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STRESS-STRAIN STATE OF NORMAL CROSS-SECTIONS OF TWO-LAYER CAOUTCHOUC CONCRETE-CONCRETE BENDING ELEMENTS OF BUILDING STRUCTURES

Problem statement. An experimental study on reinforced concrete bending elements shown that progressive increase in external load involves three typical stages of the stress-strain state. We established, however, that these stages insufficiently reflect the operation of two-layer caoutchouc concrete-concrete bending elements.

Results and conclusions. The program of research and experimental results of stress-strain state of normal cross-sections of two-layer bending caoutchouc concrete and concrete elements are presented. The results of determination of normal cross in a midspan are given. Four stages of stress-strain state are recognized. The order of crack resistance calculation of two- layer caoutchouc concrete-concrete beams is proposed.

Keywords: two-layer structures, bending elements, stress-strain state, caoutchouc concrete.

Introduction

One of the tasks of engineering science is to design advanced load-carrying structures and to create more efficient and precise methods of their calculation. In order to design efficient building constructions with a high load-carrying capacity, crack growth resistance and low deformability at the Department of reinforced concrete and stone structures of Vorornezh State University of Architecture and Civil Engineering a research was conducted on two-layer caoutchouc concrete bending elements of building constructions with caoutchouc concrete [1] in a tension area. The study and design of multi-layer concrete and caoutchouc concrete structures allows to use the most valuable properties of each of the materials to the best advantage.

Concrete assists in compression, while caoutchouc concrete has a high durability both by compression and tension. Besides, a caoutchouc concrete layer application allows to isolate the reinforcement from the aggressive environment. It is not possible to construct efficient building constructions without firstly studying the stress-strain state occurring when an effort is applied. This is also true in case of caoutchouc concrete [1] and constructions based on it, since this composite is recently discovered and thus insufficiently studied.

The experiments with reinforced concrete bending elements showed that as an external stress gradually increases, three typical stages of stress-strain state can be observed: stage I takes place before cracks start to form in a concrete tension area, stage II takes place after cracks occur in a concrete tension area and stage III takes place when failure occurs [2]. These stages of stress-strain state were discovered by Mujad [3] during the study of multilayer bending elements with thin carrying basalt concrete layers. In our opinion, these three stages of stress-strain state insufficiently reflect the operation of two-layer bending elements which include two materials with various compressibility and tension limits (caoutchouc concrete and concrete).

The aim of our research is to study the stress-strain state of normal sections of two-layer caoutchouc concrete and concrete bending elements.

1. The research program of stress-deformed state of normal sections of two-layer caoutchouc concrete and concrete bending elements

Four series of lamellar caoutchouc concrete and concrete beams with different correlations of layers and percentage of longitudinal reinforcement were made and tested for obtaining a visual image of the stress-deformed state of normal sections of two-layer caoutchouc concrete and concrete bending elements in a clear tension area under low reinforcement and in over reinforced sections. The characteristics and the loading scheme of the beams tested are presented in Fig. 1.

