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CONTEXT / MUNDARIJA

Application of the experimental mathematical planning method for optimizing the composition of modified fine-grained concrete

A.I. Adilkhodjaev[1][a], A.N. Baymurzaev[1][b]
[1]Tashkent state transport university, Tashkent, Uzbekistan

Abstract:	The creation and analysis of a mathematical model that accurately describes the influence of input variables - the ratio of raw material components of the concrete mixture - on the compressive strength of high-quality fine-grained concrete at 28 days of normal hardening. This model is considered as the final target functions of.
Keywords:	mathematical modeling, raw material components, compressive strength, high-quality fine-grained concrete, regression equation, input factors, orthogonal central planning, expression level, horizontal target function, maximum value

Modifikatsiyalangan mayda donador beton tarkibini optimallashtirish uchun eksperimentni matematik rejalashtirish usulini qo'llash

Adilxodjaev A.I.[1][a], Baymurzaev A.N.[1][b]
[1]Toshkent davlat transport universiteti, Toshkent, O'zbekiston

Annotatsiya:	Yuqori sifatli mayda donali betonning normal qotishining 28 kunligida siqilishga bo'lgan mustahkamligiga ta'sir ko'rsatuvchi kirish o'zgaruvchilari - beton aralashmasining xomashyo tarkibiy qismlari nisbatlarining ta'sirini aniq tavsiflovchi matematik modelni yaratish va tahlil qilish. Ushbu model ning yakuniy maqsadli funksiyalari sifatida qaraladi.
Kalit so'zlar:	matematik modellashtirish, xomashyo tarkibiy qismlari, siqilishga chidamliligi, yuqori sifatli mayda donali beton, regressiya tenglamasi, kirish omillari, ortogonal markaziy rejalashtirish, ifoda sathi, maqsad funksiyasining gorizontali, maksimal qiymat

1. Kirish

Eksperimentni rejalashtirish - bu qo'yilgan masalani talab etilgan aniqlik bilan hal qilish uchun zarur va etarli bo'lgan tajribalar soni va o'tkazilish sharoitlarini tanlash jarayonidir. Eksperimentni rejalashtirishning matematik usulining maqsadi matematik empirik modellarni yaratishdir, ular kiruvchi o'zgaruvchan omillarning - beton aralashmasining xomashyo tarkibiy qismlari nisbatlarining - yuqori sifatli mayda donali betonning (YuSMDB) fizik-mexanik xususiyatlariga ta'sirini aks ettiradi va bu xususiyatlar chiquvchi maqsadli funksiyalar sifatida qaraladi.

Eksperimentni rejalashtirishning matematik usuli kiruvchi o'zgaruvchan omillarning chiqadigan ob'ektiv funksiyalar sifatida ko'rib chiqiladigan mayda donador betonning fizik–mexanik xususiyatlariga ta'sirini aks ettiruvchi matematik empirik modellarni yaratishga qaratilgan (rasm 1.) [1, 2, 3].
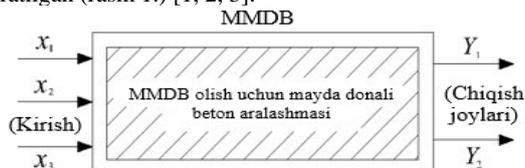
1–rasm. Eksperimental tizimning tuzilishi

Empirik modellarni tavsiflash uchun ob'ektiv funksiyalarni aniqlash. Eksperimental modelning chiqish ob'ektiv funksiyalari sifatida quyidagilar tanlandi:

- Y_1 – mayda donador beton qorishmaning harakatchanligi (D, mm);
- Y_2 – 28 kunlik normal qattiqlashuv davrida 100x100x100 mm o'lchamdagi MMDB kub namunalarining bosimga mustahkamligi (R28, MPa).

