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To Calculation Of Bended Elements Working Under The Conditions Of Exposure To High And High Temperatures On The Lateral Force By A New Method

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ABSTRACT

The article presents a new method for calculating bending reinforced concrete elements made of conventional and heat-resistant concrete operating under conditions of high and high technological temperatures on the action of transverse forces. The advantage of the proposed calculation method over the method adopted in the current design standards based on a comparison of the calculation results of the experimental data is shown.

KEYWORDS

Ordinary heavy concrete, heat-resistant concrete, reinforcement, bending element, shear force, inclined section, bending moment, heating temperature, strength, crack resistance, longitudinal reinforcement, clamp, engagement force, thrust force.

INTRODUCTION

When designing bending reinforced concrete structures of thermal units, special attention is paid to their calculation for the effect of transverse forces, since these structures often have short lengths and large transverse forces arise during operation. The design of bending reinforced concrete elements operating under conditions of high and high technological temperatures on the shear force is being improved as experimental and theoretical research is accumulating. For this purpose, complex studies of the resistance of bending reinforced concrete elements made of ordinary and heat-resistant concrete to the action of transverse forces under the influence of high and high temperatures were carried out, and proposals were developed for calculating the strength of inclined sections [1]. For this, the accumulated experimental material of both the authors and other researchers was analyzed [1-10]. The essence of the analysis was to compare the results of calculations by the KMC method [11, 12] and the proposed method.

RESEARCH METHODOLOGY

When developing a new calculation method, simple methods of statistical processing were used. As a result of comparing the experimental data with the calculation results using the new method, the following data were obtained. Analysis of the strength of inclined sections of beams tested with one-sided heating showed that the method of calculating the shear force, developed for elements operating at normal temperatures, can be applied to elements operating at elevated and high temperatures. At the same time, it was revealed the need to take into account the change in the strength and deformative properties of concrete and reinforcement during heating and the features of the stress-strain state of a bent element under conditions of one-sided heating.

A system of longitudinal and transverse forces is introduced into the design scheme of the forces of an inclined section of a bent reinforced concrete element operating under unilateral heating: in concrete above an inclined crack - N_{b1} and Q_{b1}, under an inclined crack N_{b2} and Q_{b2}, engagement forces in an inclined crack N_3 and Q_3, in a longitudinal reinforcement - N_s and Q_s and axial forces in transverse reinforcement crossing an inclined crack - Q_w (Figure 1).

The forces in the longitudinal reinforcement and the forces of engagement in an inclined crack are considered in the form of the total values $N_{s3}= N_s - N_3$ and $Q_{s3} = Q_s + Q_3$, applied at the point of intersection of the inclined crack by the longitudinal reinforcement.

The design condition for the strength of inclined sections of bent reinforced concrete elements operating with one-sided heating is as follows:

$$Q=Q_x+Q_{b1}+Q_{b2} \qquad (1)$$

The transverse force Q_x is determined taking into account the maximum heating temperature of the clamps according to the formula:

$$Q_x=\sum R_{swt}\cdot A_w=q_w\cdot c \qquad (2)$$

The transverse force Q_{b1}, perceived by the concrete in the compressed zone above the inclined crack, is determined by the formula:

$$Q_{b1}=0,5R_{sht}\cdot b\cdot x \qquad (3)$$

The transverse force Q_{b2}, which characterizes the thrust force in the longitudinal reinforcement and the engagement forces in the inclined crack, is determined by the formula:

$$Q_{b2}=0,7R_{sht}\cdot b\cdot (x_o - x) \qquad (4)$$

The value of concrete shear resistance during heating R_{sht} is determined depending on the concrete temperature at a distance of $0.2h_o$ from the most compressed edge of the section by the expression:

$$R_{sht}=2,5\, R_{bt}\cdot (1+5\cdot \sigma_y/R_{bt}) \le 0,5R_{bt}, \qquad (5)$$

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where σ_y - vertical stresses from the local action of the load or the support reaction.

