THE ULTRASONIC TOMOGRAPHY TESTS OF CONCRETE IN FOUNDATION SLAB

Krzysztof SCHABOWICZ[1], Jerzy HOLA[1], Dariusz STYS[1]

[1] Institute of Building Engineering, Wrocław University of Technology,

Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland, Phone. +48 71 320 29 00,

Fax: +48 71 322 14 65, e-mail: k.schabowicz@pwr.wroc.pl, jerzy.hola@pwr.wroc.pl

Abstract

This paper deals with the modern nondestructive elastic-wave testing of concrete in foundation slab of building put under the ground water level. The reason for the tests was assumption that the contractor make thin the foundation slab than the design and after that the slab was damage. The tests were carried out to check the thickness of slab according to the design, and to assess the technical condition of the foundation slab to take a decision about the range of repairs to be done to or about their strengthening. The Ultrasonic Tomography technique and ultrasonic, electric and electromagnetic techniques (in a support role) were used in the tests. The nondestructive test results and the analyses carried out on their basis, corroborated by exposures, have not been published before.

Key words: nondestructive tests, elastic waves, ultrasonic tomography, Impulse Response, Impact-Echo, concrete, foundation slab

1. Introduction

Today increasingly more often buildings with reinforced concrete or concrete slab foundations located much below the groundwater table are erected. As building practice shows such foundations often do not conform to the design and have workmanship defects. The defects include: slab thickness smaller than the design one, deep cracks in the concrete, defective (delamination and porosity) areas in the cross section of the slab. Because of too long breaks in concreting, delaminations often occur in the lower reinforcement region. Due to the lack of concrete compaction, porosity arises. All the defects may result in damage to and leakage of the foundations, whereby the rooms located in the basement storey cannot be normally used.

When there is a high groundwater pressure onto the foundation it is difficult and risky to check through exposure (e.g. a core borehole) what the actual slab thickness or the depth of a crack is. Such a method is destructive and poses a danger of damage to the waterproofing insulation. Considering the above, nondestructive techniques can be highly useful for the testing of concrete or reinforced concrete slab foundations accessible to testing only from one side [3-8], especially ultrasonic tomography [1, 2].

This paper presents such a comprehensive application of the techniques in situ to a structural component in a civil structure, i.e. to a defective foundation slab in a special-purpose building. Cases of the comprehensive use of the ultrasonic tomography, are hard to find in the literature on the subject [1, 2]. The authors hope that the test results and their interpretation as well as the experience gained can be useful to other researchers in similar test situations.

2. Description of foundation slab

The foundation of a large special-purpose building with a basement storey, erected in Poland, was made in the form of a 0.80 m thick concrete groundslab reinforced at the top and bottom with grids of steel bars. The groundslab was founded 3.00 m below the groundwater table. The building's external longitudinal bearing walls and its internal transverse walls were founded on the groundslab. The underground part of the building, sunk into aquifers, was protected against groundwater by means of bentonite waterproofing mats laid under the groundslab and on the outer surface of the external walls. The slab-wall contacts were protected with special sealing tapes. The slab's top surface was overlaid with finishing layers of: 0.05 m thick polystyrene foam, PVC sheeting and a 0.10 m thick concrete floor with a non-slip topping. Układ tych warstw pokazano na rysunku 1.

Soon after the building was put into service, water appeared on the floor in one of the rooms in the 100.00 m and 6.00 m wide basement storey (fig. 1). The water leaked at the concrete floor/longitudinal walls contact. In the part of the room in which the leakage was most intensive a test pit of about 0.50 m^2 was made in the finishing layers near one of the longitudinal walls. The test pit revealed water on the surface of the foundation slab and in the polystyrene foam layer (fig. 1b). Therefore a decision was taken to make a large (ca 20.00 m^2 in area) pit extending over the entire width (6.00 m) and length (3.00 m) of the room (fig. 1). After the topping, the sheeting, the polystyrene foam (fig. 1) and the water were removed and the groundslab surface was quickly dried over the pit's whole length (3.00 m), a crack with wide 1.0 mm became visible near the middle of the slab span (fig. 1d). Water was leaking out of the crack. In order to determine the length of the crack, a ca 1.00 m wide bandlike pit was made in the line of the crack. It was found that the crack in the foundation slab extended for about 50.00 m. Then it became clear that the water was leaking through a long fracture which appeared in the foundation slab.

After the visual inspection the following questions (to mention but a few) arose: what contributed to the fracture propagating over such a considerable length; how deep was the fracture; besides the visible crack, were there any other defects contributing to cracking? In order to find answers to the questions, it was decided to test nondestructively the unilaterally accessible defective ground-slab, using state-of-the-art acoustic technique: ultrasonic tomography.

