2026/08-09
№5(52-53)

ISSN 2791-3651

Молодой специалист

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ЭЛЕКТРОННЫЙ НАУЧНЫЙ ЖУРНАЛ

«Молодой специалист»

Выпуск №5(52-53) (август-сентябрь, 2026)

Свидетельство о постановке на
учет периодического печатного
издания, информационного
агентства и сетевого издания
Эл № KZ26VPY00048061
от 15 апреля 2022 г.

Главная цель журнала заключается в публикации оригинальных статей, преимущественно научного и научно-технического направления, предоставлении научной общественности, научно-производственным предприятиям, представителям бизнес-структур, а также студентам, магистрантам и докторантам вузов возможность знакомиться с результатами научных исследований и прикладных разработок по ключевым проблемам в области передовых технологий.

Задачи журнала состоят:

- в предоставлении ученым возможности публикации результатов своих исследований по научным и научно-техническим направлениям;
- достижении международного уровня научных публикаций журнала;
- привлечении внимания научной и деловой общественности к наиболее актуальным и перспективным направлениям научных исследований по тематике журнала;
- привлечении в журнал авторитетных отечественных и зарубежных авторов, являющихся специалистами высокого уровня.

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ANDIJON VILOYATI BIR SATHDAGI TEMIR YO‘L KESISHMALARINI RIVOJLANTIRISH STRATEGIYASI: XAVF USTUVORLIGI VA AVTOMATIK TO‘SISH QURILMALARINING TEXNIK-IQTISODIY ASOSLANISHI

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Annotatsiya: *Andijon viloyatidagi bir sathdagi temir yo‘l kesishmalarining holatini baholash, xavfi yuqori uchastkalarni aniqlash hamda qo‘riqlanmaydigan kesishmalarni avtomatik to‘sish qurilmalari bilan jihozlashning texnik-iqtisodiy samaradorligini asoslash. Metod: viloyatning 51 ta kesishmasi (30 ta qo‘riqlanadigan, 21 ta qo‘riqlanmaydigan) bo‘yicha uchastka kesimidagi transport oqimi, 2024–2026-yillardagi yo‘l-transport hodisalari statistikasi va «Xitoy – Qirg‘iziston – O‘zbekiston» temir yo‘li orqali kutilayotgan yuklama tahlil qilindi; xavf ekspozitsiyasi indeksi hisoblandi; uch qurilma variantining kapital va ekspluatatsion xarajatlari uch stsenariy bo‘yicha solishtirildi. Andijon 1–Jalolobod uchastkasi umumiy ekspozitsiyaning 45 foizini tashkil etib, birinchi ustuvorlikka ega. Yuk hajmi yiliga 5–20 mln tonna bo‘lganda sutkasiga qo‘shimcha 8–31 ta poyezd qatnovi kutiladi. 21 ta kesishmani jihozlash uchun kapital xarajat 1 743–3 591 mln so‘m; bazaviy stsenariyda qoplanish muddati 2,4–5,7 yil bo‘lib, natija bir hodisaning zarar bahosiga sezgir. Har bosqichda yettitadan kesishmani qamrab oluvchi uch bosqichli modernizatsiya rejasi taklif etildi.*

Kalit so‘zlar: *bir sathdagi kesishma, temir yo‘l, harakat xavfsizligi, avtomatik shlagbaum, xavf ekspozitsiyasi, texnik-iqtisodiy asoslash, Andijon viloyati.*

DEVELOPMENT STRATEGY FOR RAILWAY LEVEL CROSSINGS IN ANDIJAN REGION: RISK PRIORITISATION AND TECHNICAL-ECONOMIC JUSTIFICATION OF AUTOMATIC BARRIER DEVICES

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Abstract: ***To*** *assess the condition of level crossings in the Andijan region, identify the highest-risk railway sections, and justify the technical and economic feasibility of equipping unguarded crossings with automatic barrier systems.* ***S****ection-level traffic flows, accident statistics for 2024–2026 (16 accidents, including 5 fatalities), and the expected traffic generated by the China–Kyrgyzstan–*

