JOURNAL OF TRANSPORT

ISSUE 1, 2026 vol. 3
E-ISSN: 2181-2438
ISSN: 3060-5164

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TOSHKENT DAVLAT TRANSPORT UNIVERSITETI

Tashkent state transport university

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VOLUME 3, ISSUE 1

MARCH, 2026

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TASHKENT STATE TRANSPORT UNIVERSITY

JOURNAL OF TRANSPORT

SCIENTIFIC-TECHNICAL AND SCIENTIFIC INNOVATION JOURNAL

VOLUME 3, ISSUE 1 MARCH, 2026

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The journal benefits from its official recognition under Certificate No. 1150 issued by the Information and Mass Communications Agency, functioning under the Administration of the President of the Republic of Uzbekistan. With its E-ISSN 2181-2438, ISSN 3060-5164 the publication upholds international standards of quality and accessibility.

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Numerical Assessment of the Stress–Strain Behavior of Elevated Metro Overpass Supports

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Abstract: This study presents an advanced three-dimensional finite element assessment of the stress–strain behavior of monolithic reinforced concrete support columns used in elevated metro overpasses. Numerical simulations were performed using the LIRA-SAPR 2022 software to quantify the combined effects of reinforcement type (steel, basalt composite, and hybrid), cross-sectional geometry, and concrete class on structural performance. The results demonstrate that the ultimate axial capacity is governed primarily by concrete compression behavior, with variations in reinforcement type leading to differences of no more than 1–2%. In contrast, the deformation response is highly sensitive to reinforcement configuration, resulting in variations of 5–15% in maximum lateral displacements. An increase in concrete class from B25 to B35 enhances spatial stiffness by 10–18% and reduces lateral displacements by approximately 2–4 mm. Notably, hybrid reinforcement schemes exhibit superior performance by achieving an optimal balance between load-bearing capacity and deformability. These findings provide quantitative insight into the role of material and geometric parameters and offer a robust basis for the structural optimization and performance-based design of elevated metro overpass supports.

Keywords: finite element method, three-dimensional numerical modeling, reinforced concrete support column, elevated metro system, overpass support, stress–strain state, load-bearing capacity, lateral displacements, spatial stiffness, deformability, reinforcement schemes, steel reinforcement, composite reinforcement, concrete class, LIRA-SAPR

Yer usti metropoliteni estakada tayanchlarining kuchlanganlik–deformatsiyalanganlik holatini sonli baholash

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Annotatsiya: Ushbu tadqiqotda yer usti metropoliteni estakadalarida qo‘llaniladigan monolit temirbeton tayanch ustunlarning kuchlanganlik–deformatsiyalanganlik holati yakuniy elementlar usuliga asoslangan ilg‘or uch o‘lchamli sonli baholash orqali o‘rganildi. Sonli modellashtirish ishlari LIRA-SAPR 2022 dasturiy majmuasida bajarilib, unda armatura turi (po‘lat, bazalt kompozit va kombinatsiyalashgan), kesim geometriyasi hamda beton sinfining konstruktiv samaradorlikka birgalikdagi ta’siri miqdoriy jihatdan baholandi. Tadqiqot natijalari chegaraviy ish holatida tayanch ustunning yakuniy bo‘ylama yuk ko‘tarish qobiliyati asosan betonning siqilish zonasidagi ish xususiyatlari bilan belgilanib, armatura turining ta’siri 1–2 % dan ortiq farq qilmasligini ko‘rsatdi[2]. Biroq deformativ javob armatura sxemasiga yuqori darajada sezgir bo‘lib, maksimal gorizontal ko‘chishlar 5–15 % oralig‘ida o‘zgarishi aniqlandi. Beton sinfining B25 dan B35 gacha oshirilishi tayanch ustunning fazoviy bikrligini 10–18 % ga oshirib, gorizontal ko‘chishlarni o‘rtacha 2–4 mm ga kamaytiradi. Ayniqsa, kombinatsiyalashgan armaturalash sxemalari yuk ko‘tarish qobiliyati va deformatsiya o‘rtasida eng maqbul muvozanatni ta’minlagani bilan ajralib turadi. Olingan natijalar material va geometrik parametrlarning rolini miqdoriy jihatdan ochib berib, yer usti metropoliteni estakada tayanchlarini konstruktiv optimallashtirish va samaradorlikka asoslangan loyihalash uchun ishonchli ilmiy asos bo‘lib xizmat qiladi[5].