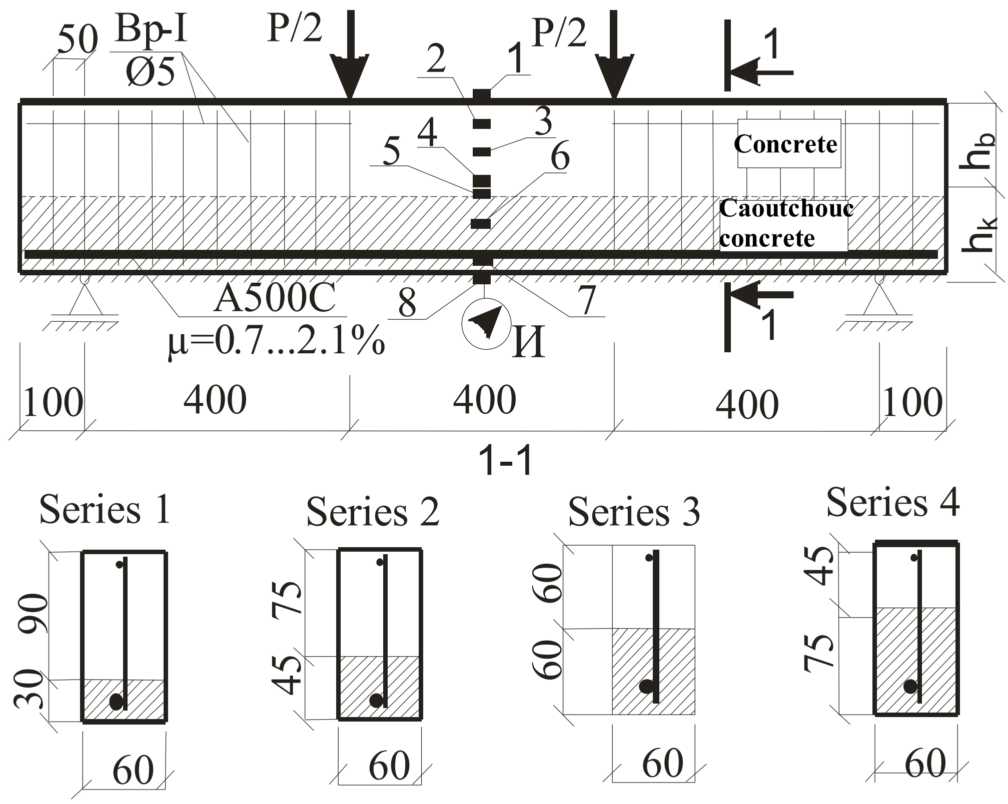

Fig. 1. The scheme of reinforcement and testing of the beams:
1—8 are resistance strain gauge for determining longitudinal deformations;
h_k is caoutchouc concrete layer height; h_b is concrete layer height

The resistance strain gauges 1—8 glued along the section height are intended for longitudinal deformations measurement. The resistance strain gauges 4 and 5 are glued near the surface contact area. The resistance strain gauge 7 is glued onto the reinforcement and intended for deformation measurement in the reinforcement.

The loading of the beams was conducted with the application of two equal concentrated forces increasing successively up to the failure (see Fig. 1).

When such a stress is applied, a clear tension area forms between the application points. The beam samples were tested on a laboratory press П-5. The loading was evenly supplied to a sample up to the moment of its failure. The maximum value of a press effort in the moment of the sample failure registered by a resistance strain gauge was accepted as a value of the destructive stress on the sample. The resistance strain gauge readings were taken by "The resistance strain gauge interface PCD-300A" device.

The test analysis allowed to determine the character of longitudinal deformations distribution along the section height in a clear bending zone. For a transition from deformations to stresses the dependences "σ-ε" were used in compression and tension (for caoutchouc concrete and concrete) obtained during the tests of sample prisms and "figures-of-eight". The four curves of deformations and loads distributions are presented for each beam.

The test results of the two most typical beams are given in Fig. 2.

