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Deformability of reinforced concrete beams under the action of repeated alternating loads

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Abstract

A technique has been developed, and experimental studies of reinforced concrete beams under repeated alternating loads at different shear spans have been carried out. It has been established that the shear span significantly affects the deformation behaviour in the oblique and normal sections. It was found that with smaller shear spans, the deformations of transverse reinforcement and concrete in oblique sections develop much more intensively and have greater values for the deformation of longitudinal reinforcement and concrete in normal sections. The residual strain appears in the first cycles of overload and decays uniformly in subsequent cycles due to decreased plastic deformations in materials.

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Keywords: repeated alternating loads, reinforced concrete beam, reinforcement, deformability, bending.

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1. Introduction

At the present stage of construction development, materials, products, elements and structures based on wood (Gomon et al. (2022); Yasniy et al. (2022); Homon et al. (2023); Janiak et al. (2023); Pavluk et al. (2023)), metal (Kovalchuk (2018), Iasnii et al. (2023); Imbirovych et al. (2023); Prentkovskis et al. (2023)), concrete (Dvorkin et al. (2021), Protsiuk et al. (2023); Iskhakov et al. (2022); Konkol (2019)) and reinforced concrete (Babych et al. (2019); Kos et al. (2022), Mel'nyk (2019); Iskhakov et al. (2023)), as well as various composites are often used (Mikulich (2023); Shvabyuk et al. (2017)). The most common are bending elements (Romashko and Romashko-Maistruk (2023); Gomon et al. (2023); Sobczak- Piastka et al. (2020); (Gomon et al. (2022)). In the construction of industrial, public, residential buildings and engineering structures (Bosak et al. (2021)) reinforced concrete elements and structures are very often used as load-bearing structures (Masiuk et al. (2018); Kos et al. (2022); Babych et al. (2019); Mel'nyk (2019)).

Nomenclature

ε_c	relative deformations of concrete in normal sections
ε_s	relative deformations of longitudinal reinforcement
ε_{cw}	relative deformations of concrete in oblique sections
ε_{sw}	relative deformations of transverse reinforcement
a	shear span
h	beam hight
l_0	beam span
n	number of loading cycles
F	concentrated force
F_u	destructive load
η	loading level

In modern design of reinforced concrete structures the calculation is carried out according to limit states using coefficients of operating conditions (DBNB.1.2-14-2018 (2018); DSTUBV.2.6-156:2010 (2011); EN 1992-1-1 (2004)). They establish a systematic dependence of the materials properties on loads but do not consider the influence of the loading history and its nature on the change in the destructive, strength and deformation characteristics of concrete and reinforcement.

A large number of reinforced concrete structures during operation are subjected to low-cycle repeated and alternating loads (Masiuk et al. (2018)), which can occur within the operational level or exceed it. Such loads include wind, technological, seismic, temperature and humidity, and other ones (Famulyak et al. (2019), Borysiuk et al. (2019); Shvabyuk et al. (2014)). Alternating loads and deformations occur in continuous beams, edge columns of industrial buildings, load-bearing and prestressed structures, etc.

The current calculation standards (DBNB.1.2-14-2018 (2018); DSTUBV.2.6-156:2010 (2011); EN 1992-1-1, (2004)) do not take into account the effect of such loads on the change in the physical and mechanical properties of concrete and stress-strain state, since this issue has not been studied enough.

So, the research goal is to conduct experimental studies and analyze the deformation characteristics of concrete, transverse and longitudinal reinforcement in bending reinforced concrete elements at various shear spans and loading levels.

2. Methodology of experimental studies

The research object is the reinforced concrete beams of rectangular sections with nominal dimensions of 100x160x2000 mm of heavy concrete of C25/30 natural hardening class. The beams are reinforced with two flat welded frames united into a spatial one (see Fig.1a). Longitudinal reinforcement is adopted with a diameter of 14 mm and of A500C class (reinforcement - double, symmetrical), which is securely anchored along the edges of the beams from sliding in the body of concrete. The transverse reinforcement is made of clamps with a diameter of 4 mm of the Vr-I class with a step of 75 mm on the support sections.