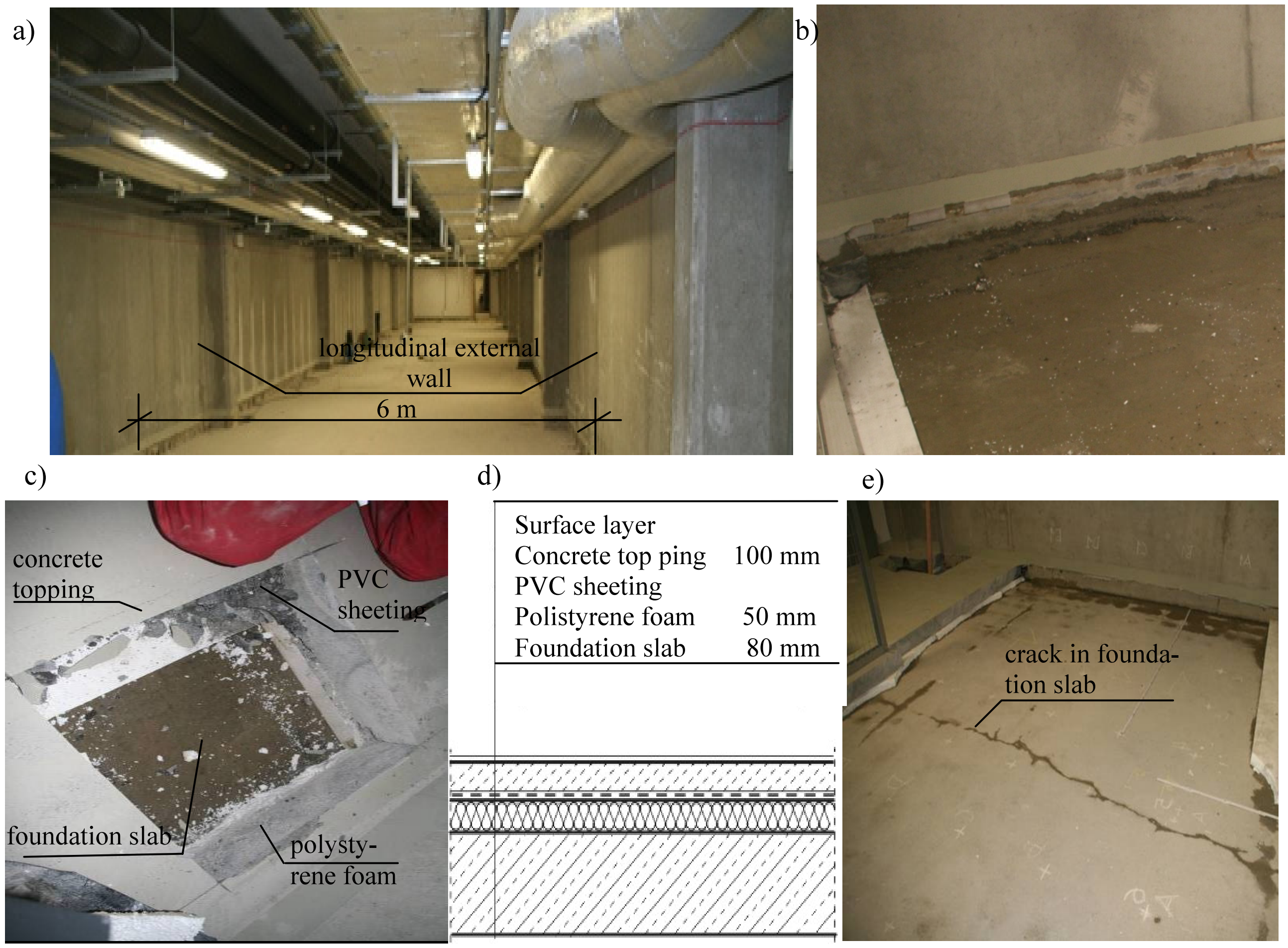

Fig. 1. View of rooms in the basement storey and location of pits in foundation slab: a) general view, b) approximate saturation with moisture floor, c) view of test pit, d) cross-section of the flooring layer, d) view of large pit

3. Nondestructive tests of foundation slab

Nondestructive testing of the defective foundation slab began in the large pit where, as previously mentioned, the leaking of water through the visible crack was most intensive (fig. 1). Line of bands were marked on the surface of the groundslab. The arrangement of bands and the location of the crack are shown in fig. 2.