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Uzbekistan railway were analysed for 51 crossings (30 guarded and 21 unguarded). A risk exposure index was calculated, and the capital and operating costs of three types of equipment—an automatic barrier, the UZP level-crossing barrier device, and a bollard system—were compared under three scenarios. The Andijan 1–Jalolobod section accounts for 45% of the total risk exposure and ranks first in terms of risk. At a freight volume of 5–20 million tonnes per year, an additional 8–31 train movements per day are expected. The estimated capital cost of equipping the 21 unguarded crossings ranges from 1,743 to 3,591 million UZS, while the payback period under the base scenario is estimated at 2.4–5.7 years and is sensitive to the assumed economic loss per accident. A three-stage modernisation plan, covering seven crossings at each stage, is proposed.

Key words: *level crossing, railway, traffic safety, automatic barrier, risk exposure, technical-economic justification, Andijan region.*

СТРАТЕГИЯ РАЗВИТИЯ ЖЕЛЕЗНОДОРОЖНЫХ ПЕРЕЕЗДОВ В АНДИЖАНСКОЙ ОБЛАСТИ: ПРИОРИТИЗАЦИЯ РИСКОВ И ТЕХНИКО-ЭКОНОМИЧЕСКОЕ ОБОСНОВАНИЕ АВТОМАТИЧЕСКИХ ШЛАГБАУМОВ

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Аннотация *Целью исследования является оценка состояния железнодорожных переездов в Андижанской области, выявление железнодорожных участков с наиболее высоким уровнем риска, а также технико-экономическое обоснование оснащения неохраняемых переездов автоматическими шлагбаумными устройствами. Для 51 переезда (30 охраняемых и 21 неохраняемого) были проанализированы участковые транспортные потоки, статистика дорожно-транспортных происшествий за 2024–2026 годы (16 происшествий, в том числе 5 со смертельным исходом), а также ожидаемый объём перевозок в связи с вводом железной дороги Китай–Кыргызстан–Узбекистан. Рассчитан индекс рисковой экспозиции, а также проведено сравнение капитальных и эксплуатационных затрат для трёх типов оборудования: автоматического шлагбаума, устройства заграждения переезда УЗП и боллардной системы — по трём сценариям. Наибольшая доля совокупной рисковой экспозиции (45 %) приходится на участок Андижан-1–Джалалабад, который занимает первое место по уровню риска. При объёме грузовых перевозок 5–20 млн тонн в год ожидается увеличение количества поездопроходов на 8–31 в сутки. Расчётные капитальные затраты на оснащение 21 неохраняемого переезда составляют 1 743–3*

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591 млн сумов, при этом срок окупаемости по базовому сценарию оценивается в 2,4–5,7 года и зависит от принятого размера экономического ущерба от одного происшествия. Предлагается трёхэтапный план модернизации, предусматривающий оснащение семи переездов на каждом этапе.

Ключевые слова *железнодорожный переезд, железнодорожный транспорт, безопасность движения, автоматический шлагбаум, рисковая экспозиция, технико-экономическое обоснование, Андижанская область.*

1. KIRISH

Transport-logistika tizimini rivojlantirish O‘zbekiston iqtisodiy siyosatining ustuvor yo‘nalishlaridan biri bo‘lib, bu «Transport to‘g‘risida»gi Qonun va Prezidentning 2025-yil 27-yanvardagi PQ-28-sonli qarorida o‘z ifodasini topgan [1, 2]. Shu yo‘nalishdagi eng yirik loyihalardan biri — Qashqar–Torugart–Makmal–Jalolobod–Andijon yo‘nalishidagi «Xitoy – Qirg‘iziston – O‘zbekiston» (XQO‘) temir yo‘lidir. Uning qurilishi 2024-yil 27-dekabrda boshlangan [3]; rejalashtirilgan yakunlanish muddati 2030-yil bo‘lib, qurilishni ikki yil ertaroq tugatish imkoniyati ham e’lon qilingan [4]. Yuk hajmi dastlabki bosqichda yiliga 5–8 mln tonna, uzoq muddatda 13–15 mln tonna deb baholanadi; Yevrosiyo taraqqiyot bankining 2026-yilgi hisobotiga ko‘ra, quvvat yakka izli variantda 7 mln tonna, ikki izli variantda 20 mln tonnagacha yetishi mumkin [4, 5].