The values of the height of the compressed concrete zone above the normal X_o and inclined X cracks are determined by the formulas:

$$X_o/h_o = 0{,}5\nu\mu_s+L^2/0{,}5\nu\mu_s+L\,; \qquad (6)$$

$$X/h_o=2L-x/h_o; \qquad (7)$$

Where $\nu=1{,}5\cdot E_{st}/E_{bt}$, $L=M/R_{bt}\cdot b\cdot h_o\cdot Z_1$,

for ordinary concrete elements $Z_1=0{,}7h_o$, from heat-resistant concrete $Z_1=0{,}6h_o$.

The length of the projection of the inclined crack "C" on the longitudinal axis of the element is determined from the equation of equilibrium of the moments in the lower block under the inclined crack.

If the height of the compressed zone of concrete X above an inclined crack, determined by formula (7), turns out to be negative, then the bending moment and shear force that can be perceived by the section are calculated taking the calculated stress diagram in concrete over normal triangular with a maximum on the most compressed face of the section R_{btem} .

In this case, the height of the compressed zone X_o above normal cracks is determined as when calculating the strength of normal sections. For small values of the relative shear span ($0.5\leq a/h_o\leq 1.5$), the design shear force is determined from the condition of the strength of short elements:

for elements without transverse reinforcement:

$$P = k_{bt}\cdot\gamma_b\cdot R_{btem}\cdot b\cdot l_p\cdot sin\alpha, \qquad (8)$$

for elements with transverse reinforcement:

$$P=[K_{bt}\cdot\gamma_b\cdot R_{btem}+\sum K_{st}\cdot\gamma_s\cdot R_{st}\cdot\mu_w\cdot sin\alpha(\alpha+\beta)]\cdot b\cdot l_p\cdot sin\alpha, \qquad (9)$$

Where $k_{bt}=0{,}7$, $k_{st}=0{,}9$ – coefficients that take into account the deviation of pleasant calculation schemes from the actual; γ_b and γ_s - coefficients that take into account the effect of surrounding concrete and reinforcement on the strength of an inclined strip, are determined according to the rules for calculating local shear according to KMK 2.03.04-98; μ_w is the transverse reinforcement coefficient; α is the angle of inclination of the calculated strip to the horizontal; β - angle of inclination of transverse reinforcement; l_p is the calculated width of the inclined strip.

RESEARCH RESULTS

Comparison of the results of calculating the strength of inclined sections according to the proposed method with the results according to the current method according to KMK 2.03.04-98 and with experimental data are given in table 1.

The new method for calculating the strength of inclined sections of bent reinforced concrete elements operating with one-sided heating has high accuracy and reliability, correctly reflects the essence of the phenomenon and gives a better agreement with experience. The ratio of the experienced shear force to the theoretical for beams made of ordinary heavy concrete was 1.05, for beams made of heat-resistant

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concrete - on alumina cement - 1.18, on Portland cement - 1.20 and on liquid glass - 1.23.

