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Scaling of precast-monolithic reinforced concrete frame building models, test program and selection of materials

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Abstract: The article presents a unified test program for the experimental study of precast-monolithic reinforced concrete frame buildings erected in permanent reinforced concrete shell formwork. Three building models are studied: *M-1* (a reference monolithic frame), *M-2* (shell-and-core columns, U-shaped precast-monolithic girders, monolithic floor slab) and *M-3* (a precast multi-hollow floor slab). The modelling is based on the *Buckingham Pi* theorem: the dimensionless π-complexes of similarity are derived, the 1:4 scale is substantiated, and recalculation formulas for the prototype are systematized. The loading scheme and test conditions comply with GOST 8829-94 and SHNK 2.03.01-19. Properties of the materials — class *B25* heavy concrete, *A400* steel, *Vr-I* wire and basalt reinforcement — were determined in an accredited laboratory. Testing of auxiliary specimens gave a mean prismatic strength R_{bm} = 30.5 MPa, a coefficient of variation C_v = 0.083 and a design strength R_b = 20.0 MPa. The results form the methodological basis for an objective comparison of the models.

Keywords: precast-monolithic reinforced concrete, frame building, scale model, *Buckingham Pi* theorem, permanent formwork, concrete strength, test program

Yig‘ma-yaxlit temirbeton sinchli bino modellarini masshtablashtirish, sinov dasturi va materiallarni tanlash

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Annotatsiya: Maqolada yechib olinmaydigan temirbeton qobiqli qoliplarda barpo etiladigan yig‘ma-yaxlit temirbeton sinchli binolarni eksperimental tadqiq etish uchun ishlab chiqilgan yagona sinov dasturi bayon etilgan. Tadqiqot obyekti sifatida uch turdagi bino modeli — *M-1* (etalon yaxlit sinch), *M-2* (qobiq-yadroli ustun, U-simon yig‘ma-yaxlit rigel va yaxlit orayopma) hamda *M-3* (ko‘p bo‘shliqli yig‘ma orayopma) qabul qilingan. Modellashtirish *Bakingem-Pi* teoremasi asosida amalga oshirilib, o‘xshashlikni belgilovchi o‘lchamsiz π-komplekslar keltirib chiqarilgan, 1:4 masshtabning qabul qilinishi asoslangan va asosiy kattaliklarni natura binosiga qayta hisoblash formulalari tizimlashtirilgan. Yuklash sxemasi hamda sinov shartlari GOST 8829-94 va SHNK 2.03.01-19 talablariga muvofiq belgilangan. Qo‘llanilgan materiallarning — *B25* sinfli og‘ir beton, *A400* sinfli po‘lat armatura, *Vr-I* sim va bazalt armaturaning fizik-mexanik xossalari akkreditatsiyalangan laboratoriyada aniqlangan. Yordamchi namunalarni sinash natijasida betonning o‘rtacha prizmatik mustahkamligi R_{bm} = 30,5 MPa, o‘zgaruvchanlik koeffisiyenti C_v = 0,083 va hisobiy qarshiligi R_b = 20,0 MPa etib aniqlangan. Natijalar uch turdagi modelni obyektiv taqqoslash uchun metodik asos bo‘lib xizmat qiladi.

Kalit so‘zlar: yig‘ma-yaxlit temirbeton, sinchli bino, masshtabli model, Bakingem-Pi teoremasi, yechib olinmaydigan qolip, beton mustahkamligi, sinov dasturi

1. Kirish

Hozirgi kunda respublikamizning barcha shaharlarida ko‘p qavatli turar-joy va jamoat binolari jadal sur’atlarda barpo etilmoqda [1]. Ularning aksariyati yechib olinadigan qoliplarda yaxlit temirbeton texnologiyasi bo‘yicha tiklanmoqda. Bunday texnologiyaning bir qator kamchiliklari — opalubka ishlarining qimmatligi, qurilish muddatining uzayishi, qurilish maydonida beton sifatini nazorat qilishning murakkabligi va ob-havo sharoitiga bog‘liqligi mavjud. Ushbu kamchiliklarni bartaraf etishning samarali yo‘li — yig‘ma va yaxlit texnologiyalarning afzalliklarini mujassamlashtirgan yig‘ma-yaxlit temirbeton texnologiyasini qo‘llashdir.