An ultrasonic tomograph (fig. 3) was used for testing. The tomograph is useful for, among other things, determining the thickness of unilaterally accessible concrete elements and detecting inhomogeneities such as air voids and highly porous zones. Tests were conducted in four bands each 0.50 m wide and 6.00 mm length (fig. 2). During testing in a band the tomograph's antenna was always shifted in one direction. The total number of measuring points was about 240. The images of the groundslab cross sections obtained from the particular measuring points were collected in a three-dimensional matrix column and three mutually intersecting cross sections of the groundslab (scan B, C and D) were produced on the basis of the matrix table. Scan B shows a cross section of ground slab in the middle of the band. Scan C shows horizontal cross section in the levels of defects. Scan D shows a longitudinal section through ground slab in the band.

Very similar groundslab thickness scans were obtained from the tests performed in the particular bands. The scans are shown in figures 4-7.

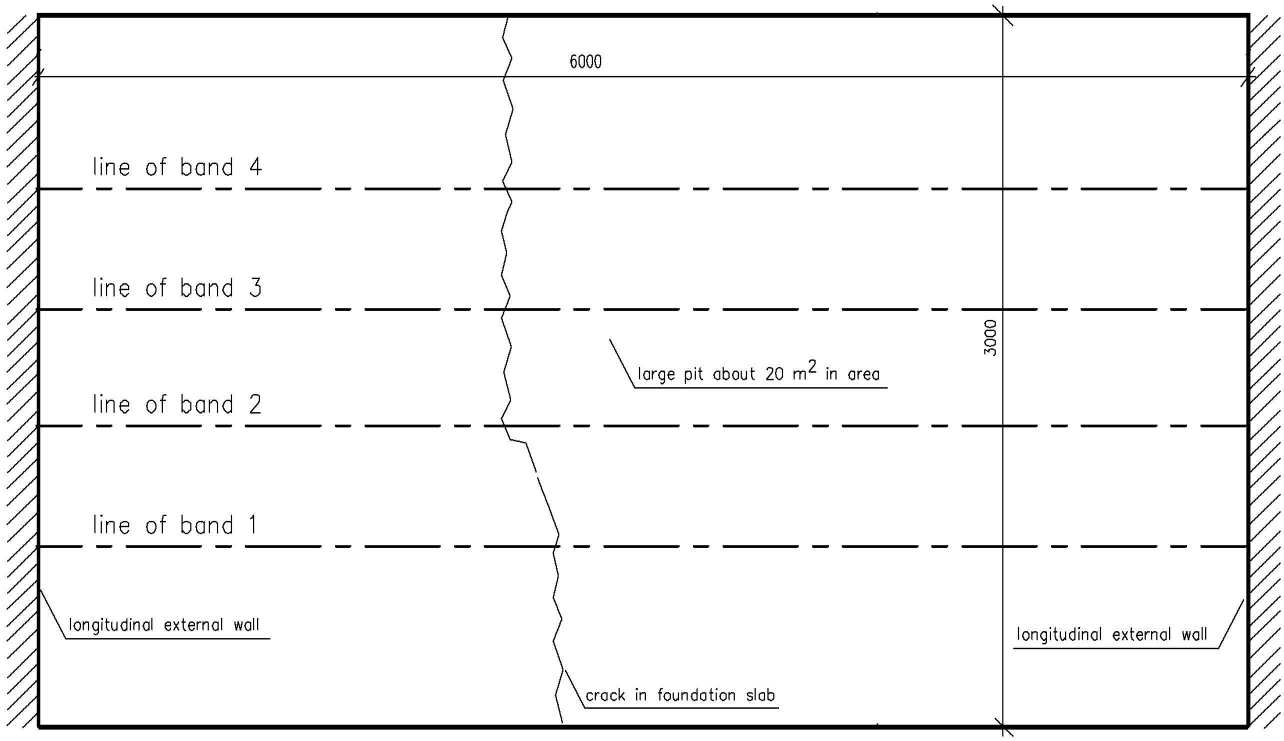

Fig. 2. Grid of line of bands, marked on groundslab within large pit

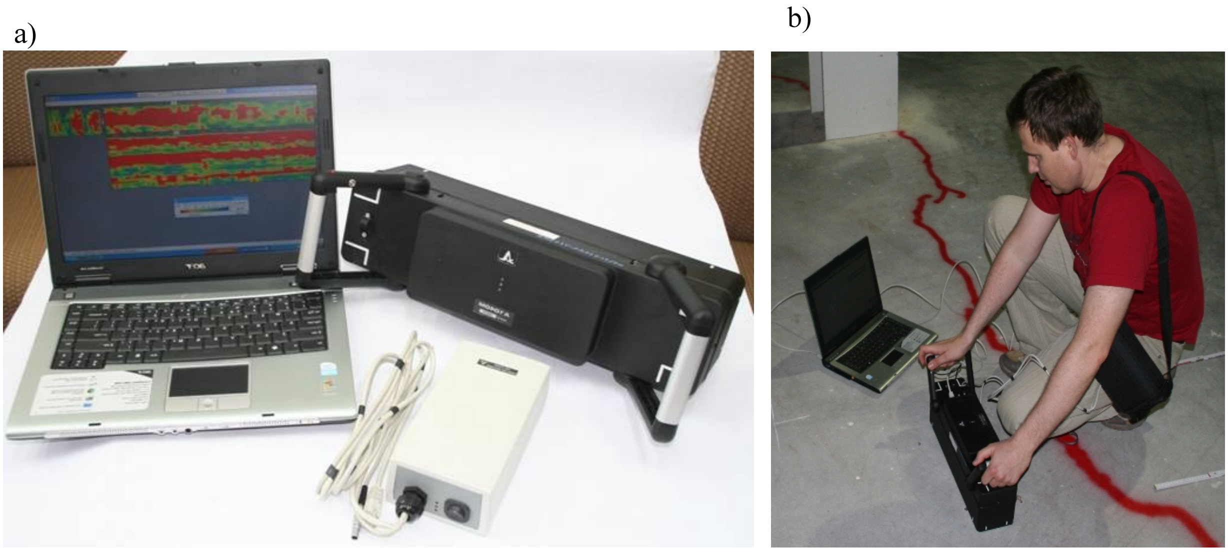

Fig. 3. Ultrasonic tomograph: a) measuring set, b) testing procedure

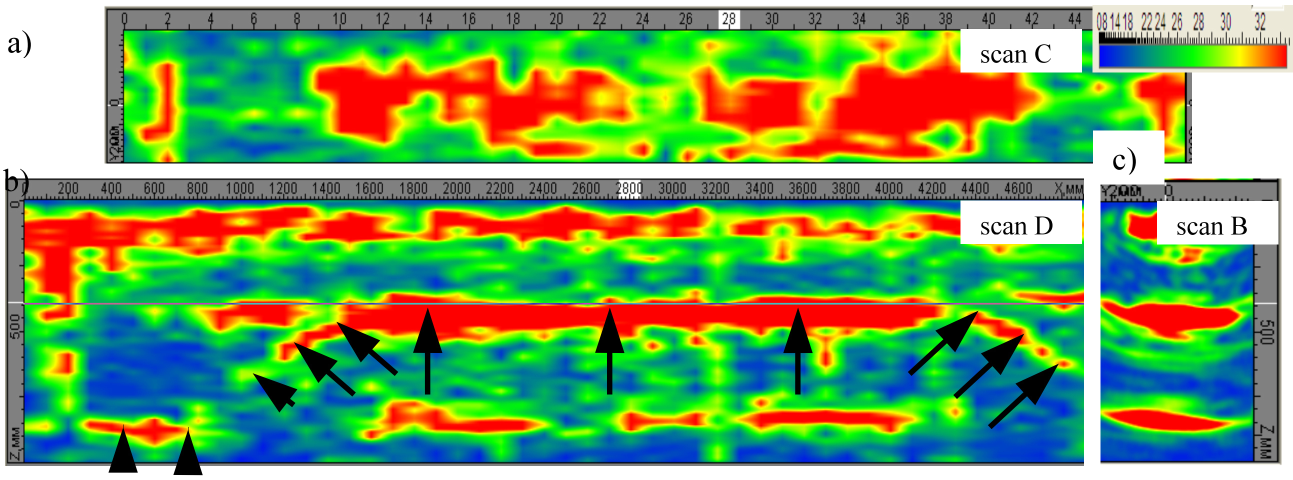

Fig. 4. Exemplary groundslab thickness scans obtained in band 1 by means of ultrasonic tomograph: a) scan C, b) scan D, c) scan B