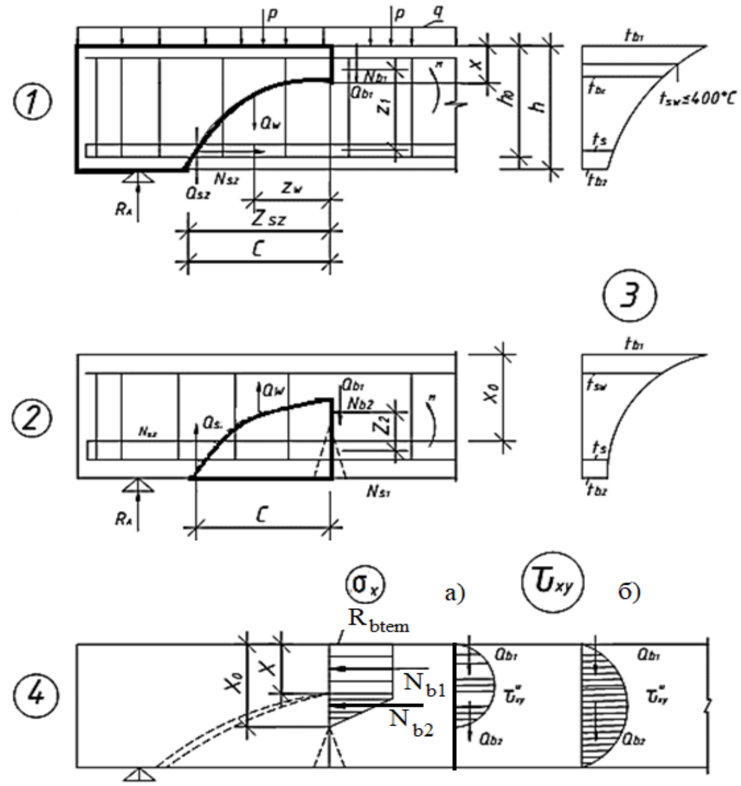

Fig. 1. Calculation diagram of efforts in an inclined section of a reinforced concrete element with one-sided heating: 1 - in the upper block; 2 - in the lower block; 3 - temperature distribution over the section height; 4 - calculated stress diagrams in concrete; a - in elements without transverse reinforcement, b - with clamps.

Before the destruction of reinforced concrete beams along an inclined section with one-sided heating, the total transverse force is perceived:

In beams without clamps: - compressed concrete over an inclined crack - 16-44%;

- the total value of the thrust forces in the longitudinal reinforcement and the forces of engagement in an inclined crack - 56-84%;

Table 1.
Comparison of Experimental and Theoretical Shear Force

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Beams cipher	Temperature , ^{0}C		Concrete type	Concrete strength, MPa		Slice span a, cm	Experienced breaking shear force Q_{ult}^{on}	Theoretical shear force KMK 2.03.04-98 Q_{1ult}^{meop} , kN	$\frac{Q^{on}_{ult}}{Q_{1ult}^{meop}}$	Theoretical shear force according to the new method Q_{2ult}^{meop}, kN	$\frac{Q_{ult}^{on}}{Q_{2ult}^{meop}}$
	On the squeezed edge	At a distance of $0.2h_o$ from the compressed face of the section		R_{btem}	R_{bttem}						
1	2	3	4	5	6	7	8	9	10	11	12
The experiments of Y.M. Makhkamov											
БО-1-20	20	20	normal heavy Portland cement with granite crushing and quartz sand	39,5	4,35	27	190	220	0,86	195	0,97
БО-1-70	80	70		33,2		27	164	184	0,89	163	1,01
БО-1-100	125	106		30,5	3,5	27	158,5	183	0,87	150	1,06
БО-1-200	245	215		36	3,9	27	182	199	0,92	177	1,03
БО-2-20	20	20		39,5	4,35	66	75	88	0,85	79	0,95
БО-2-70	80	70		33,2	3,7	66	73	78	0,94	69,4	1,05
БО-2-100	110	96		30,5	3,5	66	68	74	0,92	63,8	1,07
БО-2-200	195	175		36	3,9	66	71	78	0,91	72	0,99
БО-1-20П	20	20		39,5	4,35	27	255	246	1,04	221	1,15
БО-1-200П	248	209		36	3,9	27	234	219	1,07	200,4	1,17
БО-3-100П	120	105		30,5	3,5	66	90	121	0,75	115,5	0,78
БО-2-400П	235	198		36	3,9	68	92	129	0,72	118,8	0,78
БГ-1-20	20	20	Heat-resistant on alumina cement with fireclay aggregates	35	3,6	27	239	121,3	1,97	205	1,17
БГ-1-300	382	325		17	1,25	27	213	52,0	4,10	148	1,44
БГ-1-500	560	475		16	1,5	27	187	86,9	2,15	139	1,25
БГ-1-800	856	725		15	1,08	27	122	79,7	1,53	114	1,07
БГ-1-20А	20	20		35	3,6	27	$\frac{260}{289}$	$\frac{123,4}{152,4}$	$\frac{2,11}{1,90}$	$\frac{225}{251}$	$\frac{1,16}{1,15}$
БГ-1-300А	377	320		17	1,25	27	$\frac{195}{221}$	$\frac{54,0}{80,8}$	$\frac{3,61}{2,74}$	$\frac{148}{174}$	$\frac{1,32}{1,27}$
БГ-1-500А	528	450		16	1,5	27	$\frac{200}{225}$	$\frac{87,4}{113,7}$	$\frac{2,29}{1,98}$	$\frac{139}{164}$	$\frac{1,44}{1,37}$
БГ-1-800А	910	770		14,8	1,05	27	$\frac{129,}{153}$	$\frac{86,3}{103,7}$	$\frac{1,50}{1,48}$	$\frac{114}{138}$	$\frac{1,13}{1,11}$
Table continuation 1											
1	2	3	4	5	6	7	8	9	10	11	12
БГ-2-20	20	20		35	3,6	66	63	49,0	1,29	81	0,78
БГ-2-300	335	290		17	1,25	66	56	21,0	2,67	52	1,08
БГ-2-500	530	470		16	1,5	66	83	35,8	2,32	79	1,17