Biroq yig‘ma-yaxlit texnologiya bo‘yicha barpo etiladigan sinchli binolarning ustun–rigel–orayopma tugun zonalaridagi deformatsiya, yoriq hosil bo‘lish va mustahkamlik xususiyatlari, shuningdek yechib olinmaydigan temirbeton qobiqli ustunlarning yaxlit yadro bilan birgalikdagi ishlashi yetarli darajada tajribaviy

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o‘rganilmagan [8]. Shu bois ushbu tadqiqotda uch turdagi sinchli bino modeli — *M-1* (etalon yaxlit), *M-2* (qobiq-yadroli ustun, U-simon yig‘ma-yaxlit rigel, yaxlit orayopma) va *M-3* (qobiq-yadroli ustun, U-simon yig‘ma-yaxlit rigel, ko‘p bo‘shliqli yig‘ma orayopma) yagona sinov dasturi doirasida tajribaviy tadqiq etildi (1-rasm).

Mazkur maqolaning maqsadi — tadqiqotning birinchi bosqichini, ya’ni modellashtirish uslubi, yagona sinov dasturi va materiallarni tanlash masalalarini yoritishdan iborat.

1-rasm. Bino modellarini (M-1, M-2, M-3) tayyorlash jarayoni

2. Tadqiqot metodologiyasi

Temirbeton konstruksiyalarni to‘liq hajmda sinash katta moddiy va texnik xarajatlarni talab qilgani sababli, tadqiqot masshtabga solingan fizik modellar asosida o‘tkazildi. Modellashtirish nazariyasi G.A. Geniyev va V.N. Kissyukning ishlarida ishlab chiqilgan bo‘lib [2], uning matematik asosini *Bakingem-Pi* teoremasi tashkil etadi [3]. Ushbu teoremaga ko‘ra, fizik jarayonga ta’sir qiluvchi n ta o‘lchamli kattalik va *k* ta asosiy o‘lcham birligi (uzunlik *L*, kuch *F*, vaqt *T*) bo‘lganida, jarayonni $(n - k)$ ta o‘lchamsiz π-kompleks orqali to‘liq tavsiflash mumkin [4]. Temirbeton elementlari uchun asosiy o‘lchamsiz nisbatlar quyidagi ko‘rinishda ifodalanadi:

$\pi 1 = \sigma/Eb$; $\pi 2 = P/(fck \cdot l^2)$; $\pi 3 = (fy \cdot As)/(fck \cdot Ac)$; $\pi 4 = l1/l2$,

bu yerda σ — kuchlanish; E_b — betonning elastiklik moduli; P — yuk; f_{ck} — betonning prizmatik qarshiligi; A_s/A_c — armaturalash koeffisiyenti; l_1/l_2 — geometrik o‘lchamlar nisbati. Ushbu o‘lchamsiz komplekslar natura (original) va model uchun bir xil qiymatni saqlasa, tajriba natijalari masshtab koeffisiyenti yordamida bevosita natura binosiga ekstrapolyatsiya qilinadi.

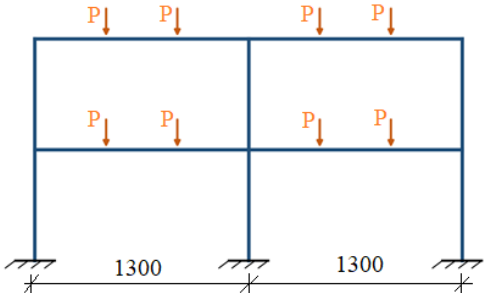
Geometrik o‘xshashlik $kl = l_m/l_p$ masshtab koeffisiyenti bilan ifodalanadi (*m* — model, *p* — natura). Tadqiqotda 1:4 masshtab qabul qilindi; bu qiymat laboratoriya sinov jihozlarining (gidravlik domkratlar, o‘lchash asboblari) imkoniyatlariga va natura binosining geometrik ko‘rsatkichlariga mutanosib ravishda tanlandi. Asosiy fizik kattaliklarni natura binosiga qayta hisoblash formulalari 1-jadvalda keltirilgan.