Koridor O‘zbekiston hududiga Andijon viloyati orqali kirib keladi, shu bois viloyatdagi temir yo‘l va avtomobil yo‘llari kesishmalariga tushadigan yuklama ortadi. Bir sathdagi kesishmalar esa har ikki transport turi uchun eng xavfli joylardan biridir. Yevropa Ittifoqida 2024-yilda temir yo‘l halokatlarida o‘lganlarning 25,5 foizi (750 kishidan taxminan 190 nafari) kesishmalarga to‘g‘ri kelgan [6]; 2010-yillarda esa yiliga 300 ga yaqin kishi kesishmalardagi to‘qnashuvlarda halok bo‘lgan [7, 8]. AQShda har yili 200 dan ortiq kishi shu sababli vafot etadi, 2023-yil uchun dastlabki ma’lumotlarda 248 ta o‘lim qayd etilgan [9, 10]. Hodisalarning asosiy sababi, odatda, yo‘l harakati qatnashchilarining xatti-harakatidir [8].

Andijon viloyatida 6 ta temir yo‘l uchastkasida 51 ta kesishma mavjud bo‘lib, ularning 21 tasi (41 foiz) navbatchi xodim va signalizatsiyasiz, ya’ni qo‘riqlanmaydigan holatda [11, 12]. Muallifga ma’lum bo‘lgan manbalarda viloyat kesishmalarining uchastkalar bo‘yicha xavf ustuvorligi aniqlanmagan, koridor yuklamasi miqdoriy baholanmagan va avtomatik to‘sish qurilmalari variantlarining iqtisodiy samaradorligi mahalliy sharoitda solishtirilmagan.

Tadqiqotning maqsadi - Andijon viloyati bir sathdagi temir yo‘l kesishmalarining holatini baholash, xavfi yuqori uchastkalarni aniqlash va qo‘riqlanmaydigan kesishmalarni modernizatsiya qilishning texnik-iqtisodiy asoslangan strategiyasini ishlab chiqish. **Vazifalar:** (1) kesishmalar va transport oqimini uchastkalar bo‘yicha tahlil qilish; (2) xavf ekspozitsiyasi asosida uchastkalarni ustuvorlash; (3) XQO‘ koridori keltirib chiqaradigan qo‘shimcha poyezd qatnovini baholash; (4) uch qurilma variantining xarajat va samaradorligini solishtirish; (5) bosqichma-bosqich modernizatsiya rejasini taklif etish.

2. MATERIALLAR VA METODLAR

Kesishmalar soni va turi «O‘zbekiston temir yo‘llari» AJ Yo‘l xo‘jaligi bo‘limining texnik ma’lumotlaridan [12], hodisalar to‘g‘risidagi ma’lumotlar Qo‘qon mintaqaviy temir yo‘l uzeli Harakat xavfsizligi bo‘limi va Ichki ishlar vazirligi Yo‘l harakati xavfsizligi xizmati statistikasidan (2024-yil – 2026-yil 1-may) [11, 13] olindi. Transport oqimi 6 ta uchastka bo‘yicha Andijon 1 stansiyasining Harakat xavfsizligi va Yo‘l xo‘jaligi bo‘limlari xodimlari bilan hamkorlikda sutkalik sanash orqali aniqlandi [11] (yuk transporti, yengil avtomobil, avtobus va marshrutka,

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mototsikl va moped, kajavali mototsikl). Uchastka bo‘yicha keltirilgan qiymatlar shu uchastkadagi barcha kesishmalar bo‘yicha jami oqim sifatida talqin qilindi.