Testing was carried out on equipment that allows the creation of alternating loads on the beams without changing their position (see Fig.1b,c). The beams were tested with a static load - two concentrated forces F, symmetrically mounted relative to the middle of the span, as single-span hinged beams with an estimated span of 1800 mm. In the process of experimental studies of reinforced concrete beams, the relative shear span *a* was changed and taken as *a* = 300 mm (a/h ≈ 2), a=450 mm (a/h ≈ 3), a=600 mm (a/h ≈ 4).

The design of samples and loading schemes are shown in Fig.1a,b,c.

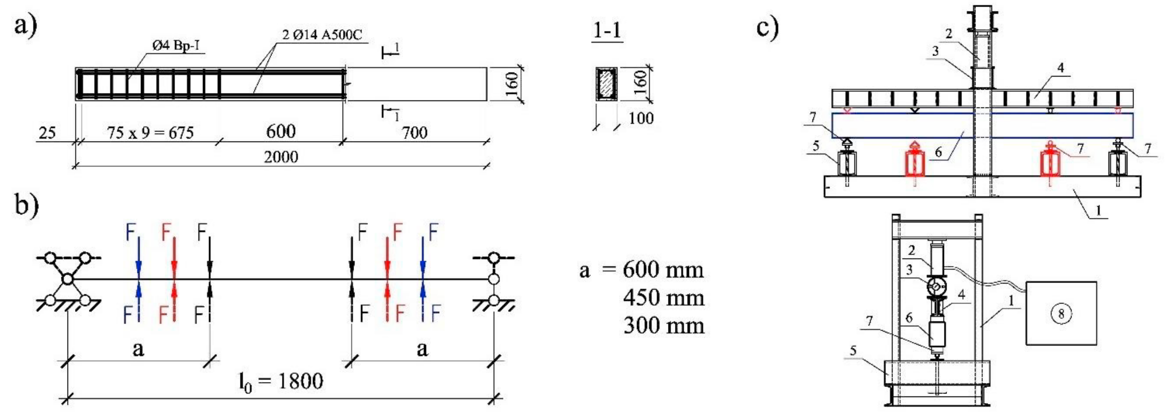

Fig. 1. Design of samples (a), loading schemes (b) and the installation scheme (c): 1 – installation frame; 2 - jack; 3 – dynamometer; 4 - traverse; 5 - supports; 6 - sample; 7 - tips; 8 - pumping station.

Deformations of concrete in calculated sections and deformations of longitudinal and transverse reinforcement were measured by mechanical and tensometric instruments (see Fig.2)

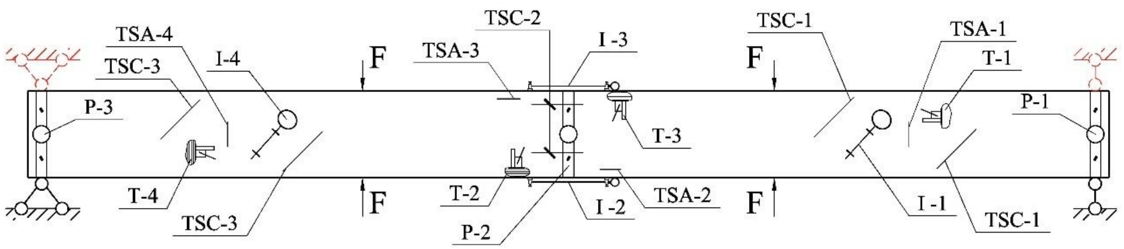

Fig. 2. Layout of measuring devices: I – dial indicator 2MIG; T – Hugenberger strain gauge;TSA - strain gauges with a base of 20 mm (installed on the reinforcement); TSC – a strain gauge with a base of 50 mm (installed on concrete); P is a deflection gauge 6PAO.

The beams were tested with a ten-cycle alternating load (in half-cycles "a" and "b" with the first half-cycle of tension in the lower zone). The beams were loaded in steps with a holding time of 10 minutes at each "loading-unloading" half-cycle.

