.

It is also advisable to install insulation at the joint between the internal walls and the foundation slab. This is a fairly simple procedure to implement during the construction process, one which effectively prevents damp from rising in these walls.

There will always be moisture in underground garages, even if brought by the vehicles parked there – it is necessary to ensure effective drainage through a sealed drainage system. The use of gravel troughs inside the substructure makes it possible in this case to collect and drain water from under the floor, which is beneficial if any moisture appears underneath it. It is important to remember to avoid filling in these troughs with water, for example when washing the floor.

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