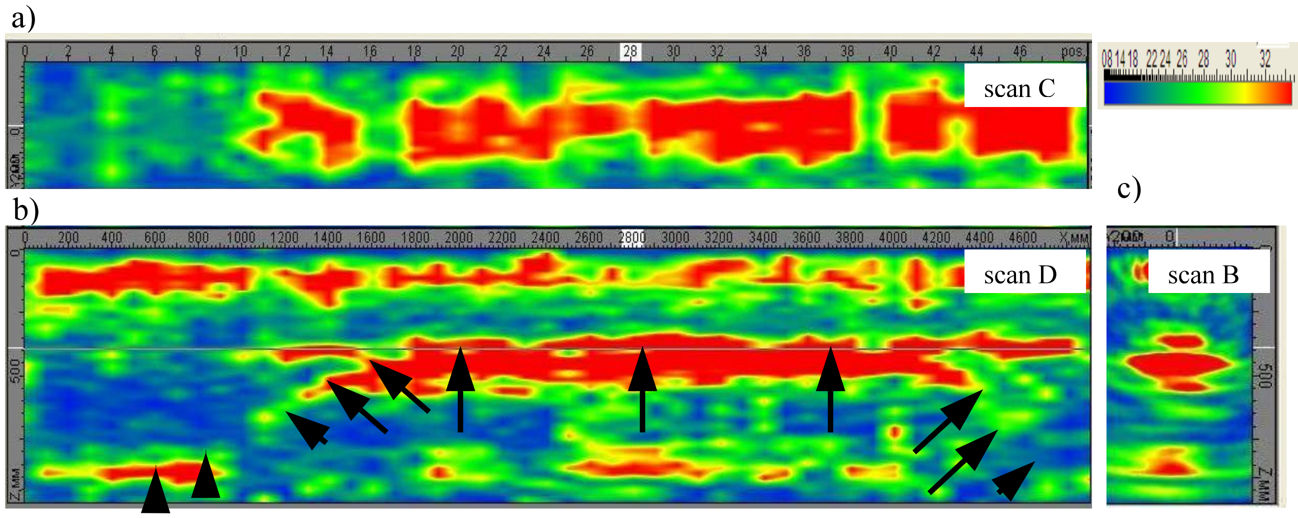

Fig. 5. Exemplary groundslab thickness scans obtained in band 2 by means of ultrasonic tomograph: a) scan C, b) scan D, c) scan B

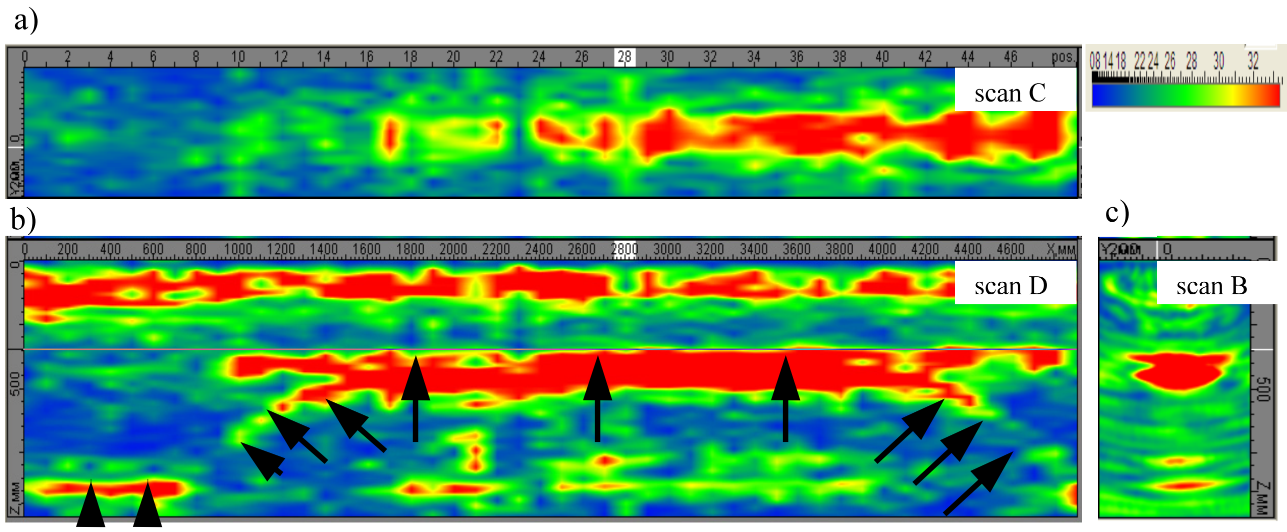

Fig. 6. Exemplary groundslab thickness scans obtained in band 3 by means of ultrasonic tomograph: a) scan C, b) scan D, c) scan B