Beams B4-3/0.65, B4-4.5/0.65 and B4-6/0.65 were loaded in half-cycles up to the level of η=0.65·Fu from the destructive load, which corresponds to the calculated operational value of loads on structures. On the fifth cycle, the samples were additionally loaded to η=0.8·Fu, which corresponds to the calculated limit load. After ten "loading-unloading" cycles, the beams were fractured on the "10-b" half-cycle without unloading. A total of 3 beams were tested.

3. Research results and discussion

Based on the conducted experimental studies, it was established that the stress-strain state of the calculated cross-sections of the tested beams depends on the load level and the shear span.

With a decrease in the shear span, the deformations of the transverse reinforcement and concrete in the areas of oblique sections increase at the same level of loading, as evidenced by the "ε-n" graphs (see Fig.3a,b,c and Fig.4a,b,c).

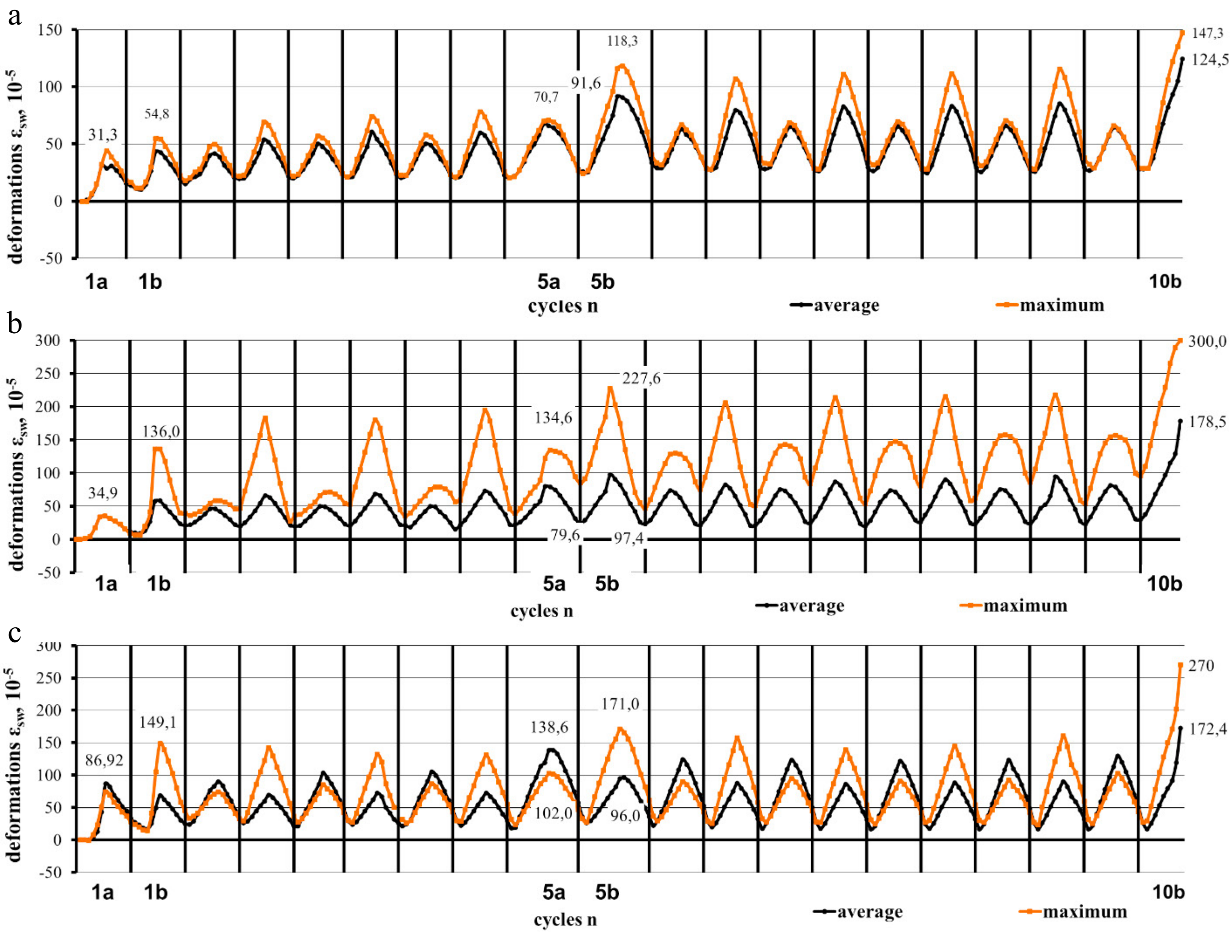

Fig. 3. Graphs of transverse reinforcement deformations by cycles in beams with different shear spans: B4-6 / 0.65 (a), B4-4.5 / 0.65 (b), B4-3 / 0.65 (c).

It should be noted that the deformations of the transverse reinforcement, regardless of the shear span, have a similar character: in the “b” half-cycle, the deformations are always greater than the corresponding deformations in the “a” half-cycle. However, the largest increase in the deformations of the transverse reinforcement with a change in the alternating load is observed at a shear span of a = 450 mm (B4-4.5 / 0.65 beam), namely, by 3.9 times in the first cycle. At the same time, for the shear span of a = 300 mm (B4-3/0.65 beam) in the half-cycle “b” the deformations of the transverse reinforcement increased by 2 times, and of a = 600 mm (B4-6/0.65 beam) - by 1.25 times. An increase in the deformation of the transverse reinforcement when the value of the load applied changes (in the half-cycle “b”), can be explained by the destructive processes occurring in the oblique: the concrete is decompacting, the grafting with the reinforcement is lost, and as a result, most of the transverse force is perceived by the clamps, and not by the concrete.

As can be seen from the graphs (see Fig.4a,b,c), the change in the shear span affects the nature of the concrete deformation in the oblique sections of the experimental beams. In beams with a shear span of a = 600 mm, the total tensile strains of concrete in the "b" half-cycle is 2.4 times greater than the deformations in the "a" half-cycle (see Fig.4a). For shear spans of 450 and 300 mm, on the contrary, on the half-cycle "a" is greater than the deformation in the half-cycle "b" by 2.1 and 1.1 times, respectively (see Fig.4b,c).