MMDB zichligi va mustahkamligiga, shuningdek beton aralashmaning harakatchanligiga ta'sir qiluvchi kiruvchi o'zgaruvchan omillar sifatida xom ashyoning sarflari tanlandi: S, S, Q, UK, GQK, ACE 388 superplastifikator (C388) va polipropilen yupqa dispresli tolalar (PYuT).

2. Tadqiqot metodologiyasi

1. MMDB zichligi, mustahkamligi va chidamliligiga ta'sir qiluvchi kirish omillarini tanlash. Tajribalar sonini kamaytirish uchun eksperimental tadqiqotlar va ilmiy–texnik adabiyotlarni tahlil qilish natijasida GQK, C388 va PYuT xarajatlari 10%, 1% va 1,5% sement og'irligidan mos ravishda doimiy va teng tanlangan. Mayda donador beton qorishmaning harakatchanligiga va MDB ning bosim

[a] https://orcid.org/0000-0001-5729-5178
[b] https://orcid.org/0009-0003-3966-1746

kuchiga ta'sir qiluvchi kirish omillari quyidagi shaklida tanlangan (1–jadval):

– x1 – nisbatlar S/S 0,36dan 0,40 miqdorgacha
– x2 – nisbatlar UK/S 0,45 dan 0,55 miqdorgacha;
– x3– nisbatlar Q/KM 0,8 dan 1,2 miqdorgacha.

1–jadval
Birinchi darajali rejalashtirish uchun kirish omillarining darajalari va ularning o'zgarish intervallari

Kirish omillari		O'zgarish darajalari			O'zgarish oralig' i δ
Tabiiy shaklda	O' zgaruvchi lar shaklida	– 1	0	+ 1	
S/S	x1	0,36	0,38	0,40	0,02
UK/S	x2	0,45	0,50	0,55	0,05
Q/KM	x3	0,8	1	1,2	0,2

Birinchi tartibli rejalashtirishda N zarur tajribalar soni formula bilan aniqlanadi (1):

$$N = 2^k = 2^3 = 8 , \qquad (1)$$

Bu erda k = 3 – kirish omillari soni.

1–tartibdagi ortogonal Markaziy rejalashtirish usuli yordamida hisoblangan modifikatsiyalangan mayda donador betonning kompozitsiyalari 2–jadvalda va 28 kunlik normal qattiqlashuvda (25 ± 5 ^{0}C haroratda va 95% namlikda) beton qorishmalarining harakatchanligi va betonning bosim kuchining qiymatlari 3 va 4–jadvallarda keltirilgan.

2 – jadval
1–darajali ortogonal Markaziy rejalashtirish usuli bilan hisoblangan MMDB tarkibi

№	O' zgaruvchilar shaklida			Tabiiy shaklda			Beton qorishmalarning tarkibi, kg/m³						
	x1	x2	x3	SS	UK S	Q KM	S	UK	GQK	Q	S	S388	PYu T
1	+1	+1	+1	0,40	0,55	1,2	551	303	55	1092	221	5,51	8,27
2	−1	+1	+1	0,36	0,55	1,2	564	310	56	1117	203	5,64	8,46
3	+1	−1	+1	0,40	0,45	1,2	580	261	58	1079	232	5,80	8,70
4	−1	−1	+1	0,36	0,45	1,2	594	267	59	1105	214	5,94	8,91
5	+1	+1	−1	0,40	0,55	0,8	643	353	64	848	257	6,43	9,64
6	−1	+1	−1	0,36	0,55	0,8	660	363	66	871	238	6,60	9,90
7	+1	−1	−1	0,40	0,45	0,8	675	304	67	837	270	6,75	10,12
8	−1	−1	−1	0,36	0,45	0,8	694	312	69	860	250	6,94	10,41