Qurilmalarning kapital va ekspluatatsion xarajatlari 2025-yil O‘zbekiston bozori narxlari va ishlab chiqaruvchilar (Siemens, CAME, FAAC) mahsulot ma’lumotlari asosida baholangan [14]. Har bir variant asosiy qurilma bilan birga svetofor, elektron axborot taxtasi, IP-kamera va poyezdni aniqlash datchiklarini o‘z ichiga oladi.

Uchastkalarni ustuvorlash uchun xavf ekspozitsiyasi indeksi kiritildi:

$$I_j = U_j \cdot (F_j / N_j), \quad (1)$$

bunda U_j — j-uchastkadagi qo‘riqlanmaydigan kesishmalar soni; F_j — uchastkadagi sutkalik jami transport oqimi (barcha turlar bo‘yicha); N_j — uchastkadagi kesishmalar soni. Indeks qo‘riqlanmaydigan kesishmalardan o‘tuvchi taxminiy sutkalik oqimni ifodalaydi. Hisobda uchastka oqimi uning kesishmalari orasida tekis taqsimlanadi deb qabul qilindi.

XQO‘ koridori bo‘yicha yuk hajmi Q (t/yil) ning yuk poyezdlari qatnoviga ekvivalentini hisoblash uchun quyidagi ifoda qo‘llandi:

$$n_{yuk} = Q / (365 \cdot q), \quad n = 2 \cdot n_{yuk}, \quad (2)$$

bunda q — yuk poyezdining o‘rtacha netto massasi (shartli 3 500 t, loyiha ma’lumotlari bo‘yicha aniqlashtirilishi lozim); n_{yuk} — yuk bilan qatnovchi poyezdlar soni (sutkasiga); n — jami qatnov. Yuk asosiy yo‘nalishda yuk bilan, teskari yo‘nalishda bo‘sh tashiladi va oqim yil davomida tekis deb qabul qilindi.

Yillik foyda, qoplanish muddati va 10 yillik sof natija quyidagicha hisoblandi:

$$B = N_0 \cdot s \cdot r \cdot Z + T, \quad (3)$$

$$PP = K / (B - E), \quad S_{10} = 10 \cdot (B - E) - K, \quad (4)$$

bunda N_0 — yillik hodisalar soni (2024–2025-yillar o‘rtachasi, 6,5); s — hodisalarning qo‘riqlanmaydigan kesishmalarga to‘g‘ri keladigan ulushi (0,72) [11, 13]; r — qurilma o‘rnatilgandagi hodisalar kamayishi: passiv kesishmani chiroqli signalizatsiya bilan jihozlashda 70 %, avtomatik to‘siq bilan jihozlashda 83 % [15, 16]; Z — bir hodisaning iqtisodiy zarari (tibbiy yordam, infratuzilma va transport vositasini tiklash, tirbandlik, huquqiy xarajatlar), bazaviy qiymat 300 mln so‘m, oraliq 150–450 mln so‘m [14]; T — kesishmada to‘xtab qolish vaqtining qisqarishidan tejash; K — kapital xarajat; E — yillik ekspluatatsion xarajat amortizatsiyasiz (texnik xizmat, masofaviy operator, elektr va aloqa). Qo‘riqlanmaydigan kesishmalarda navbatchi xodim yo‘q bo‘lgani uchun xodimlar ish haqini tejash foydaga kiritilmadi. Diskontlash qo‘llanmadi.

Uch stsenariy ko‘rib chiqildi: S1 — konservativ (r = 70 %); S2 — bazaviy (r = 83 %); S3 — S2 va vaqt tejash bo‘yicha T = 1 000 mln so‘m/yil (muallifning dastlabki bahosining pastki chegarasi [14]). Bundan tashqari S2 uchun zarar bahosi Z = 150 va 450 mln so‘m bo‘lgandagi sezgirlik tekshirildi.

