The cost of repairing damage caused by the inadequate demolition of walls in a multi-family building

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Abstract. The article analyses the cost aspects related to the inappropriate demolition of interior walls in a multi-family building in Wroclaw. As a result of demolition and dismantle works on the ground floor of a multi-family building, which was erected using traditional masonry technology, the structural elements on the upper floors were damaged. The expertise report and performed tests confirmed the cause of damage, and the condition of the structure, resulting from the conducted works, was analysed. Recommendations for repairing the structure, and an analysis of the costs associated with the repair were also specified.

1. Introduction
A housing estate is an urban unit that is characterized by a unified residential development that consists of a set of residential buildings with an infrastructure, service and commercial facilities, and green areas [1]. In typical multi-family buildings, commercial premises, i.e. rooms intended for utility purposes, are usually located on the ground floor [2].

Commercial premises, depending on their function, have strict rules regarding their use [3]. A very common practice when changing the function of commercial premises is the enlargement of interior space. In order to achieve this, it is necessary to perform dismantling works of partition walls. Partition walls are internal, non-structural, and non-load bearing [4], and their main function is to divide premises into smaller rooms. As indicated in construction practice, a number of mistakes can be made during demolition and dismantle works. They result from the ignorance of the static behaviour of a structure, which in turn can lead to the occurrence of damage. There are many different methods for repairing damaged structural elements of walls, e.g. reinforcing masonry walls with FRP fibers [5] or using repair anchors [6] or the possibility of using post-tensioned concrete rocking walls [7]. In each case useful in the assessment of technical state of masonry walls are non-destructive methods [8]. Therefore, when planning demolition works, it is necessary to know the details of the design documentation and to determine the correct technology of conducting the works, while at the same time also taking into account the spatial rigidity and stability of the building [9].

The article presents an example of wall damage in a 20-year old multi-family building, which occurred as a result of the inadequate demolition of separating walls. The multi-family residential building was built in the year 2000 in Wroclaw. The building was erected using traditional masonry technology [10]. During the adaptation works, which involved a change in the function of the rooms and the demolition of the internal walls, numerous scratches and cracks were revealed both in the thin partition walls and in the thick walls separating apartments on the fourth and fifth floors (two-story apartments).
2. Research methodology
The article presents the impact of the incorrect demolition of the partition walls on the damage to the building's structural elements. Factors that may have affected the damage were analysed, and economic analysis of damage repairs was conducted with regards to the costs that were generated in one of the subsequent stages of the life cycle of the building, namely in the operational and maintenance phase. These phases include, among others, the costs of repairs and maintenance incurred during the operation of the facility [11].

In the article, a simple Life-Cycle Cost Analysis (LCCA) method was used to estimate the components of the cost of the renovation works, i.e. an engineering method of cost estimation (direct testing, component by component) without the discounting process [12].

3. Description of the structure and damage of the building
The investigated multi-family building was designed in 1999 and built in 2000. It is a five-storey building with two-storey flats on the fourth floor, which translated into a different division of the flats on floors 1 to 3 and also 4 to 5. This division of the flats on the last two floors required the use of additional partition walls with adequate sound insulation between the flats. These walls were made of aerated concrete and were 24 cm thick. The weight of the walls additionally loaded the ceilings, which meant that the floor slabs had to be strengthened in the central part of the building.

The walls and ceiling of the ground floor were made of monolithic concrete, while on the higher floors there were Filigran type ceilings with variously reinforced monolithic parts. The load-bearing and partition walls were made of silicate blocks and ceramic blocks with a thickness of 24 and 8(12) cm using traditional masonry technology. These walls suffered the most scratches during the operational phase due to rheological deflections of the ceilings. From the possessed documentation, it was not possible to determine whether the designer had determined the method and order of making the partition walls and floors. The documentation also lacked information about the conducted order of executing the above-mentioned works during the erection and modernization of the building.