3 – jadval
Mayda donador beton qorishmalarning harakatchanligi

№	Tabiiy shaklda			Harakatchanlik D, mm						dispersiya S_i^2 xatolar
	S/S	UK/S	Q/KM	D_1	D_2	D_3	$Y_{1i}^{sr} = D_1^{sr}$	D_{li}	$(Y_{li}^{sr} - Y_{li})^2$	
1	0,40	0,55	1,2	95	100	95	96,667	103,96	53,193	8,333
2	0,36	0,55	1,2	90	90	95	91,667	83,54	66,043	8,333
3	0,40	0,45	1,2	105	100	105	103,333	103,96	0,393	8,333
4	0,36	0,45	1,2	85	85	80	83,333	83,54	0,043	8,333
5	0,40	0,55	0,8	115	120	120	118,333	116,88	2,112	8,333
6	0,36	0,55	0,8	80	80	75	78,333	96,46	328,576	8,333
7	0,40	0,45	0,8	120	125	125	123,333	116,88	41,646	8,333
8	0,36	0,45	0,8	105	105	110	106,667	96,46	104,176	8,333
Max S^2 = 8,333				$\sum (Y_{li}^{cp} - Y_{li})^2 = 596,181$						$\sum S_{li}^2 = 66,667$

4 – jadval
28 kun mobaynida MMDB namunalarining bosimga mustahkamligi

№	Tabiiy shaklda			Bosimga mustahkamlik R28 MMDB, MPa						Dispersiya S_i^2 xatolar
	S S	ZU S	Q K M	R_1	R_2	R_3	$Y_{2i}^{sr} = R_{2i}^{sr}$	R_i	$(Y_{2i}^{sr} - Y_{2i})^2$	
1	0,40	0,55	1,2	65,2	66,0	64,4	65,20	65,49	0,08	0,64
2	0,36	0,55	1,2	70,4	71,2	70,8	70,80	69,97	0,68	0,16
3	0,40	0,45	1,2	64,4	64,8	64,0	64,40	65,49	1,19	0,16
4	0,36	0,45	1,2	69,6	71,6	70,4	70,53	69,97	0,31	1,01
5	0,40	0,55	0,8	62,2	62,6	62,4	62,40	61,41	0,99	0,04
6	0,36	0,55	0,8	67,6	66,8	64,8	66,40	65,89	0,26	2,08
7	0,40	0,45	0,8	61,8	61,6	62,0	61,80	61,41	0,16	0,04
8	0,36	0,45	0,8	63,2	64,4	64,4	64,00	65,89	3,57	0,48
Max S^2 = 2,08				$\sum (Y_{2i}^{sr} - Y_{2i})^2 = 7,24$						$\sum S_{2i}^2 = 4,61$

2. Tajribalarning takrorlanuvchanligi gipotezasi (dispersiyalarning bir xilligi bo'yicha) Koxran mezoni G_{pass} yordamida sinovdan o'tkazildi. Kohren mezoninng hisoblangan qiymati (2) quyidagi formula bo'yicha hisoblab chiqilgan :

$$G_{pacc} = \max S^2 / \sum S_i^2 \qquad (2)$$

Koxran mezoninng kritik qiymati $G_{kr} = G_\alpha$ (f_1, f_2) qiymatlarga qarab [4] topilgan:

▪ xisoblagichning erkinlik darajasi $f_1 = k − 1 = 3 − 1 = 2$;

▪ maxraj $f_2 = N = 8$;

▪ ahamiyat darajasi $\alpha = 0,05$.
Shunda: $G_{kr} = 0,5157$.
Mayda donador beton qorishmaning harakatchanlik qiymatlarini hisobga olgan holda biz quyidagilarni olamiz:

$$S_{li}^2 = \sum S_i^2 = 66{,}667 \text{ ва } \max S^2 = 8{,}333 \rightarrow G_{pacc} =$$

$$\frac{S_{max}^2}{\sum S_i^2} = \frac{8{,}333}{66{,}667} = 0{,}125 \text{ ва } G_{pacc} = 0{,}125 < G_{kp} = 0{,}5157$$

Shunday qilib, dispersiyalarning bir xilligi gipotezasi qabul qilinadi.