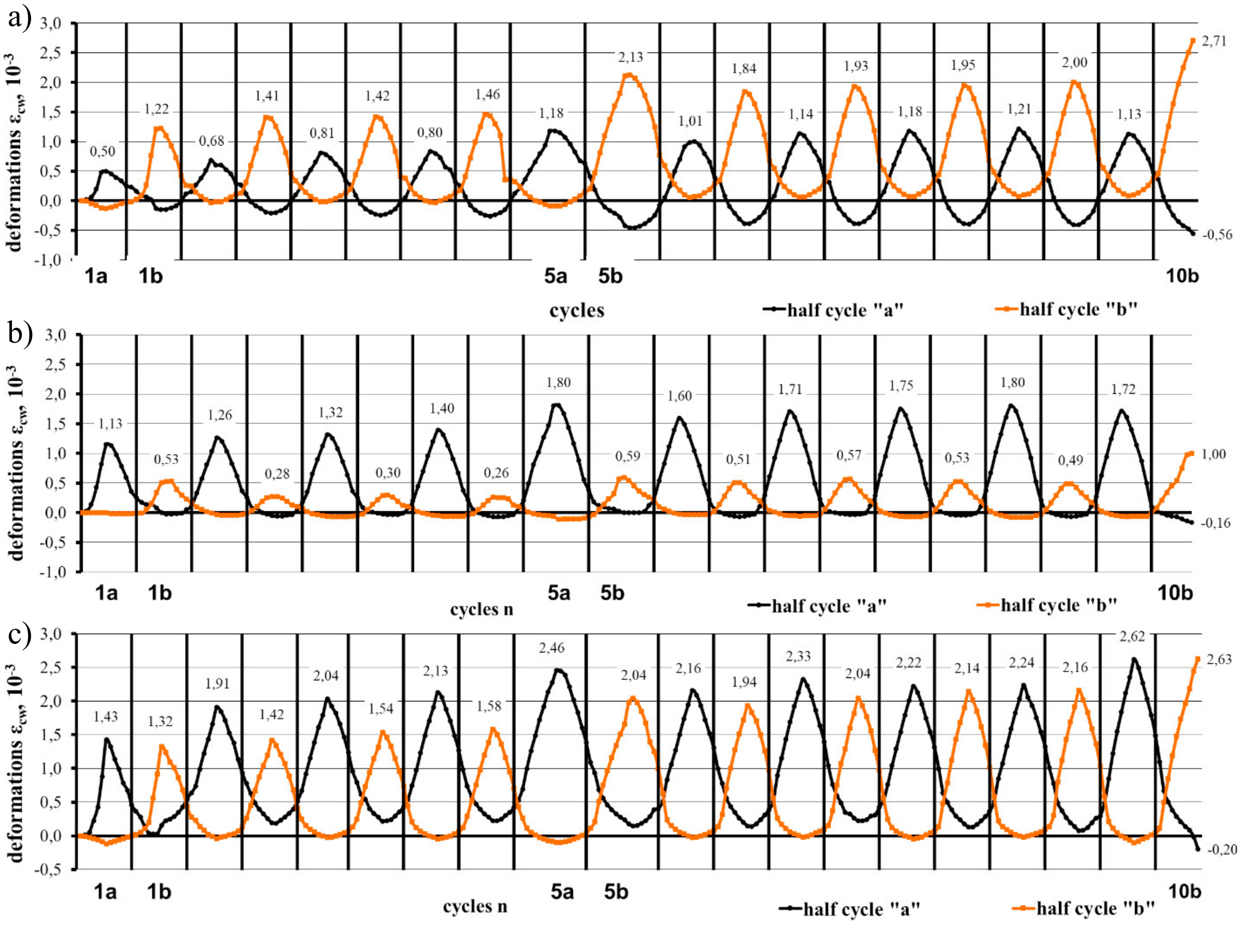

Fig. 4. Graphs of concrete deformations in oblique sections by cycles in beams with different shear spans: B4-6/0,65 (a), B4-4,5/0,65 (b), B4-3/0,65 (c).

The longitudinal reinforcement and concrete deformations in normal sections of the experimental beams are shown in Fig.5a,b,c and Fig.6a,b,c. A change in the shear span also affects the nature of the deformation of both longitudinal reinforcement and concrete.

Longitudinal reinforcement deformations in "b" half-cycles with a shear span of a = 600 mm are 1.03…1.2 times greater than similar deformations in "a" half-cycles. A similar pattern of deformations is also observed for a span of 450 mm. As for the deformations of the longitudinal reinforcement in the beams with a shear span of 300 mm, they are almost the same in the half-cycles "a" and "b".

Deformations of concrete in normal sections of experimental beams with spans of a = 600 and 450 mm in half-cycles "b" are 1.5 ... 2.0 times greater than similar deformations in half-cycles "a". Concrete deformations are almost the same in beams with a shear span of 300 mm. This fact can be explained by a rather small shear span (a/h $\approx$ 2) and, therefore, insignificant influence of the alternating load on the operation of normal sections (both for reinforcement and concrete).