![Figure 1. Damage in walls and ceilings.](image-url)
In the investigated commercial premises located on the ground floor of the building, construction works started at the beginning of 2019 and consisted of the demolishing of parts of the internal partitions (using electric tools), making a new ventilation, and erecting new walls. After the start of the planned construction works, apartment tenants, whose flats were located next to the same staircase, reported many irregularities and damage, such as scratches, cracks, and a lot of loosening of the wall's surface, which forced the contractor to suspend the works. The facility manager commissioned the execution of technical expertise. During an on-site visit, no significant damage was found in the ceilings, which indicates that the ultimate limit state and safety of the structure were maintained. However, the serviceability limit state was not maintained, as was evidenced by numerous scratches and cracks in the walls. A lot of damage was observed within the walls in the form of scratches and cracks, and also in the form of gaps between the load-bearing walls and partition walls that were based on the ceilings (figure 1).

4. Analysis of research and observation results
Preliminary observations of the partition walls showed that the main cause of damage involved the deflections of ceilings that exceeded permissible values, and therefore ceiling deflection measurements were also conducted. The measurements were made using the geodetic method, and the obtained ceiling deflections on individual floors (for the limit value of 1/500 = 12.3mm [13]) were as follows:

- ceiling above the ground floor - from 12.5 to 17.5 mm,
- ceiling above the first floor - approx. 13.5 mm,
- ceiling above the second floor - 14.3 mm,
- ceiling above the third floor - no consent was obtained for the measurements,
- ceiling above the 4th floor - up to 7.5 mm <12.3 mm.

A detailed analysis of the obtained measurement results showed that:

- the deflection of the ceiling above the ground floor exceeded the value of the permissible ceiling deflection (the permissible value: 12.3 mm). The ceiling above the ground floor had the largest deflection, which ranged from 12.5 to 17.5 mm. Such a large deflection is a consequence of the adopted method of supporting the ceiling, because the partition walls on the ground floor partly supported the ceiling before their demolition. It should be stated that the exceeding of the permissible deflection is not large and does not threaten the safety of the reinforced concrete structure, but it does pose a threat to the filling elements, i.e. partition walls. A similar situation occurred above the first and second floors (deflection was equal to 13.5 mm and 14.3 mm, respectively),
- the ceiling above the third floor was strengthened due to the different layout of the apartments on the last two floors of the building, and is heavily loaded with 24 cm thick aerated concrete walls. Measurements of the deflections of this ceiling would be interesting, but the consent of the apartment owners for measurements was not obtained,
- the ceiling above the top IV floor deformed relatively little (the deflection value was less than 7.5 mm). According to the authors, the small deflection value is caused by the fact that this is the highest storey and there are no higher floors from which loads could be transferred through the partition walls. Moreover, there are probably vaults created in the walls of the highest storey, which is indicated by a horizontal crack above the ceiling.

Based on the obtained measurements, it can be concluded that the exceeding of the permissible deflection is not large, although its effects can be seen to be significant. The building has a lot of damage (scratches, cracks) in the walls based on the ceilings. Almost 20 years of using the building, which was erected on quite unstable ground, as well as improperly carried out demolition and dismantling works, contributed to the rheological deflection of the ceilings and the leaning of them on the partition walls. As a result of changes in the load scheme, excessive stresses appeared on the walls, which is why scratches occurred most often between the walls and ceilings and between the partition and load-bearing walls.
Vibrations caused by inadequately performed demolition works in the premises on the ground floor also affected the numerous scratches and the chipping of plaster along the scratches. During the demolition of the partition walls on the ground floor with the use of electric tools, which caused large vibrations transmitted to the structure, the ceilings were not supported next to the walls that were dismantled. This caused the walls to be scratched on subsequent floors. The vibrations additionally caused the appearance of numerous scratches on the upper floors in the elements in which the state of stress was close to the limit values.