1-jadval

Masshtab koeffisiyentlari va qayta hisoblash formulalari

Kattalik	Belgisi	Qayta hisoblash formulasi	Izoh
Uzunlik	l	$l_p = l_m \cdot kl$	$kl = 4$
Kuch	P	$P_p = P_m \cdot kl^2 \cdot k\sigma$	to‘liq o‘xshashlikda $k\sigma = 1$
Kuchlanish	σ	$\sigma_p = \sigma_m \cdot k_\sigma$	—
Salqilik	f	$f_p = f_m \cdot kl \cdot k\sigma/kE$	kE — elastiklik modullari nisbati

Yuklash sxemasi sifatida har bir oraliqda rigel bo‘ylab oraliq uzunligining 1/3 nisbatida ikki nuqtaga to‘plangan vertikal statik yuk qabul qilindi (2-rasm). Yuklash gidravlik domkratlar va traversa yordamida bosqichma-bosqich amalga oshirildi; har bir yuklash bosqichining qadami loyihaviy chegaraviy yukning *0,1* ulushiga teng olindi. Sinovlar GOST 8829-94 [5] hamda SHNK 2.03.01-19 [7] talablariga muvofiq o‘tkazildi.



2-rasm. Bino modelining yuklash sxemasi

Namunalar Samarqand davlat arxitektura-qurilish universiteti (SamDAQU) qoshidagi tajriba-sinov laboratoriyasida tayyorlandi. Beton sifatida B25 sinfli portlandsementli og‘ir beton ishlatildi. Bog‘lovchi sifatida Jizzax shahridagi «HUAXIN CEMENT JIZZAH» MChJda ishlab chiqarilgan M450 markali portlandsement qo‘llanildi; sement aktivligi 32,7 MPa ni tashkil etdi. Model elementlari uchun beton qorishmasining tarkibi (1 m³ ga): sement 490 kg, qum 970 kg, chaqiqtosh 730 kg, suv 245 l; suv-sement nisbati S/S = 0,5; o‘rtacha hajmiy zichligi 2440 kg/m³. Yechib olinmaydigan temirbeton qobiq uchun mayda donali beton (sement 550 kg, qum 1590 kg, suv 275 l, D_{max} = 5 mm) ishlatildi.

Bo‘ylama armatura sifatida diametri 8 mm bo‘lgan A400 sinfli po‘lat armatura, ko‘ndalang armatura sifatida diametri 2 mm bo‘lgan *Vr-I* sinfli sim qo‘llanildi. Yechib olinmaydigan qobiqni armaturalashda diametri 4 mm bo‘lgan bazalt armaturadan foydalanildi. Barcha materiallarning fizik-mexanik xossalari GOST 31108-2020, GOST 30744-2001, GOST 8736-93, GOST 34028-2016 va GOST 12004-81 talablariga muvofiq, Oqdaryo tumanidagi «Regional Testing Centre» MChJ qoshidagi

akkreditatsiyalangan laboratoriyada tekshirildi (3–5-rasmlar).