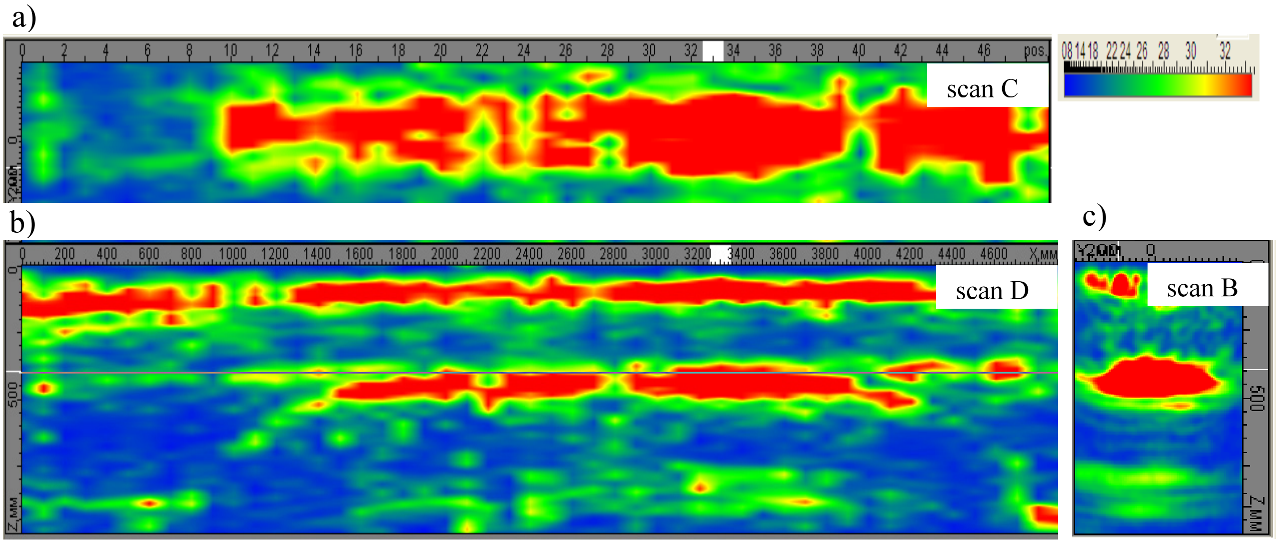

Fig. 7. Exemplary groundslab thickness scans obtained in band 4 by means of ultrasonic tomograph: a) scan C, b) scan D, c) scan B

An analysis of the obtained scans adopted a very likely that:

- the thickness of the tested foundation slab in the approx. 1.00 m wide zones adjoining the longitudinal external walls was about 0.80 m and conformed to the design,
- the foundation slab thickness in the approx. 4.00 m wide central zone was 0.36-0.40 m and it did not conform to the design,
- the thinning of the groundslab thickness from 0.80 m to 0.36-0.40 m in the transition zone was made at an angle of 45^{o},
- the space under the groundslab in its central zone was probably filled with heterogeneous material, e.g. construction debris.

Considering the above and the discovery (after the bandlike pit was cut) of the 50 m long crack in the groundslab, it was decided to remove the finishing layers from the latter. Then additional nondestructive ultrasonic tomography tests were carried out in randomly selected bands along the groundslab's length. Similar results as the ones shown in figs 4-7 were obtained. Therefore it was concluded that the reduction in the groundslab's load-bearing capacity could pose a safety risk. Numerical static-strength analyses were carried out to test this supposition. Their results are summarized in section 4.

4. Results of numerical analysis

The Autodesk Robot Structural Analysis software was used for the numerical analyses. The computations were performed for the same loads as those in the building design, taking into account the reduced groundslab thickness in the central zone. The groundslab's geometry is shown in fig. 8. A numerical model of the groundslab with marked supports, and the FE mesh are shown in fig. 9. The total number of finite elements was 1536. Diagrams of moments in the longitudinal section and in the cross section are shown in fig. 9.