Kalit so‘zlar: Yakuniy elementlar usuli, uch o‘lchamli sonli modellashtirish, temirbeton tayanch ustun, yer usti metropoliteni tizimi, estakada tayanchi, kuchlanganlik–deformatsiyalanganlik holati, yuk ko‘tarish qobiliyati, gorizontal ko‘chishlar, fazoviy bikrlik, deformativlik, armaturalash sxemalari, po‘lat armatura, kompozit armatura, beton sinfi, LIRA-SAPR

1. Kirish

Yirik shaharlarda transport infratuzilmasining jadal rivojlanishi yer usti metropoliteni estakadalari qurilishini kengaytirishni taqozo etmoqda[5]. Ushbu inshootlarning ishonchliligi va uzoq muddatli ekspluatatsiyasi ko‘p jihatdan

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tayanch konstruksiyalarining mustahkamligi va deformatsiya xatti-harakati bilan belgilanadi. Amaliy loyihalash jarayonida monolit temirbeton tayanch ustunlar murakkab fazoviy yuklanishlar — bo‘ylama kuchlar hamda ikki o‘qli egilish momentlari ta’sirida ishlaydi[1,3].

Amaldagi loyihalash amaliyotida ko‘plab hisoblashlar soddalashtirilgan tekis modellar asosida bajariladi. Biroq bunday yondashuvlar beton va armatura o‘rtasidagi kuchlarning qayta taqsimlanishi, yoriq paydo bo‘lish jarayonlari hamda fazoviy deformatsiyalarni yetarli aniqlikda aks ettira olmaydi. Shu sababli elementlar usuliga asoslangan fazoviy kompyuter modellashtirishdan foydalanish dolzarb ilmiy-amaliy masalaga aylandi. Mazkur tadqiqot armatura materiali, kesim shakli va beton sinfining birgalikdagi ta’sirini fazoviy modelda kompleks baholash orqali mavjud ilmiy bo‘shliqni to‘ldirishga qaratilgan[4].

2. Tadqiqot metodologiyasi

Tadqiqot yakuniy elementlar usuliga asoslangan holda LIRA-SAPR 2022 dasturiy majmuasida bajarildi. Tadqiqot obyekti sifatida balandligi 7,95 m bo‘lgan monolit temirbeton tayanch ustun qabul qilindi. Hisobiy modelda tayanch ustunning bo‘ylama kuch (N) hamda ikki o‘qli egilish momentlari (Mx va My) ning birgalikdagi ta’siri ko‘rib chiqildi[9].

Modellashtirish jarayonida “bitta parametrni o‘zgartirish” tamoyiliga qat’iy amal qilinib, geometrik o‘lchamlar, yuklanish sxemalari va chegaraviy shartlar barcha variantlar uchun o‘zgarmas holda qabul qilindi. O‘zgaruvchi parametrlar sifatida armatura materiali va joylashuvi, kesim shakli hamda beton sinfi tanlandi. Yuklama kombinatsiyalari va chegaraviy holat mezonlari amaldagi normativ hujjatlar talablariga muvofiq shakllantirildi[11].

Beton fazoviy hajmiy chekli elementlar, bo‘ylama armatura esa sterjenli chekli elementlar orqali modellashtirildi. Beton va armatura o‘rtasida deformatsiyalarning tengligi prinsipi asosida siljishsiz yopishish (perfect bond) sharti qabul qilindi. Materiallarning mexanik parametrlari normativ hujjatlar asosida belgilandi[15].

3. Natija va muhokamalar

Bazaviy model sifatida faqat po‘lat armatura bilan armaturalangan monolit temirbeton tayanch ustun qabul qilindi. Yuklama oshishi bilan konstruktsiyaning dastlab elastik ishlashi, betonning cho‘zilish zonasida yoriqlanishning boshlanishi hamda beton va armatura o‘rtasida ichki kuchlarning qayta taqsimlanishi kuzatildi[6].

Chegaraviy holatda betonning siqilish zonasida nisbiy deformatsiyalar normativ chegaraviy qiymatlarga yaqinlashdi, po‘lat armaturada esa elastik-plastik ish rejimi namoyon bo‘ldi. Bazaviy variant uchun aniqlangan maksimal gorizontal ko‘chishlar keyingi taqqoslamalar uchun etalon ko‘rsatkich sifatida qabul qilindi.