In addition, it is worth paying attention to the fact that there are balcony slabs of considerable size made on the gable wall of the investigated building (figure 2). The span of three balconies is from 1.40 to 2.00 m, and with their considerable length of about 8.0 m they may have an impact on additional damage to the apartment walls due to inadequate demolition and modernization works in the premises on the ground floor.

According to the authors, the damage could be minimized if the partition walls were connected to the load-bearing walls in accordance with the principles of building art and also by being separated from the ceilings using flexible felt spacers, and if the building had properly executed foundations - with an appropriate soil compaction under the foundations during the construction phase.

To sum up, it can be stated that the investigated building did not show any signs of threat to the structure's safety (no damage of the load-bearing elements), and the measured ceiling deflections indicate a safe condition of the structure. However, the non-load bearing components and their connections with the load-bearing walls required repair.
5. Propositions of damage repairs

The building has a lot of damage (scratches, cracks) in the walls based on the ceilings, which was caused by the deflections of the ceilings. However, this damage does not threaten the safety of the structure. Some of the damage arose during the construction phase of the building, some during the operational phase, and a lot during the demolition and dismantling works in the ground floor premises. Damage, in particular scratches and cracks on the walls of residential buildings, are a typical execution error and a consequence of improper renovation works [14]. In the investigated building, vibrations that were accompanying the demolitions and which were transferred along the load-bearing walls and ceilings were the main reason for the occurrence of a significant number of scratches on the upper floors. Some of the scratches were not removed earlier, despite being created before the works on the ground floor were carried out.

The authors of the article proposed the following method of repairing the scratches and gaps in the walls and at the connections of the partition walls with the load-bearing walls:

- it is recommended to anchor vertical contacts between the partition walls and load-bearing walls using connectors at a height of 20 cm, 70 cm and 150 cm from the top of the ceiling,
- as the anchors - using steel expansion bolts screwed at an angle of 90°, or flat galvanized bars bent at an angle of 90° with a thickness of 4 mm mounted in carved recesses in 3 of the levels indicated above,
- widening the scratches, and after priming, filling them with putty reinforced with glass fibres, plaster or gypsum,
- forging damaged ceramic tiles in rooms and installing new ones.

6. Cost analysis of damage repairs

The authors and the insurer estimated the presented recommendations for repairing the damage with regards to cost. The following stages of works were proposed:

- the anchoring of the partition walls with the load-bearing walls in places where they are detached,
- the repairing of vertical, horizontal and diagonal scratches in partitions as described in section 4,
- the replacement of damaged glaze tiles in the kitchens and bathrooms,
- the execution of painting works for the entire area under renovation,
- the execution of preparatory and cleaning works including: removal of debris, removal of tiles, protection of floors and other necessary elements during works, disassembly of bathroom and kitchen installations, etc.

Above the premises on the ground floor in which the works were carried out, 13 apartments with areas ranging from 50-95 m² were located. The tenants of two apartments from the first and second floors with an area of about 80 m² in which the largest damage occurred applied to the insurance company for a valuation of the cost of repairing the damage. The insurer's initial valuation was PLN 3 500 – 4 500. The apartment owners questioned the amount of the valuation and scope of work, and commissioned to the authors of the paper to verify the costs of the works. Renovation works were carried out in the summer months, and the cost of renovating the flat within the required scope was equal to PLN 12 000. The valuation of the insurance company was three times lower and did not include all the works that were necessary and executed during the renovation.

The analysis of the estimated cost of repairing the damage was made with the following assumptions:

- the renovation concerns half of the premises above the renovated ground floor and covers half of the total floor area of the apartments. The total area of flats is 650 m², and therefore the area undergoing renovation works is equal to 325 m²,
- the estimated cost of the renovation works was referred to 1 m² of the flat's area, taking into account the total cost of the full scope of the works, which was valued based on the bill of quantities, catalogues of inputs, and also current rates of labour, equipment and machinery using cost estimation software that is available on the Polish market,
• the scope of properly completed renovation works also included the placing of supports under the demolished walls and the manual dismantling of the partition walls,
• the conducted analysis also included the cost of correct compaction of soil under the foundations at the stage of erecting the building under its entire surface. As demonstrated, incorrect soil compaction under the foundations during the construction phase had an indirect impact on the occurrence of damage.