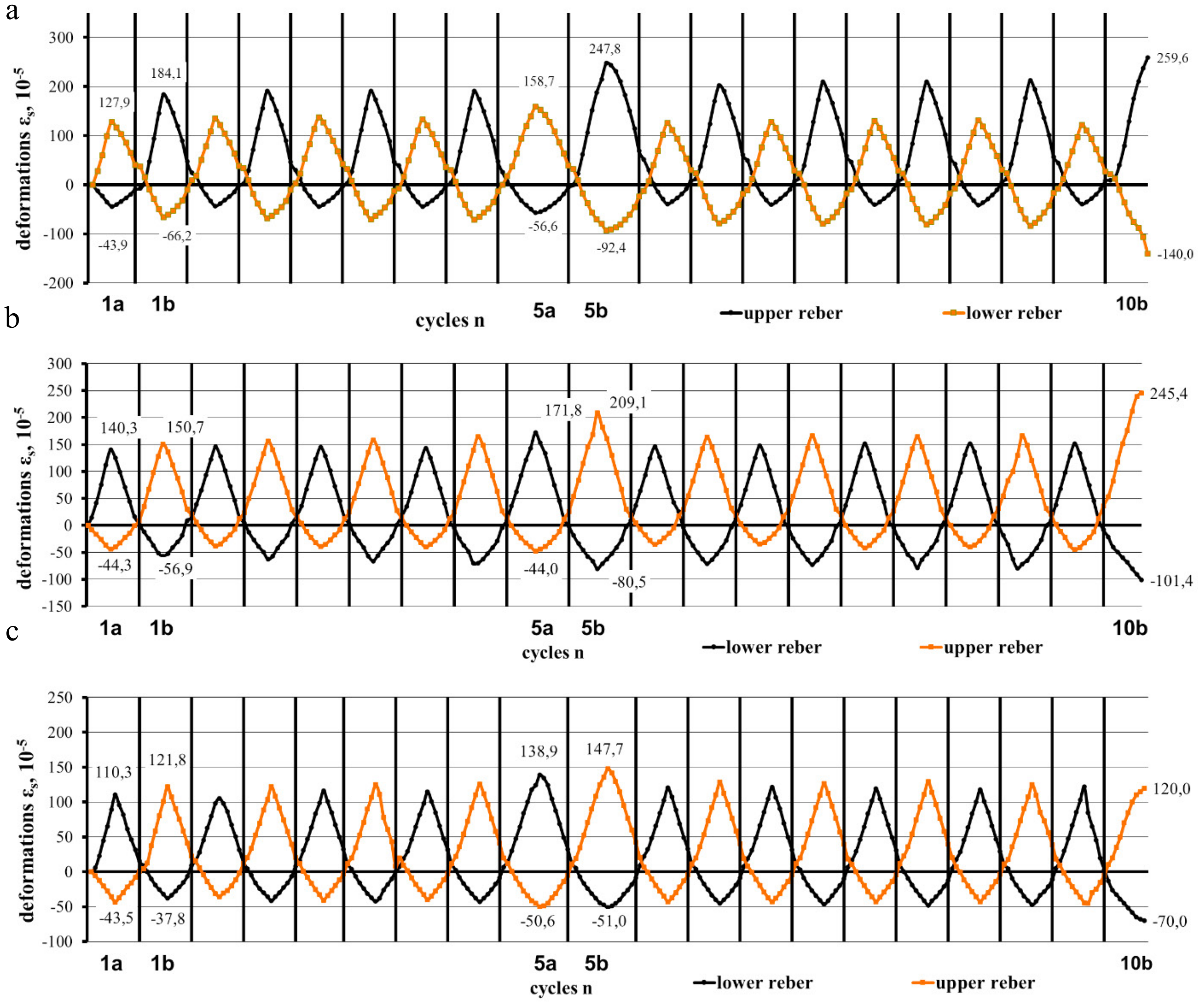

Fig. 5. Graphs of longitudinal reinforcement deformations by cycles in beams with different shear spans: B4-6/0,65 (a), B4-4,5/0,65 (b), B4-3/0,65 (c).

