Journal of Civil Engineering and Architecture 9 (2015) 268-273
doi: 10.17265/1934-7359/2015.03.004

Operation Phase Problems of Prefabricated Residential Buildings with Integrated Autoclaved Aerated Concrete Panel Walls

Stanisław Fic and Danuta Barnat-Hunek

Faculty of Civil Engineering and Architecture, Lublin University of Technology, Lublin 20-618, Poland

Abstract: Growing technical problems with the maintenance of precast concrete housing stock result in the search for efficient repair methods. The paper analyses the effects of flaws in the design concept and assembly accuracy of integrated AAC (autoclaved aerated concrete) panel walls, type GWO (Gazobetonowa Wielka Płyta Osłonowa which means large cover panel from aerated concrete in English), used as curtain walls in a system of precast concrete housing blocks erected in Lublin. The results of in-situ observations and laboratory tests of the panel walls have been described, and the opinion on the further use of these elements has been presented. As for the analysed case, there is no possibility of replacing damaged elements, thus, additional reinforcement with steel tendons has been proposed as a repair measure.

Key words: AAC, precast concrete housing, cracks, insulation.

1. Introduction

Residential buildings in the precast concrete housing W-70 system, implemented between the years 1970 and 1990, were characterized by fairly complex processes of production in house factories as well as during the on-site assembly [1, 2]. These complex processes contributed to the formation of many defects in constructed and operated buildings as a consequence of dishonoring the technological regimes. However, over the years, the system has been modified and redesigned. The changes mainly concerned the production process and subsequent use of curtain walls in buildings. In addition, forced installation of the panels by rectification of the screws, difficulty in performing nodes which connect different prefabricates provided the basis for the development and implementation of an integrated curtain wall system signed as GWO (Gazobetonowa Wielka Płyta Osłonowa which means large cover panel from aerated concrete in English) [3-6] in eastern Poland.

The introduction of more stringent requirements for thermal protection and energy conservation was the basis for performing the expertise of existing residential buildings managed by housing associations in the region of Lublin. Visible cracks of AAC (autoclaved aerated concrete) panels in buildings which have been in operation for several years were pointed out by customers. The starting point was to show whether it is possible to insulate curtain walls and cover existing damage of wall panels by applying additional downforce, as well as to demonstrate the possibility of further safe operation.

Survey, conducted on existing buildings, highlighted the need for the detailed study and analysis. The aim of the study was to identify the reasons for the damage, to provide the ways to repair existing ones and to discuss the possibility of insulation of partitions.

Corresponding author: Stanisław Fic, associate professor, research fields: building materials, and passive and low-energy housing. E-mail: s.fic@pollub.pl.

2. Basic Principles of Installation Technology of Merged Panels in Residential Buildings

The essence of installation technology of integrated curtain panel walls on buildings referred to their suspension in the upper part of the special steel brackets. Depending on the length of GWO panels, suspension was carried out on two or three brackets. Steel brackets were attached to the external ceiling hollow slabs of a thickness of 22 cm, with a special supporting rib. The plate suspended on the brackets was levelled by screws placed on the steel tie-beam (Figs. 1 and 2). In the early days of AAC panel systems' use, the exact type of the steel of the hangers was not determined. As a result of the research carried out at the BRI (Building Research Institute) in the 1980s, it was recommended to execute hangers from H13N4G9 steel. Nevertheless, in reality, St3SX steel fasteners were used, and on the basis of the elements diagnosis, galvanized St0S steel rods were found [7-10].

The individual GWO panels were made by merging the strips of autoclaved aerated concrete of 500 classes with a thickness of 30 cm. Strips made of autoclaved aerated concrete were placed horizontally in the upper zone of header, in the bottom under the window, and vertically—functioning as pillars between windows. Merging of the walls took place through pre-drilled holes, through which steel rods were postponed—tie rods with threaded ends (Fig. 1) [4]. Empty voids around steel tie rods were filled by injection with cement mortar. For example, the weight of a 3.60 m length GWO plate was approximately about 2,000 kg, and a 6.00 m length GWO plate—3,000 kg [5].

In the adopted solution, a plate suspended on the brackets could not impose with its own weight, a plate hanging below. Slots at the brackets should be filled with cement mortar and perimeter spaces with the width of about 16 mm between the plates should be sealed by using a rope and permanently elastic material.