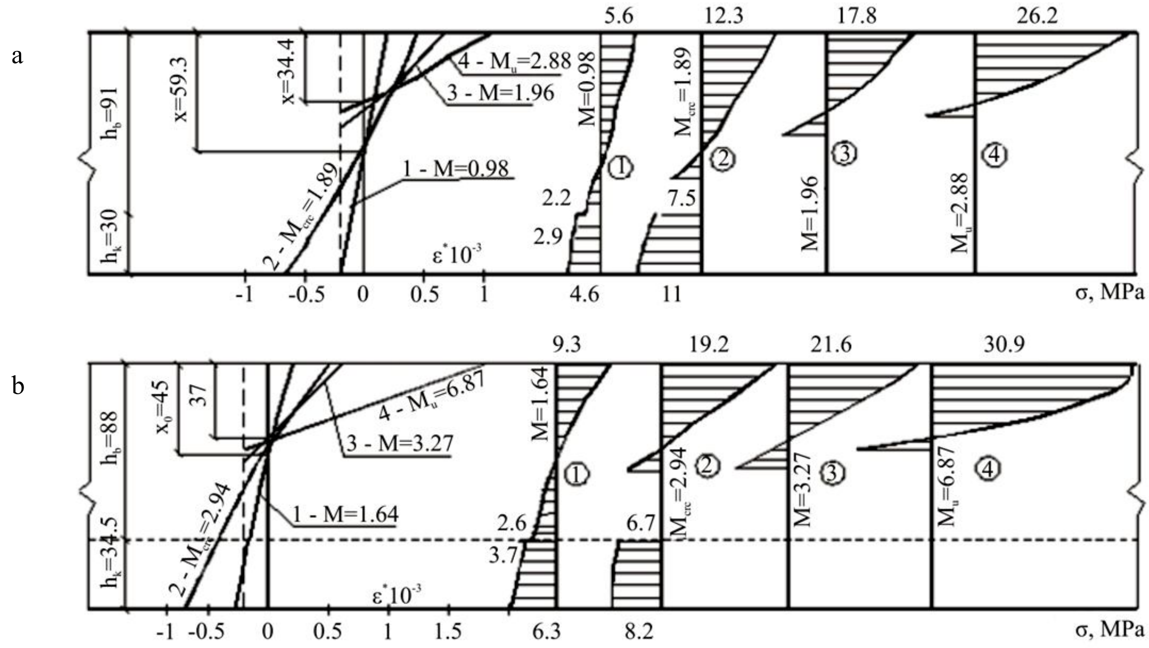

Fig. 2. Stress-deformed state of a normal section in the middle of a span:
a — beams C1-8K-30-a (failure in the reinforcement); b — beams C1-14K-30-a (failure in concrete);
h_k — caoutchouc concrete layer height, mm; h_b is a concrete layer height, mm;
M_{crc} — moment of crack formation, kNm; M_u is a moment of failure, kNm;
1 — a curve of deformations and loads distribution before the crack formation in concrete;
2 — a curve of deformations and stresses distribution after the crack formation in concrete and before the first normal crack appeared in caoutchouc concrete; 3 — a curve of deformations and stresses distribution after the first normal crack appeared in caoutchouc concrete;
4 — a curve of deformations and stresses distribution before the failure of the beam

2. Stages of stress-deformed state of a normal section of two-layer caoutchouc concrete and concrete bending elements in the middle of a span. Analyzing the relationship between the deformations and loads along a section height to a stress level, it is possible to conclude that a normal section of two-layer caoutchouc concrete and concrete bending elements in the middle of a span undergoes the four stages of stress-deformed state.

Stage 1 takes place before the first normal cracks formation in concrete. Till the moment first normal cracks start to appear in concrete, the deformations of compression and tension are distributed according to the linear law.

At this stage the stresses in concrete, caoutchouc concrete, and the reinforcement are not large, deformations are of elastic nature, the relationship between the deformations and stresses is linear. Before cracks start to appear in concrete, the values of deformations of an extreme stretched fibre reach the limit [2]. As the stresses further supplied increase, transition to a new qualitative state in the construction operation begins.

Stage 2 takes place after cracks appear in concrete and before first normal cracks appear in caoutchouc concrete. Besides, the deformations of the lower fibre reached their maximum (limit) values, inelastic deformations develop in a tension region of caoutchouc concrete. The relationship between the deformations and stresses in stretched caoutchouc concrete is non-linear.

At this stage, a part of the concrete from a tension region are withdrawn from operation. The tension stress profile is slightly curved, while the compression stress profile remains almost straight (see Fig. 2a, b, curve 2). The deformations of the extreme fiber of a tension face of all the beams tested are presented in the table below.

Table

Compressed zone height and deformations of a tension area at the moment of the first crack formation and compressed zone height at the moment of failure

Beam code	x_0, mm	x_p, mm	ε_{kt}*10^3
С1-8К-30-а	38.2	34.4	0.67
С2-8К-45-а	52.3	41.5	0.55
С2-8К-45-б	39.8	37	0.65
С3-8К-60-а	52	30.8	0.67
С3-8К-60-б	58.21	27.5	0.7
С4-8К-75-а	54.2	54.2	0.82
С4-8К-75-б	49.8	49.8	0.92
С1-10К-30-а	49.6	30.2	0.73
С1-10К-30-б	55.8	31.6	0.48
С2-10К-60-а	47.2	30	0.71

End of Table

Beam code	x_0, mm	x_p, mm	ε_{kt}*10^3
C2-10K-60-б	44.2	28.8	0.7
C3-10K-30-a	55.1	35.6	0.67
C3-10K-30-б	52.3	35	0.75
C4-10K-75-a	56	38.3	0.68
C4-10K-75-б	54.7	27	0.77
C1-12K-30-a	51	35.7	0.44
C1-12K-30-б	43.7	26.4	0.67
C2-12K-45-a	45.4	32.1	0.56
C2-12K-45-б	49.2	37.4	0.75
C3-12K-60-a	52.2	37.4	0.64
C3-12K-60-б	45.4	26.6	0.61
C3-12K-60-в	53.6	43.9	0.62
C4-12K-75-a	55	45.3	0.72
C4-12K-75-б	58.6	32.4	0.8
C1-14K-30-a	45	37	0.69
C2-14K-45-a	60	58	0.54
C2-14K-45-б	49	41.7	0.48
C3-14K-60-a	51.2	43.2	0.54
C3-14K-60-б	53.8	36.7	0.77
C3-14K-60-в	45.4	31.7	0.68
C4-14K-75-a	52.7	45.4	0.6
C4-14K-75-б	61	39.4	0.71