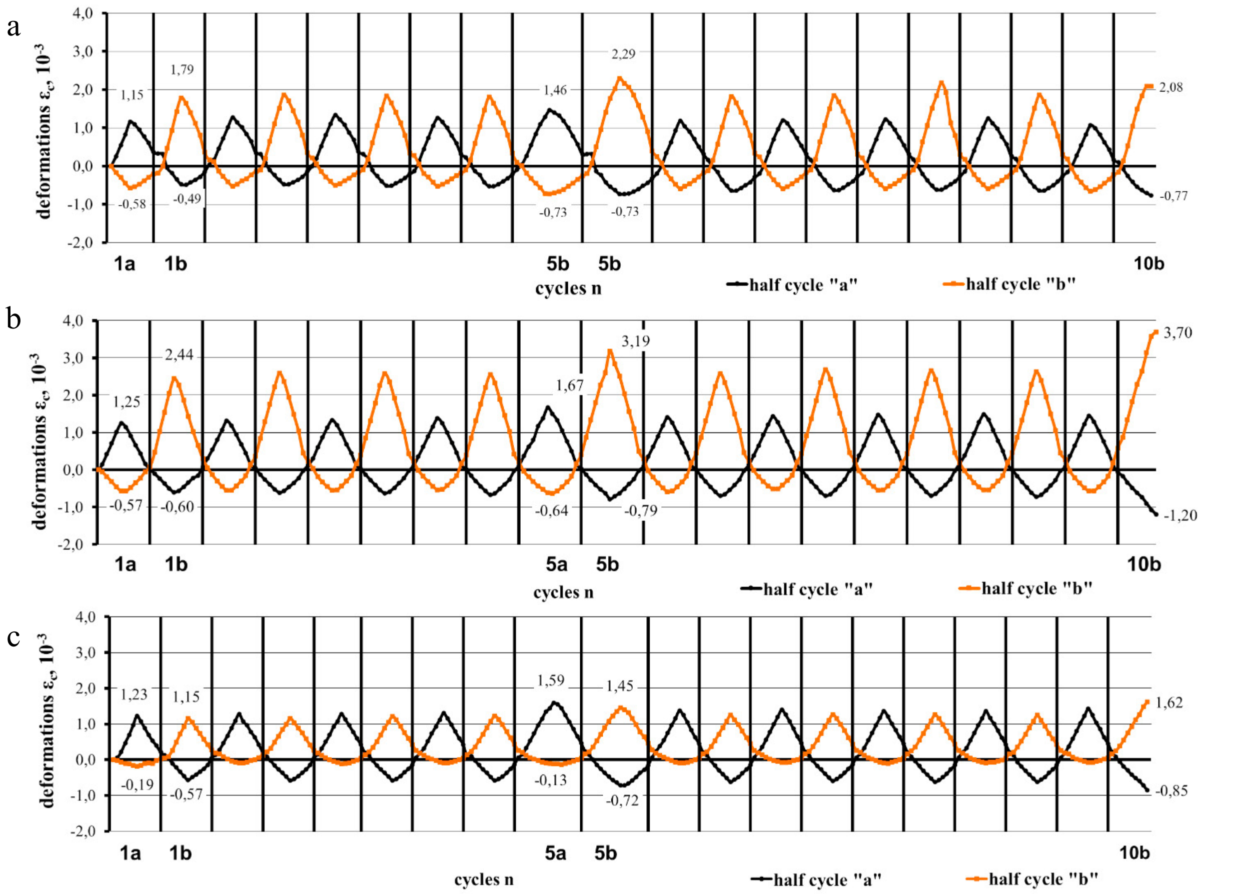

Fig. 6. Graphs of concrete deformations in normal sections by cycles in beams with different shear spans: B4-6/0,65 (a), B4-4,5/0,65 (b), B4-3/0,65 (c).

4. Conclusions

The following conclusions can be drawn from the article: 1) a methodology has been developed, and experimental studies of reinforced concrete beams under the action of repeated alternating loads at various shear spans have been carried out; 2) the shear span has a significant effect on the nature of the deformation of the materials in oblique and normal sections; 3) with smaller shear spans the deformations of transverse reinforcement and concrete in oblique sections develop much more intensively and have greater values than the deformation of longitudinal reinforcement and concrete in normal sections; 4) residual deformations appear in the first cycles of loading and gradually fade in subsequent cycles due to a decrease in plastic deformations in materials; 5) these experimental studies can be used by designers in the calculation of bending reinforced concrete elements under the action of repeated alternating loads.

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