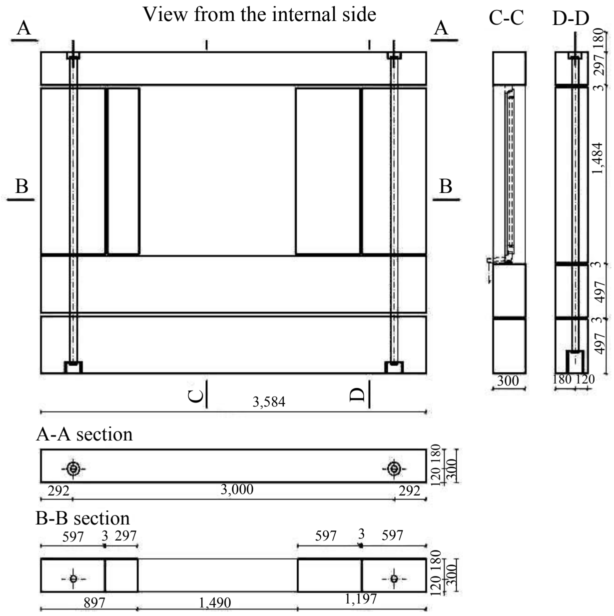


Fig. 1 GWO curtain wall in accordance with catalog (units in mm) [2].

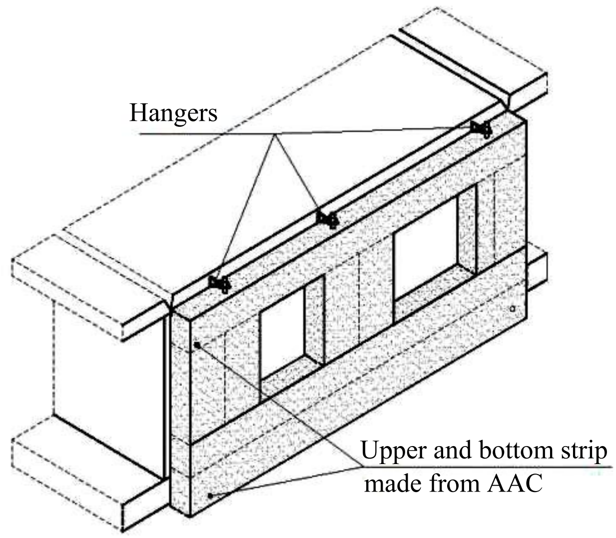


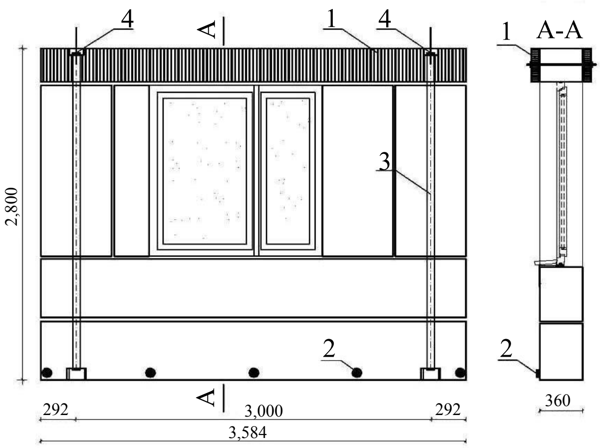
Fig. 2 The scheme of suspension of GWO panel.

3. Program of Research

Research range has been described [11], which was performed on one of the eight residential buildings with a height of 10 floors in the W-70 system with merged curtain wall, having a thickness of 30 cm. In the first place, the geodetic measurements of the verticality of individual plates in the facades of the building were made. Measurements were carried out on the 115 wall elements which showed differences in vertical deviation between the data in the upper point of suspension, and the bottom edge of wall panel. In the 28 elements, the difference was from 15 mm to 38 mm, the vertical deviation in the remaining 87 measurements was in range of 6~13 mm [3].

The next stage of the research was to measure the vertical displacement of selected panels and determine the deflection on the steel supports at probationary load. The scheme of the load method is shown in Fig. 3.

Deformation measured by the clock strain gauge in the bottom part of plates (Fig. 4) showed a large variation in the length of the plates, from 1 mm to 12 mm. However, steel brackets strain measurements were small and ranged from 1 mm to 2 mm.



1—test load 100 kg/m
2—strain clock gauges
3—tie rods in the panel
4—strain clock gauges in the point of suspension

Fig. 3 Scheme of GWO plate load, external view (units in mm).

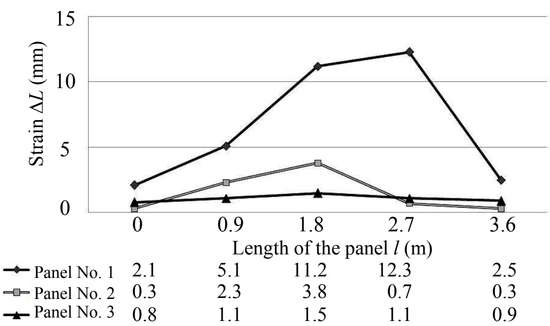


Fig. 4 Sample strain of GWO plate after additional load q = 100 kg/m in bottom of the panel.