To‘liq po‘lat, to‘liq bazalt kompozit hamda kombinatsiyalashgan armaturalash variantlari bo‘yicha hisoblashlar shuni ko‘rsatdiki, armaturaning umumiy miqdori bir xil bo‘lgan sharoitda maksimal bo‘ylama kuch qiymatlari deyarli o‘zgarmaydi. Barcha variantlarda maksimal bo‘ylama kuchlar farqi 1–2 % dan oshmadi, bu esa yuk ko‘tarish qobiliyati asosan betonning siqilish zonasidagi ish rejimi bilan belgilanishini tasdiqlaydi[7].

Shu bilan birga, armatura materiali va uning kesim bo‘ylab joylashuvi deformativ xatti-harakatga sezilarli ta’sir ko‘rsatdi. To‘liq po‘lat armatura qo‘llanilgan variantlarda maksimal gorizontal ko‘chishlar bazalt kompozit armaturali variantlarga nisbatan o‘rtacha 8–12 % ga kichik bo‘ldi. Kombinatsiyalashgan armaturalash sxemalarida maksimal ko‘chishlar bazaviy po‘lat variantga nisbatan 3–6 % dan oshmadi va mustahkamlik–deformativlik muvozanati ta’minlandi[6].

Aylana, oltiburchakli va to‘rtburchak kesimlar bo‘yicha o‘tkazilgan tahlillar kesim geometriyasining konstruktiv samaradorlikdagi muhim rolini ko‘rsatdi. Aylana kesim bilan solishtirganda shestigranli kesimda maksimal gorizontal ko‘chishlar 8–10 % ga, to‘rtburchak kesimda esa 18–22 % ga kamaydi. Aylana kesim kuchlanishlarning nisbatan bir tekis taqsimlanishini ta’minlasa, to‘rtburchak kesim fazoviy bikrlik nuqtai nazaridan eng samarali bo‘lib chiqdi[8].

B25, B30 va B35 beton sinflari bo‘yicha hisoblashlar beton sinfi oshishi bilan tayanch ustunning yuk ko‘tarish qobiliyati va fazoviy bikrligida barqaror ortish kuzatilishini ko‘rsatdi. B25 dan B35 gacha oshirilganda maksimal bo‘ylama kuchlar o‘rtacha 5–7 % ga oshdi. Shu bilan birga, maksimal gorizontal ko‘chishlar 2–4 mm ga kamayib, umumiy bikrlik 10–18 % ga oshdi. O‘sishning qat’iy chiziqli emasligi kuchlarning beton va armatura o‘rtasida qayta taqsimlanishi bilan izohlanadi[10].

Natijalar tayanch ustunning kuchlanganlik–deformatsiyalanganlik holati bir nechta omillarning kompleks ta’siri bilan belgilanishini ko‘rsatadi. Armatura turini o‘zgartirish yuk ko‘tarish qobiliyatiga sezilarli ta’sir ko‘rsatmagan bo‘lsa-da (1–2 %), deformativlikka ta’siri 10–15 % gacha yetdi. Kesim shakli va beton sinfi umumiy bikrlikka hal qiluvchi ta’sir ko‘rsatib, to‘rtburchak kesimli va yuqori beton sinfli variantlarda maksimal ko‘chishlar bazaviy aylana kesimga nisbatan 20 % gacha kamaydi. Fazoviy modellashtirish konstruktiv parametrlarning ta’sirini an’anaviy tekis modellar bilan solishtirganda ancha aniqlik bilan baholash imkonini berdi[12,13].

4. Xulosa

1. Chegaraviy ish holatida tayanch ustunning yuk ko‘tarish qobiliyati asosan betonning siqilish zonasidagi ish rejimi bilan belgilanadi; armatura turini o‘zgartirish maksimal bo‘ylama kuchlarga 1–2 % dan ortiq ta’sir ko‘rsatmaydi.
2. Armatura materiali va joylashuvi deformativ xatti-harakatga sezilarli ta’sir ko‘rsatib, maksimal gorizontal ko‘chishlarni 5–15 % oralig‘ida o‘zgartiradi.
3. Beton sinfining B25 dan B35 gacha oshirilishi fazoviy bikrlikni 10–18 % ga oshirib, maksimal gorizontal ko‘chishlarni o‘rtacha 2–4 mm ga kamaytiradi.
4. To‘rtburchak kesimli tayanch ustunlarda maksimal ko‘chishlar aylana kesimga nisbatan 18–22 % ga kam bo‘ladi.
5. Kombinatsiyalashgan armaturalash sxemalari mustahkamlik va deformativlik o‘rtasida eng maqbul muvozanatni ta’minlaydi.

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