Kunlik modifikatsiyalangan mayda donador betondan namunalarning bosimga mustahkamlik qiymatlarini hisobga olgan holda biz quyidagilarni olamiz:

$$S_{li}^2 = \sum S_i^2 = 4{,}61 \text{ ва } \max S^2 = 2{,}08 \rightarrow G_{pacc} = \frac{S_{max,}^2}{\sum S_i^2}$$

$$= \frac{2{,}08}{4.61} = 0{,}4512 \text{ ва } G_{pacc} = 0{,}4512 < G_{kp} = 0{,}5157$$

Shunday qilib, dispersiyalarning bir xilligi gipotezasi qabul qilinadi.

3. 1–tartibli regressiya tenglamalarini tuzish

5–jadval
1–tartibli regressiya tenglamalarining koeffitsientlar

Y_j \ b_i	b_0	b_1	b_2	b_3	b_{12}	b_{23}	b_{31}	b_{123}
Y_1　D, mm	100,21	10,21	– 3,96	– 6,46	1,04	4,38	3,96	–4,79
Y_2　R^{28}MMDB, MPa	65,69	–2,241	0,508	2,041	–0,692	–0,158	– 0,242	0,292

Hisoblash natijalariga ko'ra quyidagi regressiya tenglamalari (3) va (4) olingan:

$$Y_1 = 100{,}21 + 10{,}21x_1 - 3{,}96x_2 - 6{,}46x_3 + 1{,}04x_1x_2 + 4{,}38x_2x_3 - 3{,}96x_3x_1 - 4{,}79x_1x_2x_3 \quad (3)$$

$$Y_2 = 65{,}69 - 2{,}241x_1 + 0{,}508x_2 + 2{,}041x_3 - 0{,}692x_1x_2 - 0{,}158x_2x_3 - 0{,}242x_3x_1 + 0{,}292x_1x_2x_3 \quad (4)$$

Regressiya tenglamalari koeffitsientlarining ahamiyati Styudent mezoniga muvofiq tekshirildi ($t\alpha/(f_2)$).

b_j koeffitsienti muhim hisoblanadi, agar: $t_{bj} \geq t\alpha$ (f_2) (5) bu erda $t\alpha$ (f_2) – Styudenta taqsimotining kritik qiymati.

Muhim darajada $\alpha = 0{,}025$ va erkinlik darajalari $f_2 = N \times (k-1) = 8 \times (3-1) = 16$, 3.2–jadvalga asosan $t_{0,025}$ (16) = 2,1199 qiymatini topamiz [5].

Regressiya tenglamasining b_j koeffitsientlari uchun Styudent mezonining t_{bj} qiymatlari formula (6) yordamida aniqlandi:

$$t_{bj} = \frac{|b_j|}{S_{b\delta}}. \quad (6)$$

Regressiya tenglamasining koeffitsientlarining dispersiyasini baholash (7) formula bilan aniqlandi:

$$S_{b\delta} = \sqrt{\frac{S_{li}^2}{N}} \quad (7)$$

$S_{li}^2 = \sum S_l^2 = 0{,}753$ va $N = 8$ bo'lgan regressiya tenglamasi uchun biz quyidagilarni olamiz:

$$S_{b\delta} = \sqrt{\frac{S_{li}^2}{N}} = \sqrt{\frac{0{,}753}{8}} = 0{,}3068 \quad (8)$$

Regressiya tenglamasi koeffitsientlarining ahamiyatini tekshirish uchun Styudent mezonining qiymatlari (3) 5–jadvalda keltirilgan.