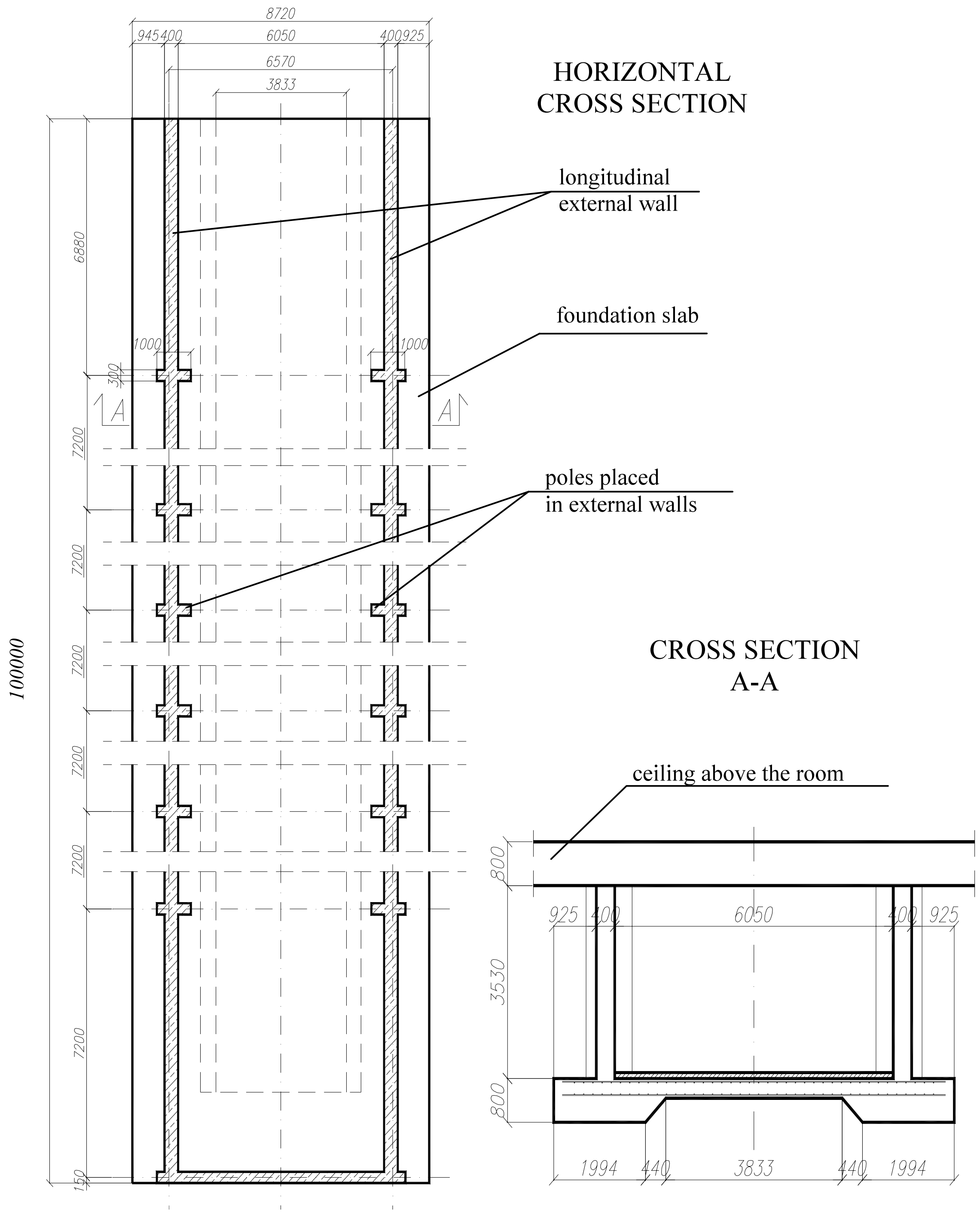

Fig. 8. Groundslab's geometry (plan and cross section)