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БГ-2-800	780	650		15,5	1,10	66	72	32,6	2,21	56	1,29
БГ-2-20А	20	20		35	3,6	66	78 145	49,0 117,0	1,59 1,24	82 149	0,95 0,97
БГ-2-300А	342	295		17	1,25	66	103 164	22,6 85,5	4,56 1,92	67 128	1,54 1,28
БГ-2-500А	528	460		16	1,5	66	81 140	35,8 97,0	2,26 1,44	74 133	1,09 1,05
БГ-2-800А	802	690		15,5	1,10	66	67 123	32,7 73,5	2,05 1,67	65 121	1,03 1,02
The experiments of V.M. Pryadko											
Б-1-20П	20	20	Heat-resistant on Portland cement with chamotte aggregates finely ground additive	23	1,71	91,5	75	26,8	2,80	84	0,89
Б-2-500П	525	410		29	1,0	91,5	125	23,5	5,32	108,5	1,15
Б-3-1000П	982	760		22	0,6	91,5	108	23,0	4,70	77,5	1,39
Б-3^А-1000П	1023	770		22	0,6	91,5	107	23,0	4,66	77,5	1,38
Б-4-20П	20	20		17	1,39	61	97	36,5	2,66	91,5	1,6
Б-5-500П	562	445		22	0,74	61	102	30,5	3,34	99,3	1,03
Б-6-1000П	935	760		16	0,49	61	125	27,7	4,52	88,7	1,41
Б-6^А-1000П	916	730		17	0,55	61	161	31,0	5,19	100,4	1,60
Б-7-20П	20	20		32	1,96	30,5	366	93,3	3,93	382,5	0,86
Б-8-500П	574	430		33	1,0	30,5	402	77,8	5,16	392,7	1,03
Б-8^А-500П	575	410		33	1,05	30,5	321	74,2	4,33	392,7	0,82
Б-9^А-1000П	1029	780		26,5	0,62	31,4	408	70,3	5,80	309,6	1,32
Б-10-20П	20	20		23	1,71	91,5	162	110,0	1,47	139	1,17
Б-11-400П	533	405		29	1,0	91,5	155	108,5	1,44	152	1,02
Б-12-1000П	997	810		20	0,52	91,5	119	91,5	1,30	110,5	1,08
Б-13-20П	20	20		17	1,64	61	295	155,5	1,90	186,5	1,58
Б-14-500П	534	420		22	0,9	61	247	136,2	1,83	197,3	1,25
Б-15-1000П	996	775		16	0,57	61	226	129,4	1,75	192,5	1,17
Б-15^А-1000П	1004	780		16	0,57	61	216	158,2	1,37	181,6	1,19
Table continuation 1											
Б-1-20Ж	20	20	Heat-resistant on liquid glass	17	1,69	91,5	95	26,5	3,59	101,5	0,94
Б-2-500Ж	525	410		32	1,05	91,5	125	24,7	5,06	118	1,06