Notes on the table: x_0 is a compressed zone height before the crack formation; x_p is a compressed zone height after the crack formation in caoutchouc concrete; ε_{kt} is a deformation of the extreme caoutchouc concrete fibre in a tension area at the moment of the crack formation in caoutchouc concrete.

Stage 3 takes place after the normal crack formation in caoutchouc concrete. At this stage there is a significant redistribution of deformations in normal sections. At that point of the tension area where the cracks had formed, a tension effort is perceived by the reinforcement. There is reinforcement adherence to caoutchouc concrete in the intervals between the cracks in a tension area. As the crack edges move away, tension efforts develop in caoutchouc concrete and decrease in the reinforcement. As the stress further increases in a compressed zone concrete, inelastic deformations develop and the tension profile in a compressed zone is curved.

The upper fibre compression deformations increase but they do not reach the limit values.

At this stage a part of a tension area not damaged by the cracks continues to resist the external stress and is responsive the tension effort. Here new cracks appear and those already existing develop (see Fig. 2a, b, curve 3). The compressed zone height decreases significantly (see Table).

Stage 4 takes place immediately before the moment of failure. At this stage there are inelastic deformations in compressed zone concrete, the compression stresses are of curvilinear nature. The compressed zone height decreases significantly (see 2a, b, curves 3).

During low reinforcement, the reinforcement reaches the yield stress, the stresses in compressed zone concrete under the effect of a growing deflection of an element. The reduction of the compressed zone height also reach the values of a temporary resistance to compression.

The failure of a caoutchouc concrete and concrete element starts from the compressed zone reinforcement and ends with the breaking-up of the compressed zone concrete. Like in case of reinforced concrete bending element, this failure is of elastic nature. The tests show that the deformations in the reinforcement during this failure are similar to the deformations of the reinforcement yielding during the compression of a single rod. During an over reinforced section the failure occurs in concrete (in the compressed zone). In this case, the concrete deformations reach the limit compression. This failure is also of a fragile nature.

Besides, it should be noted that the change in stress-deformed state of the samples as well as their load-carrying capacity is mostly dependent on the longitudinal reinforcement percentage and the caoutchouc concrete layer height.

The four stages of stress-deformed state of typical beams with a low thickness of a caoutchouc concrete layer were examined above. At a high thickness of a caoutchouc concrete layer cracks in compressed zone concrete develop at Stage 3.

The tests performed showed that in this case the material (caoutchouc concrete) expenses increase. However, the main characteristics of the constructions such as load-carrying capacity, crack growth resistance and low deformability enhance insignificantly. It should also be noted that at a low reinforcement and greater concrete layer height, Stage 3 may be missing, since the moment of crack formation coincides with the moment of failure (e. g. in the beam C4-8K-75-a).

The experimental research revealed that the contact surface between the two materials does not fail during the test (shear deformations in the contact zone are absent). In some beams a difference of the deformations in the materials was observed at some distance from its border, however.

Conclusions

The tests performed showed that in order to get a full insight into the way two-layer caoutchouc concrete and concrete bending elements operate, it is necessary to single out the four stages of stress-deformed state.

The tests also revealed that the calculation of crack growth resistance of two-layer caoutchouc concrete and concrete beams should be conducted in two stages: the calculation on the basis of crack formation in caoutchouc concrete and in concrete according to Stage 1 and Stage 2 of the stress-deformed state; the durability calculation according to Stage 4 of the stress-deformed state. At all the stages the deformations in a section obey the law of plane sections. Thus, this law can be applied while calculating the two-layer caoutchouc concrete and concrete bending elements on the basis of load-carrying capacity and crack growth resistance.

Additionally, while calculating on the basis of load-carrying capacity of two-layer caoutchouc concrete and concrete bending elements at the failure in a tension area (failure in the reinforcement), it is necessary to consider an increase in the tension limit due to reinforcement adherence to caoutchouc concrete.

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