6–jadval
Regressiya tenglamasi koeffitsientlarining ahamiyatini tekshirish uchun Styudent mezonining qiymatlari (3)

j	0	1	2	3	4	5	6	7
	b_0	b_1	b_2	b_3	b_{12}	b_{23}	b_{31}	b_{123}
bj	100,21	10,21	– 3,96	– 6,46	1,04	4,38	3,96	– 4,79
$|b_j|$	100,21	10,21	3,96	6,46	1,04	4,38	3,96	4,79
t_{bj}	34,713	3,536	1,371	2,237	0,361	1,516	1,371	1,660

Koeffitsientlarning ahamiyatini tekshirgandan so'ng, ahamiyatsiz koeffitsientlar bekor qilindi, natijada tenglama paydo bo'ldi. (9):

$$Y_1 = 100{,}21 + 10{,}21x_1 - 6{,}46x_3 \quad (9)$$

$S_{li}^2 = \sum S_l^2 = 4{,}61$ va $N = 8$ (4) bo'lgan regressiya tenglamasi uchun biz quyidagilarni olamiz.

$$S_{b\delta} = \sqrt{\frac{S_{li}^2}{N}} = \sqrt{\frac{4{,}61}{8}} = 0{,}759$$

Regressiya tenglamasi (4) koeffitsientlarining ahamiyatini tekshirish uchun Styudent mezonining qiymatlari 7–jadvalda keltirilgan

7–jadval
Regressiya tenglamasi koeffitsientlarining ahamiyatini tekshirish uchun Styudent mezonining qiymatlari (4)

j	0	1	2	3	4	5	6	7
	b_0	b_1	b_2	b_3	b_{12}	b_{23}	b_{31}	b_{123}
bj	65,69	– 2,241	0,508	2,041	–0,692	– 0,158	– 0,242	0,292
$|b_j|$	65,69	2,241	0,508	2,041	0,692	0,158	0,242	0,292
t_{bj}	86,548	2,953	0,669	2,689	0,912	0,208	0,319	0,385

Koeffitsientlarning ahamiyatini tekshirgandan so'ng, ahamiyatsiz koeffitsientlar bekor qilindi, natijada tenglama hosil bo'ldi (10):

$$Y_2 = 65{,}69 - 2{,}241x_1 + 2{,}041x_3 \quad (10)$$

4. (9) va (10) tenglamalarning muofikliligini tekshirish

Modelning adekvatligi haqidagi gipotezani tekshirish S_{2ad} (11) adekvatlik dispersiyasi va F_{rass} Fisher mezonlari (12) hisoblashlariga asoslanadi.

$$S_{ad}^2 = \frac{\sum(Y_i^{cp} - Y_i^-)^2}{N - m}$$

$$F_{pacc} = \frac{S_{ad}^2}{S_{li}^2}$$

Bu erda: Y_i – regressiya tenglamasidan hisoblangan javob qiymati; N – barcha mumkin bo'lgan sinovlar soni, $N = 8$;

m – baholangan regressiya koeffitsientlari soni; m = 3.

F_{rass} ning hisoblangan qiymati $f_1 = N = 8$ va $f_2 = N - m = 8 - 3 = 5$ erkinlik darajalari raqamlari bilan aniqlangan 6–jadvaldagi F_{tabl} (f_1, f_2) qiymati bilan taqqoslandi [5]. Shunday qilib, kritik qiymat: F_{tabl} (8, 5) = 3,6875. Regressiya tenglamasi uchun (10):

$$S_{ad}^2 = 596{,}181/8 - 3 = 119{,}236 \text{ va } S_{li}^2 = \sum S_i^2 = 66{,}667$$

$$\rightarrow F_{pacc} = \frac{S_{ad}^2}{S_{li}^2} = 1{,}789 \text{ ва } F_{pacc} = 1{,}789 < F_{таб} = 3{,}687$$