The main task of building research was to determine the causes of cracks in slabs. The conducted survey showed that about 20% of the panels in all tested buildings have this type of damage. Scratches and cracks most frequently occur in lintel stripes above the window openings and in the lower stripes of panel. Other kinds of panels damage were visible in the joints connecting the stripes made of autoclaved aerated concrete. The phenomenon of connections delamination most frequently occurred in the horizontal and vertical directions of pillars between windows. The instances of panels damage are shown in Fig. 5.

4. Analysis of the Results

The results obtained from geodetic measurements can indicate inaccuracies in the assembly of the ceiling slabs on external and internal load-bearing walls. The assembly defects were consequent upon the differences in face planes of load-bearing walls, stacked hollow ceiling slabs and created displacements in the vertical direction.

Outcrops ocurring in the vicinity of the metal brackets showed that GWO plates suspended by means of tie rods were properly made. Steel suspension

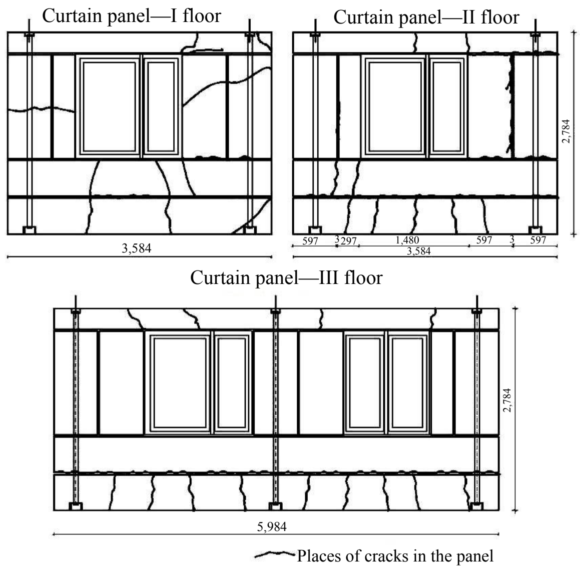


Fig. 5 Delamination in the joints and cracks in the panel stripes at various floors of building (units in mm).

elements in outcrops were galvanized and raised no objections in the area of excessive damage caused by corrosion. Nevertheless, the use of galvanized steel, which appeared too fragile to carry hangers, did not fulfill its function. In many cases, there showed errors both in the deployment and the number of hangers, which is confirmed by the findings of other authors' research [7, 12, 13].

Significant defects observed in the buildings included cracks in individual GWO panels which can be divided into:

- defects caused by deformation of steel in bars—tie rods;
- damage resulting from improper assembly;
- deformation caused by temperature;
- damage caused by transport and improper storage on site.

In the present case, there was no possibility of taking samples from the object to carrying out laboratory tests. Steel has the ability to deform, creep and relax. Hence in the tie rods which connect curtain panels, round steel St3S rods were used which have the tensile strength of 380~400 MPa, the value of yield strength of 240 MPa and possible elongation to 27% [3]. Yet, the calculation of the elongation of steel tie rods is possible to be executed by assuming the maximum temperature on the surface of the curtain panel of about 43 °C during the summer time. Because of the difference in temperature between the outer surface of plate and steel rods, disposed in the hole of hollow slab at a distance of 12 cm from the external side, the elongation of rods of about 1.68×10^{-3} m takes place. This contributes to the creation of delaminations and cracks in the joints between the stripes from autoclaved aerated concrete. The uncontrolled transfer of loads from the top plate to the bottom was observed due to the assembly errors. The spaces between the panels had to be filled with material which is permanently elastic, yet not mortar, as in the present case. After the execution of probationary load and making the strain gauge readings unacceptable, load transfer from top panel to bottom was observed. There was more damage in the joints of stripes and in individual elements in panels on the lower floors. Geodetic measurements of the verticality of the suspended panels constitute another study that confirmed irregularities of assembly. The lack of verticality of many panels was observed and the differences between the upper and lower measurement of panels with the height of 2.80 m amounted to 35 mm. Therefore, the eccentric and wrong stability of some curtain panels appeared. In addition, the assessment of the technical condition of steel components in terms of corrosion, which showed good condition of hangers and galvanized rods, was also performed.