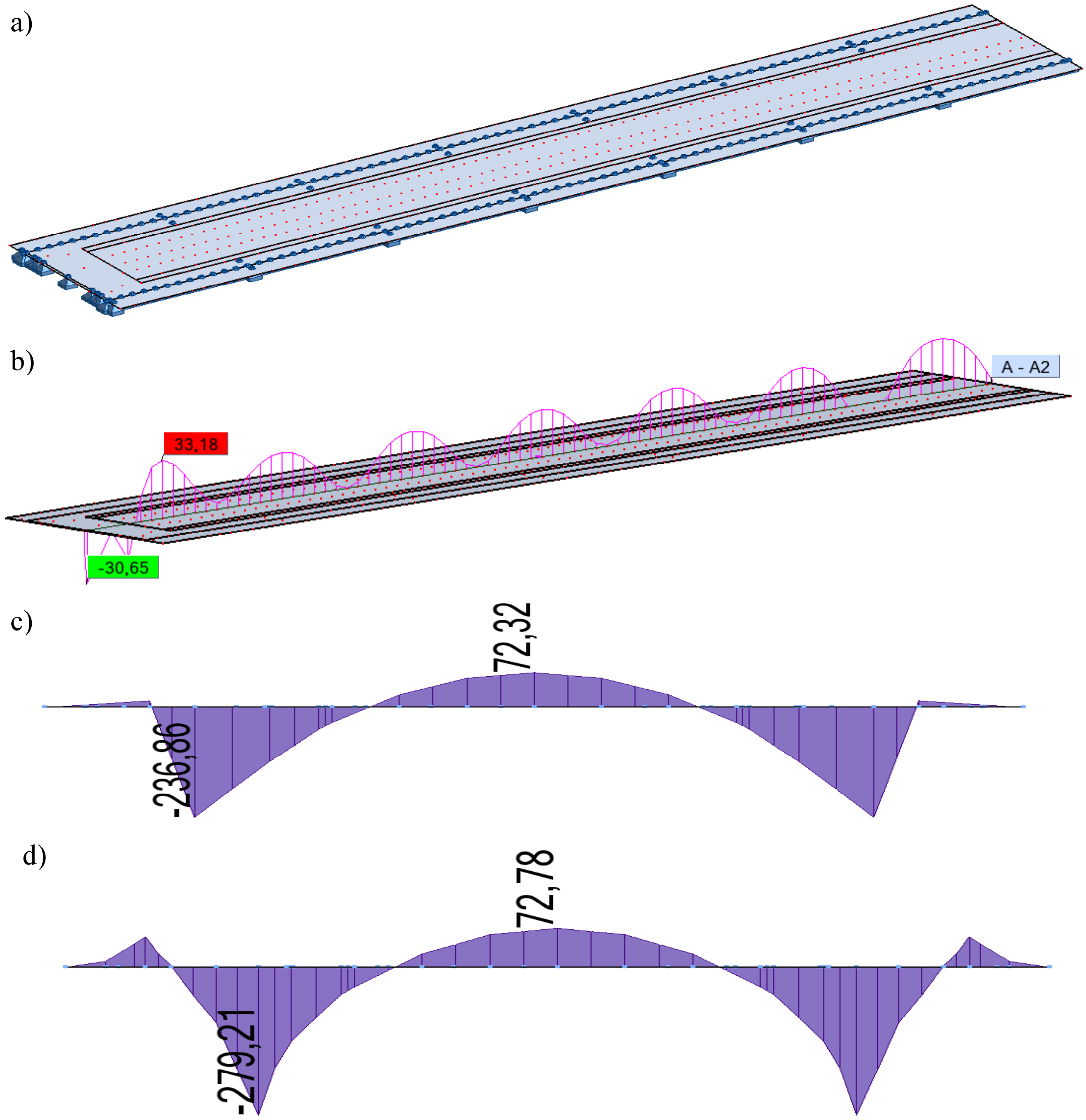

Fig. 9. Groundslab numerical model and calculation results: a) numerical model with marked supports under columns in external walls, and FE mesh, b) diagram of moment M_{yy} under characteristic loads in longitudinal section, c) diagram of moment M_{xx} in cross section between columns in external walls, d) diagram of moment M_{xx} in cross section between columns in external walls

The analyses showed that the groundslab's load-bearing capacity was exceeded by about 45% relative to the design capacity. Considering this fact, it is not surprising that the 50 m long crack appeared in the groundslab. As a result of this long crack, the groundslab's waterproofing could have been damaged whereby groundwater penetrated onto the basement floor. Having the safety of the building in mind, a decision was made to repair and reinforce the groundslab.

5. Conclusion

The paper describes how the ultrasonic tomography method was applied to investigate the groundslab in a special-purpose building. The nondestructive tomographic investigations contributed to the discovery of a structural defect in this element. It was found that the actual thickness of the groundslab in the (about 4 m wide) central zone amounted to 0.36-0.40 m, which means that it did not conform to the design. In the (about 1 m wide) zones adjoining the longitudinal external walls, groundslab thickness amounted to about 0.80 m, conforming to the design. It was also found that the reduction in slab thickness in the transition zone from the thickness of 0.80 m to 0.36-0.40 m had been made at an angle of ca 45%. The results of the nondestructive investigations were used in groundslab load-bearing capacity verification computations. The latter showed that the groundslab's load-bearing capacity was exceeded by about 45% relative to the design capacity. Having the safety of the building in mind, it was decided to repair and reinforce the groundslab.

Bibliography

[1] Samokrutov A. A., Kozlov V. N., Shevaldykin V. G. Ultrasonic testing of concrete objects using dry acoustic contact. Methods, instruments and possibilities. The 5th International Conference "Non-Destructive Testing and Technical Diagnostics in Industry". Mashinostroenie, p.152. 2006

[2] Bishko A. V., Samokrutov A. A, Shevaldykin V. G Ultrasonic echo-pulse tomography of concrete using shear waves low-frequency phased antenna arrays. e-Journal of Nondestructive Testing & Ultrasonics. e-Journal of Nondestructive Testing & Ultrasonics. vol. 13. 2008

[3] Jerga J., Pokorny M. Damage detection of concrete by nonlinear acoustic testing methods. Civil and Environmental Engineering. Vol. 3. No. 1. 2007

[4] Rucka M.. Wilde K. Application of continuous wavelet transform in vibration based damage detection method for beams and plates. Journal of Sound and Vibration 297. 2006

[5] Hoła J., Sadowski Ł., Schabowicz K. Nondestructive evaluation of the concrete floor quality using impulse response method and impact-echo method. e-Journal of Nondestructive Testing & Ultrasonics. Vol. 14 No. 3. 2009

[6] American Concrete Institute Report ACI 228.2R-98. Nondestructive Test Methods for Evaluation of Concrete in Structures. ACI. Farmington Hills, Michigan. 1998.

[7] Bungey J., Millard S., Gratham M. Testing of concrete in structures. Taylor&Francis. London and New York. 2006

[8] Garbacz A. Nondestructive investigations of polymer-concrete composites using stress waves – repair efficiency evaluation (in polish). Prace naukowe. Budownictwo z. 147, Oficyna Wydawnicza Politechniki Warszawskiej. 2007