3-rasm. Beton kublarni (a) va armaturani (b) sinash

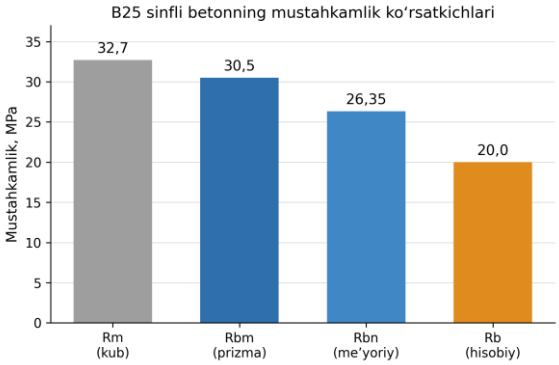
4-rasm. Prizma namunalarni sinash

5-rasm. Beton namunalarni sinash natijasi

3. Natija va muhokamalar

Yordamchi sinov namunalari asosiy modellar bilan bir vaqtda, bir xil beton partiyasidan tayyorlanib, bir xil sharoitda (nisbiy namlik 90%, 28 sutka) saqlandi. Har bir quyish partiyasidan o‘lchamlari 100×100×100 mm bo‘lgan kamida 3 ta kub namuna hamda 100×100×400 mm bo‘lgan 3 ta prizma namuna tayyorlanib, GOST 10180-2012 [6] talablariga muvofiq sinaldi. Prizmatik mustahkamlik va statistik tahlil natijalari asosida quyidagi ko‘rsatkichlar olindi: prizmatik mustahkamlikning o‘rtacha qiymati R_{bm} = 30,5 MPa; o‘rta kvadratik chetlanish S = 2,54 MPa; o‘zgaruvchanlik koeffisiyenti $Cv = S/R_{bm}$ = 0,083.

95% ishonchlilik bilan ta’minlangan me’yoriy qarshilik $R_{bn} = R_{bm}\cdot(1 - 1{,}64\cdot Cv)$ = 26,35 MPa, hisobiy qarshilik esa $R_b = R_{bn}/\gamma_{bc}$ = 26,35/1,3 = 20,0 MPa etib aniqlandi (6-rasm, 2-jadval). Ushbu qiymatlar keyingi nazariy hisoblar va chekli-elementli modellashtirish uchun dastlabki ma’lumot sifatida qabul qilindi.



6-rasm. B25 sinfli betonning mustahkamlik ko‘rsatkichlari

2-jadval

B25 sinfli betonning sinov natijalari

Ko‘rsatkich	Belgisi	Qiymat	Birlik
Sement aktivligi	—	32,7	MPa
Prizmatik mustahkamlik (o‘rtacha)	R_{bm}	30,5	MPa
O‘rta kvadratik chetlanish	S	2,54	MPa
O‘zgaruvchanlik koeffisiyenti	Cv	0,083	—
Me’yoriy qarshilik	R_{bn}	26,35	MPa
Hisobiy qarshilik	R_b	20,0	MPa

Po‘lat armatura namunalari GOST 12004-81 talablariga muvofiq universal sinov mashinasida (UMM-50) cho‘zilishga sinaldi; oqilish chegarasi, mustahkamlik chegarasi, nisbiy uzayishi va elastiklik moduli aniqlanib, olingan qiymatlar SHNK 2.03.01-19 [7] ning hisobiy ko‘rsatkichlariga mos kelishi tasdiqlandi. Shunday qilib, yagona sinov dasturi, 1:4 masshtabli modellashtirish uslubi va materiallarning ishonchli mexanik xossalari uch turdagi bino modelini bevosita taqqoslash imkonini beradigan metodik asosni tashkil etdi.

4. Xulosa

1. Yechib olinmaydigan temirbeton qobiqli qoliplarda barpo etiladigan yig‘ma-yaxlit sinchli bino modellarini tajribaviy o‘rganish uchun yagona sinov dasturi ishlab chiqildi.

2. *Bakingem-Pi* teoremasiga asoslangan 1:4 masshtabli modellashtirish uslubi qo‘llanilib, masshtab koeffisiyentlari va natura binosiga qayta hisoblash formulalari asoslandi.

3. Yordamchi namunalar sinovi asosida B25 sinfli betonning o‘rtacha prizmatik mustahkamligi R_{bm} = 30,5 MPa, me’yoriy qarshiligi R_{bn} = 26,35 MPa va hisobiy qarshiligi
R_b = 20,0 MPa etib aniqlandi.

4. Ishlab chiqilgan metodik asos uch turdagi modelning (*M-1*, *M-2*, *M-3*) kuchlanish-deformatsiya holati, yoriqbardoshligi va mustahkamligini obyektiv taqqoslash imkonini beradi.

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