5. Proposals for the Repair of Curtain Walls

In the case of specificities and continuous operation of the building, it is not possible to replace damaged, cracked panels. Thus, to prevent the demonstrated mechanism of panels destruction, it was resolved to reduce the concentration of compressive stresses, transmitted from the top plate to the bottom by strengthening and safeguarding individual plates with additional steel tie rods, which is shown in Figs. 6 and 7.

The method of strengthening referred to applying

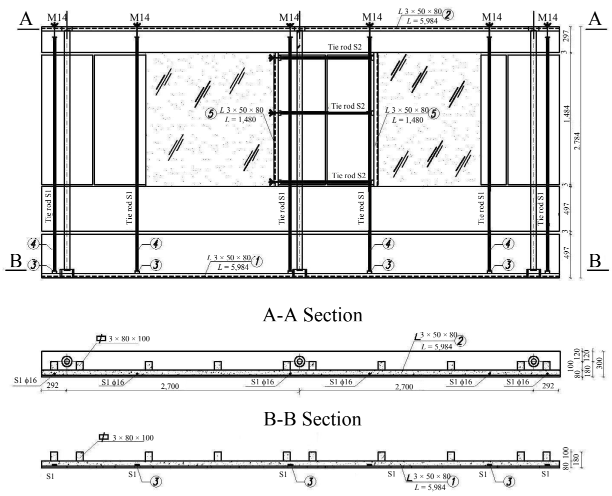


Fig. 6 Strengthening of pillar between windows and GWO curtain panel (units in mm).

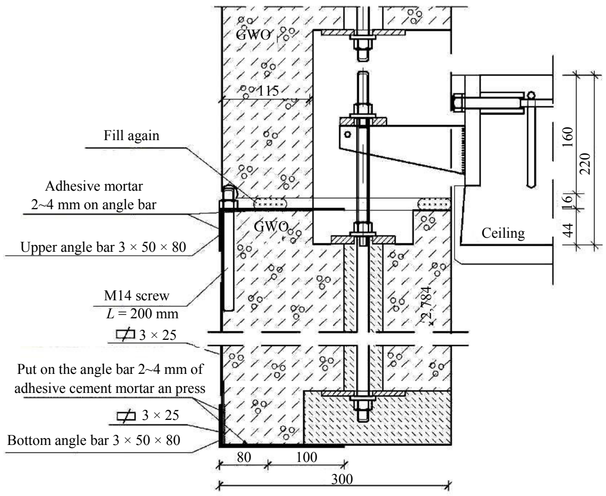


Fig. 7 The detail of GWO panel suspension on the bracket with strengthening (vertical section, units in mm).

the upper and lower angle bars of 3 × 50 × 80 mm connected through flat bars of 3 × 25 mm, twisted by the use of M14 screws. In order to angle bars, steel paws of 3 × 80 × 100 mm were welded. In the site of flat bars, external plaster should be gently forged to a thickness of 4~5 mm.

Moreover, pillars between windows were strengthened in the similar way (Fig. 6). The joints between the panels were cleaned and filled with plastic putty. Firstly, the vertical tie rods S1 should be made, and secondly, the pillar between windows should be supported by using tie rods S2.

The cross section of vertical tie rod is presented in Fig. 7.

6. Conclusions

The proposals for the development and implementation of the GWO curtain wall in the place of the three-layer outer wall was directed to identify better and easier solutions in the manufacture, installation and operation of buildings. However, as it was shown by the operating conditions, the applying GWO wall burdened a number of defects:

- The use of suspension of the panels by using two or three brackets is an unusual solution. While a static scheme can be considered as proper, the adoption of such a solution did not consider strain and relaxation of steel in time, in the case of structural tie rods which appears to be problematic. In the studies of GWO system, the analysis and calculations explaining the effect of strain over time and changes in the stresses in tie rods even under such factors as temperature were not found;
- There appeared technical difficulties in determining the forces in the tie bars during the study. The observed strain and damage of strips can indicate that the strength of the individual tie rods within a single panel can differ significantly as a result of twisting the screw after the manufacture in the prefabrication factory. Such a defect can be confirmed by the variation in the size of delamination between the stripes running through the mortar joint;
- The important factor contributing to the formation of cracks in the strips was a “concreting” panel often at the bottom in the entire width. This created an unintended support, hence the static scheme was changed so as the weight of top plate was transferred to the bottom plate;
- Delamination between the stripes at the joints was probably due to the elongation of tie rods. This is particularly seen between the elements in pillars between windows. It should also be stated that the first damage and slack of stripes connections could arise during transportation, while the elements were transported to the construction site at a distance of 70~80 km from the plant fabrication.

