Strength and deformation of bending normal sections made of concrete frame structure

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Abstract. Concrete of the frame structure, obtained by the separate concreting technology by immersing a coarse aggregate in a low-viscosity mortar component due to increased concentration of coarse aggregate, have a number of advantages in comparison with the traditional concretes of vibration compaction.

1. Introduction
In order to effectively use the frame structure in reinforced concrete bent concrete structures, it is necessary to study the physical and mechanical properties of such concretes: cubic and prismatic strength, elastic modulus, longitudinal and transverse deformations. In addition, to study the operation of structures under load, it is necessary to have experimental data obtained on the experimental basis.

2. Methodology
Portland cement CEM I 42.5; quartz sand with a fineness module of 1.3 as fine aggregate; sandstone crushed stone M 1200 with factions 5 – 20 mm as coarse aggregate; coarse aggregate void 0.408 with density in a piece 2703 kg/m³; superplasticizer Vinavil Flux 3 were used for the research.

The composition of the mortar component: C/S = 1/1.11 by mass. Crushed stone from quartz sandstone with elastic modulus 40300-41800 N / mm² was used as a coarse aggregate.

Compressive Strength Samples - Cubes 150x150x150 mm. Samples for determining the elastic modulus - prisms 150x150x600 mm.

The following indicators have been determined: limit of cubic and prismatic compressive strength, modulus of deformations, dependence of “stress-strain”, moment of beams cracking, dependence “moment-deflection”, limiting value of bending moment, relative deformations at the level of compressed and stretched reinforcement (Figure 1).

The rectangular beams 125x250 mm with a span of 2400 mm, tested by the concentrated forces in the span thirds were used as experimental samples.

The beams were made of concrete with a design strength of 46 MPa. The beams were reinforced 2∅12 A500 in the extended area and 2∅6 A400 in the compressed zone.

The test procedure included stepwise loading with a short-term static load with the beams being brought to failure. The tests were carried out on a special stand equipped with a mechanical jack. The magnitude of the loading steps was 5% and 10% of the expected maximum load, respectively, at the initial stages and after the cracks’ appearance.
3. Results
The research results are presented in Table 1 and in Figures 2 - 6.

| Index                                | Value  |
|--------------------------------------|--------|
| Prismatic strength, N/mm²            | 46.7   |
| Elastic modulus, N/mm²               | 37420  |
| Flexural moment maximum, T·M         | 3.19   |
| Deflection maximum, mm               | 18.1   |

Figure 1. Procedure for testing the reinforced concrete beam.

Figure 2. Relationship between level of compressive strength and relative deformation of concrete. long – longitudinal deformation; trans – transverse deformation.
Figure 3. Relationship between level of compressive strength and volume change of concrete (left) and time of ultrasonic pulses (right).

Figure 4. Relationship between flexural moment and relative deformations of concrete under steel bars.
\[ \varepsilon_{\text{comp}} \] – concrete under compressive strength; \[ \varepsilon_{\text{tens}} \] - concrete under tensile strength.
Figure 5. Relationship between deflection and level of flexural moment.
0.2 … 0.966 – level of flexural moment.

Figure 6. Relationship between deflection of beam and level of flexural moment.

4. Discussion
The beams failure started with reinforcement in the tensile zone and ended with concrete in the compression zone. The beams failure was accompanied by the formation of a large number of cracks and their opening, an increase in deflections and deformations and a reduction in the height of the
compressed zone. Compared with the beams made of ordinary concrete [1-3], the number of cracks was greater, but the width of their opening was less.

With the end of the stable deformation zone, the formation of concrete spalling in the compressed zone started. The stability loss of the compressed reinforcement occurred simultaneously with the delamination of concrete spalls. Moreover, the area of the spalls was less than in ordinary concrete [4, 5], but their number is greater.

The strength of the normal sections of the test beams was characterized by the value of the greatest moment in the pure bending zone. The stresses in the concrete of the extreme compressed fiber and tensile reinforcement were determined using the experimental diagrams \(\delta - \varepsilon\) by measured deformations.

Reinforcement failures that could not be measured were calculated using the hypothesis of flat sections through the deformation of the extreme compressed fiber and the height of the compressed zone.

Analysis of the critical values of the experimental parameters of the stress-strain state of normal sections shows that their change obeys, in general, the laws characteristic of bending elements made of ordinary concrete [5-8]. The beams showed a stable decrease in the height of the compressed zone with increasing load.

All beams’ extreme compressed fiber experimental deformations showed that their values, when the maximum load is reached, are on the descending branch of the compression diagram of the experimental concrete prisms. In this case, the stresses in the extreme compressed concrete fibers are significantly lower than the prismatic strength and reach \((0.6 - 0.8) R_b\).

Framing concrete has a positive effect on the compressive concrete strength.

This is fully manifested in flexible elements, the bearing capacity of which is higher than that of the elements made of ordinary concrete [7-9].

Reinforcement failure at the maximum moment turned out to be higher than the deformations when the yield point was reached.

In order to test the possibility of applying the methodology of norms when calculating the strength of the reinforced concrete elements made of concrete of the frame structure, the theoretical values of the breaking moments for the author’s experimental beams were calculated. Comparing them with the experimental ones shows the excess of the experimental moments over the theoretical ones (up to 25%).

In general, such results are typical for the beams made of ordinary concrete [8-12].

At the same time, the resistance of the frame structure reinforced concrete beams made of concrete has a number of features. For the purpose of their determination, the experimental values of the compressed zone diagram completeness \(\xi_0\) were revealed as well as the boundary value \(\xi_R\).

The experiments show that the coefficient of completeness of the stress diagram \(\xi_0\) of the frame structure for the elements made of concrete is 10-15% lower than for equal strength heavy concrete [13-16].

Reduced values \(\xi_0\) and \(\xi_R\) testify to the less practical work nature of the bending elements made of concrete of the frame structure at the limiting stage. These data correspond to the diagrams \(\delta - \varepsilon\) concrete prisms of the frame structure, which, in comparison with the diagrams for heavy concrete [15-19], are more straightened and have flatter ascending and steep descending branches, which reflects their less plastic deformation.

Comparison of the experimental deflections in the range of operational loads with the calculated ones according to the norms showed their satisfactory convergence.

The crack resistance of the beams was estimated from the moments of formation and the width of normal cracks. The process of cracking and crack opening in general does not differ from the beams made of ordinary concrete [1-12]. At the same time, the characteristic drop in the load at the moment of the first crack formation and a sharp increase in deformations are less pronounced.

The relative value of the cracking moment was 0.4-0.5, which is significantly higher than in the ordinary structures [20-25].
5. Summary
It is possible to assume, that the frame structure bending reinforced concrete elements made of concrete have a higher resistance to external loading. Their strength and crack resistance are higher, and the width of crack opening and deflections is lower than the similar bending elements made of ordinary concrete.

Therefore, according to the experimental reinforced concrete beams studies results, it can be concluded that the concrete of the frame structure has a positive effect on the operation of bending structures under load.

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