Table 1 presents the analysis of the estimated damage repair costs.

Table 1. Analysis of the estimated costs of repairing damages and the increase in expenditure on the modernization of the commercial premises

| Type of cost                                                                 | Total cost [PLN] | Average cost per 1 m² of floor space [PLN/m²] | Renovation cost per 325 m² of floor space [PLN] | Renovation cost per 325 m² of floor space + expertise report [PLN] |
|------------------------------------------------------------------------------|------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|
| **DAMAGE REPAIRS**                                                           |                  |                                               |                                               |                                                              |
| Valuation of the insurer - average value per 80 m² of premises provided by insurer 1¹ | 4 000            | 50                                            | 16 250                                        | 22 250                                                       |
| Author's valuation/valuation of renovation company 1¹                         | 12 000           | 150                                           | 48 750                                        | 54 750                                                       |
| Technical expertise report ²                                                   | 6 000            | 18.46                                         |                                               |                                                              |
| **INCREASE OF EXPENDITURE ON THE MODERNIZATION OF THE COMMERCIAL PREMISES - INVESTOR'S COST** |                  |                                               |                                               |                                                              |
| Correctly performed works:                                                    |                  |                                               |                                               |                                                              |
| 1. manual demolition of walls ΔT=132 r-g, ΔR= 2 224 PLN                       | 4 474            | 13.76                                         |                                               |                                                              |
| 2. positioning of supports 10 pcs./week of work, ΔS=250 PLN                   | 1 500            | 2.30                                          |                                               |                                                              |
| Compaction of soil in the phase of erecting the building per 650 m² of the floor surface according to assumptions ³ |                  |                                               |                                               |                                                              |

* per 80 m² of premises, according to the scope of works of the insurer ¹
** per 325 m² of floor surface, according to assumptions ²
*** per 650 m² of floor surface, according to assumptions ³

The values presented in table 1 show that the correct manual dismantling of the walls and the executing of the support of ceilings generates an increase in the cost of renovation works on the ground floor by approx. PLN 4 500 and extends the work time by 132 man-hours, which, when employing a 6-person work crew, extends the work time by 2 days.

The actual time of completed works amounted to 30 working days. Correct execution of the renovation works, including the manual dismantling of the walls and the positioning of supports, would extend the work to 32 working days. Extending the working time by only 2 working days does not significantly affect the total implementation time.

The authors of the article did not achieve a detailed valuation of works carried out by the insurance company for individual residential premises, however, the proposed amount of PLN 3 500 to 4 500 for the renovation of an apartment of approx. 90 m² gives the total renovation cost of the damaged premises of PLN 22 500 (table 1). When referring to the real value of the necessary renovation costs that are equal to PLN 54 750, an underestimation of about 58.1% was obtained.
7. Summary and conclusions
As a result of the analysis of the case study, the following was indicated:

- in the investigated building, excessive stresses on the walls occurred as a result of changing the load scheme, which in turn resulted in the scratches,
- the formation of numerous scratches and chipping of parts of plaster along the scratches was affected by vibrations caused by inadequately performed demolition works in the premises on the ground floor,
- an increase in the cost of renovation works by about PLN 4 500 in the premises on the ground floor, and also an extension of the work execution time by 2 days, could have prevented the need for repair works in the premises above the ground floor for an amount 12 times higher.

In conclusion we also need to realise is that incorrect planning and the execution of the demolition and dismantling works of the internal partition walls in a building that was made using traditional masonry technology can cause a lot of damage (scratches and cracks) to the walls, what has been proved in this work.

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