Shuningdek, tenglama (10) amaliy tajriba natijalarini qanoatlantiradi.
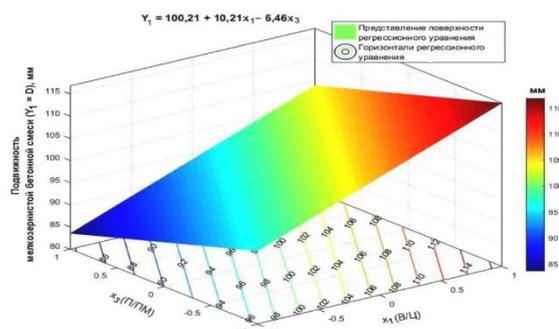
Regressiya tenglamasi uchun (11):

$$S_{ad}^2 = 7{,}24/8 - 3 = 1{,}448 \text{ va } S_{li}^2 = \sum S_i^2 = 4{,}61$$

$$\rightarrow F_{pacc} = \frac{S_{ad}^2}{S_{li}^2} = 0{,}3141 \text{ ва } F_{pacc} = 0{,}314 < F_{таб} = 3{,}6875$$

Shuningdek, tenglama (11) ham amaliy tajriba natijalarini qanoatlantiradi.

Matlab kompyuter dasturidan foydalanib, (10) va (11) regressiya tenglamalari uchun ob'ektiv funksiyani ifodalash yuzasi tasvirlari olindi, ular 2 va 3–rasmlarda keltirilgan.

2–rasm. 1–tartibli mayda donador beton qorishmasining harakatchanligining regressiya tenglamasi yuzasi tasviri
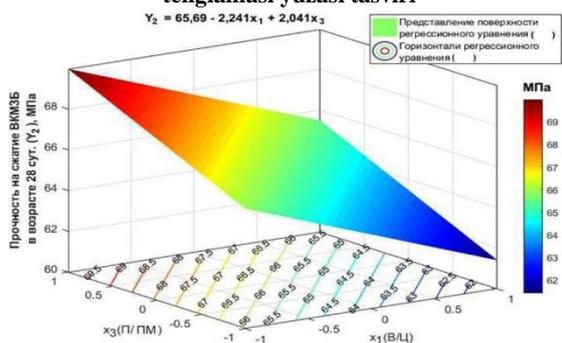
3–rasm. 1–tartibli MMDB (9) bosimga mustahkamligining regressiya tenglamasi yuzasining tasviri

3. Xulosa

1–tartibli regressiya tenglamalari yordamida olingan tajribani matematik rejalashtirish natijalaridan quyidagi xulosalar chiqarish mumkin:

1. Mexanik faollashtirilgan GQK, past kalsiyli UK, ACE 388 superplastifikatori va polipropilen tolalarni o'z ichiga olgan organo–mineral modifikatorlarni o'z ichiga olgan modifikatsiyalangan mayda donador betonlar 1–darajali tajribani rejalashtirishning maqsadli funksiyalariga ega :mayda donador beton qorishmasining harakatchanligi(D, mm) va regressiya tenglamalari (10) va (11) bo'yicha x_1 (C/S) va x_3 (Q/KM) o'zgaruvchilarga qarab, 28 kunlik normal qattiqlashuv S/KM (R^{28} MMDB, MPa) davrida MMDB dan namunalarning bosimga kuchi.

2. (10) va (11) regressiya tenglamalaridan kelib chiqadiki C/S (x_1) nisbatning pasayishi va Q/KM (x_3) nisbatning oshishi bilan mayda donador beton qorishmaning harakatchanligi pasayadi va eksperimental beton namunalarining bosimga mustahkamligi oshadi. Ko'rib chiqilgan qiymatlar oralig'ida UK (x_2) nisbati ta'siri ahamiyatsiz va shuning uchun uni e'tiborsiz qoldirish mumkin.

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Mualliflar to'g'risida ma'lumot/ Information about the authors

Adilxodjaev Anvar Ishanovich	Toshkent davlat transport universiteti rektorining strategik va istiqbolli vazifalarni amalga oshirish bo'yicha maslahatchisi e-mail: anvar1950@mail.ru Tel.: +998998704117 https://orcid.org/0000-0001-5729-5178
Baymurzaev Alisher Nukusbay uli	Toshkent davlat transport universiteti "Bino va sanoat inshootlari qurilishi" kafedrasi doktoranti e-mail: baymurzaev1818@gmail.com Tel.: +998913018882 https://orcid.org/0009-0003-3966-1746