On the whole, the strengthening of cracked GWO curtain panels requires a detailed analysis of the reasons for damage and the selection of an adequate way of strengthening. In this case, the strengthening of panels by using steel tie rods was proposed which, to a large extent, should be insensitive to the displacement and strains caused by load and temperature difference, and also secure it from further degradation of panels.

Acknowledgments

The study was performed at Lublin University of Technology in Poland as part of research project

S-14/B2012.

References

[1] Dębowski, J. 2012. "Cała Prawda o Wielkiej Płycie (The Whole Truth about Prefabricated Concrete Buildings)." *Przegląd Budowlany (Construction Overview)* 83 (9): 28-35. (in Polish)

[2] Dębowski, J. 2012. "Typowe Uszkodzenia w Budynkach Wielkopłytowych (Typical Forms of Damage in Prefabricated Concrete Buildings)." *Przegląd Budowlany (Onstruction Overview)* 83 (10): 25-32. (in Polish)

[3] Fic, S., and Barnat-Hunek, D. 2012. "Analiza Uszkodzeń i Propozycja Naprawy Scalonych Płyt Zewnętrznych z Dyli z Betonu Komórkowego Zastosowanych w Systemie W-70 (Analysis of Damage and Repair Proposal of Integrated External Plates in the W-70 System)." *Materiały Budowlane (Building Materials)* 9: 66-7. (in Polish)

[4] Inwestprojekt. 1979. *Katalog Elementów. Ściana Scalona W-70 (Catalog of Items, W-70 Integrated Wall).* Lublin: Inwestprojekt. (in Polish)

[5] Biliński, T., and Gaczek, W. 1982. *Systemy Uprzemysłowionego Budownictwa Ogólnego (Systems of Industrial General Construction).* Warszawa: PWN (Polish Scientific Publishers). (in Polish)

[6] Dzierżewicz, Z., and Starosolski, W. 2010. *Systemy Budownictwa Wielkopłytowego w Polsce w Latach 1970-1985. Przegląd Rozwiązań Materiałowych, Technologicznych i Konstrukcyjnych (Systems of Big Plate Buildings in Poland, in the Years 1970-1985. Overview of Material, Technological and Construction Solutions).* Warszawa: Oficyna Wolters Kluwer Business. (in Polish)

[7] Krentowski, J., and Tribiłło, R. 2010. "Stany Zagrożenia Zewnętrznych Ścian Warstwowych. Kształtowanie Rozwiązań Prototypowych (The Danger Condition of Outer Layer Walls. Prototype Solutions)." *Civil and Environmental Engineering* 1 (2): 149-54. (in Polish)

[8] Builidng Research Institue. 1999. *Badania i Ocena Betonowych Płyt Warstwowych w Budynkach Mieszkalnych (Testing and Evaluation of Concrete Panels in Residential Buildings). Instruction No. 360/1999.* Warszawa: Building Research Institute. (in Polish)

[9] Lewicki, B. 1964. *Budynki Mieszkalne z Prefabrykatów Wielkopłytowych—Obliczanie i Konstrukcja (Prefabricated Residential Buildings—Calculation and Design).* Warszawa: Arkady. (in Polish)

[10] Wierzbicki, M. S. 2013. "Konstrukcje Budynków Wielkopłytowych z Punktu Widzenia Zabezpieczenia Przed Awarią Oraz Możliwości Modernizacji (The Construction of Prefabricated Panel Buildings from the Point of View of Failure Protection and the Ability to Upgrade)." Presented at XXVI Conference: Buildings Failures, Szczecin, Poland. (in Polish)

[11] Wayzbun, I., and Wójtowicz, M. 2002. *Metodyka Oceny Stanu technicznego Wielkopłytowych Warstwowych Ścian Zewnętrznych. Budynki Wielkopłytowe—Wymagania Podstawowe (Methodology for Assessing the Technical Condition of Big Plate, External Walls. Big Plate Buildings—Basic Requirements).* Warszawa: Building Research Institute. (in Polish)

[12] Runkiewicz, L. 2002. *Błędy i Uszkodzenia w Budownictwiewielkopłytowym. Błędy i Uszkodzenia Budowlane Oraz ich Usuwanie (Errors and Damage in Big Plate Buildings. Errors and Building Damage and Its Repairs).* Warszawa: WEKA Publisher. (in Polish)

[13] Ściślewski, Z. 1998. "O Trwałości Łączników w Ścianach Warstwowych (On Durability of Fasteners in Prefabricated Wall Panels)." *Inżynieria i Budownictwo (Engineering and Civil Engineering)* 54 (8): 402-4. (in Polish)