Б-3-1000Ж	824	635	with chamotte fillers and finely ground magnesite	26,5	0,84	81,5	125	31,2	4,01	97	1,29
Б-3^{А}-1000Ж	999	820		23	0,68	91,5	112	31,5	3,56	81	1,38
Б-4-20Ж	20	20		18	1,64	61	88	40,3	2,18	107	0,83
Б-5-500Ж	584	435		26,5	1,06	61	174	41,7	4,17	164	1,06
Б-5^{А}-500Ж	660	450		26,5	1,06	72	177	34,0	5,21	159	1,11
Б-5^{Б}-500Ж	572	430		26,5	1,05	61	125	37,5	3,34	134	0,94
Б-6-1000Ж	772	470		26,5	1,05	72,5	177	36,2	489	142	1,25
Б-6^{А}-1000Ж	879	710		25	0,76	61	177	42,0	4,22	158	1,12
Б-7-20Ж	20	20		25	2,14	29,7	288	103,2	2,79	286	1,01
Б-8-500Ж	649	470		26,5	1,26	30,5	277	100,0	2,77	303	0,92
Б-8^{А}-500Ж	636	450		27	1,26	30,5	429	102,0	4,20	309	1,39
Б-9-1000Ж	951	760		19	0,91	30,5	379	109,5	3,46	269	1,41
Б-9^{А}-1000Ж	926	700		20	0,96	31	389	104,5	3,71	239	1,63
Б-10-20Ж	20	20		14	1,36	91,5	113	99,4	1,14	129	0,88
Б-11-500Ж	586	460		24	0,8	91,5	137	125,0	1,42	121	1,43
Б-11^{А}-500Ж	606	490		23	0,75	91,5	174	122,0	1,42	121	1,43
Б-12-1000Ж	1008	820		17	0,55	91,5	210	117,0	1,79	108,5	1,93
Б-12^{А}-1000Ж	946	760		19	0,58	91,5	210	122,0	1,72	116	1,81
The experiments of Z.D. Zatulovsky											
Б-0-2	150	80	Normal heavy on Portland cement with granite crushed stone and edge sand	20	1,05	63	52	38,5	1,35	46,5	1,12
Б-1-1Л	540	350		27	1,63	70	76	54,5	1,40	73,8	1,03
Б-1-1П	550	350		27	1,63	70	76	51,7	1,47	73,8	1,03
Б-1-2Л	400	250		26	1,5	70	76	41,7	1,82	70,4	1,08
Б-1-3Л	400	250		26	1,5	70	76	42,3	1,80	70,5	1,07
Б-2-2Л	580	400		35	1,96	55	94	101,5	0,93	103,2	0,91
Б-2-2П	440	350		35	1,82	80	102,5	99	1,04	88,4	1,16
Б-2-3Л	580	400		35	1,96	55	94	101,5	0,93	92,2	1,02

Б-2-3П	435	350		35	1,82	80	102,5	99,4	1,03	90,7	1,13
Б-3-2П	410	300		32	1,72	80	102,5	105,6	0,97	84,7	1,21
Б-4-1Л	500	200		28	1,54	60	99,5	70,6	1,41	90,5	1,10
Б-4-1П	420	200		28	1,54	80	99,5	70,6	1,41	83,4	1,18
Б-4-3Л	430	200		28	1,54	80	99,5	70,6	1,41	83,4	1,18
Б-3-1Л	20	20		32	2,65	50	230	152,4	1,51	221,2	1,04
Б-4-3П	20	20		28	2,80	60	140	123	1,14	146	0,96
Б-0-5	20	20		20,5	2,10	75	60	63	0,95	57	1,05
Б-1-3П	20	20		26	2,50	70	90	62	1,46	79	1,14
V. N. Shcherbatyuk's experiments											
БВ-1	125	110	Heat-resistant on Portland cement with fireclay aggregates and a finely ground additive	21,6	1,6	40	35,6	8,5	4,19	28,5	1,25
БВ-2	120	108		21,6	1,6	40	38,2	8,8	4,34	28,5	1,34
БВ-3	120	107		21,6	1,6	40	34,3	9,5	3,61	28,5	1,20
БС-1	112	102		27	2,6	40	40,7	17,3	2,35	37,5	1,09
БС-2	123	112		27	2,6	40	42	18,8	2,23	36	1,17
БС-3	120	108		27	2,6	40	44,5	19,3	2,31	36	1,24

Notes. 1. The theoretical shear force according to KMK 2.03.04-98 was calculated at the values of R_{bttem}, when heated to an average concrete temperature of the compressed section zone equal to $0.4h_0$.

2. Above the line - data for the span of the cut without clamps, below the line - with clamps.

CONCLUSION

The developed practical recommendations for calculating the strength of inclined sections of bent reinforced concrete elements made of ordinary and heat-resistant concrete correctly reflect the actual stress-strain state of bent elements under the action of transverse forces under conditions of high and high temperatures. The new calculation method makes it possible to more accurately assess the design strength of an element along an inclined section, increase their reliability and durability during operation, and provide steel savings, reduce the cost and labor intensity of constructing structures, and achieve a significant economic effect.

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