3. NATIJALAR

Viloyatdagi 51 ta kesishmaning 30 tasi qo‘riqlanadigan, 21 tasi (41,2 %) qo‘riqlanmaydigan (1-jadval). Asaka–Shahrixon va Andijon 2–Paxtaobod uchastkalarining barcha kesishmalari (jami 10 ta) qo‘riqlanmaydi. Uchastkalar bo‘yicha jami sutkalik oqim 502 681 birlikni tashkil etadi; uning 73,5 foizi ikki uchastka — Marg‘ilon–Andijon 1 (179 916) va Andijon 1–Jalolobod (189 754) hisobiga. Yuk transporti ulushi o‘rtacha 9,9 % bo‘lsa-da, Andijon 2–Paxtaobod uchastkasida 40,1 %, Asaka–Shahrixonda 15,5 % ga yetadi.

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1-jadval

Temir yo‘l uchastkalari bo‘yicha kesishmalar va sutkalik transport oqimi [11, 12]

Uchastka	**Jami**	**Qo‘riqlanadigan**	**Qo‘riqlanmaydigan**	**Qo‘riqlanmaydigan ulushi, %**	**Sutkalik oqim, birlik**	**Yuk transporti ulushi, %**
Marg‘ilon–Andijon 1	9	8	1	11,1	179 916	8,5
Andijon 1–Jalolobod	17	11	6	35,3	189 754	7,9
Uchqo‘rg‘on –Post 331 km	10	7	3	30,0	61 907	9,2
Asaka–Shahrixon	7	0	7	100,0	16 144	15,5
Andijon 2–Paxtaobod	3	0	3	100,0	20 265	40,1
Savay–Honobod	5	4	1	20,0	34 695	9,5
Jami	**51**	**30**	**21**	**41,2**	**502 681**	**9,9**

Viloyat kesishmalarida 2024-yilda 7 ta, 2025-yilda 6 ta va 2026-yil 1-mayigacha 3 ta hodisa qayd etilgan; jami 16 ta hodisaning 5 tasi (31 %) o‘lim bilan yakunlangan [13]. Hodisalarning 72 foizi qo‘riqlanmaydigan kesishmalarga to‘g‘ri kelgan [11, 13], holbuki bunday kesishmalar umumiy sonning 41 foizini tashkil etadi. 2026-yilning dastlabki to‘rt oyidagi 3 ta hodisa yillik hisobga o‘tkazilganda taxminan 9 taga to‘g‘ri keladi; tanlanma kichik bo‘lgani uchun bu tendensiya sifatida emas, ehtiyotkorlik bilan kuzatuv sifatida qaralishi lozim.

(1) formula bo‘yicha hisoblangan ekspozitsiya indeksi 2-jadval va 1-rasmda keltirilgan. Andijon 1–Jalolobod uchastkasi (I = 66 972) jami ekspozitsiyaning (148 883) 45,0 foizini beradi va ikkinchi o‘rindagi uchastkadan 3,3 barobar yuqori. Buning sababi shundaki, bu uchastkada qo‘riqlanmaydigan kesishmalar soni (6 ta) ham, kesishmaga to‘g‘ri keladigan o‘rtacha oqim (11 162) ham yuqori. Marg‘ilon–Andijon 1 uchastkasida faqat bitta qo‘riqlanmaydigan kesishma bor, biroq unga to‘g‘ri keladigan o‘rtacha oqim eng katta (19 991).

2-jadval

Uchastkalarning xavf ekspozitsiyasi indeksi

O‘rin	**Uchastka**	**Qo‘riqlanmaydigan kesishmalar, U**	**Kesishmaga o‘rtacha oqim, F/N**	**Indeks I**
1	Andijon 1–Jalolobod	6	11 162	66 972
2	Andijon 2–Paxtaobod	3	6 755	20 265
3	Marg‘ilon–Andijon 1	1	19 991	19 991
4	Uchqo‘rg‘on–Post 331 km	3	6 191	18 572
5	Asaka–Shahrixon	7	2 306	16 144
6	Savay–Honobod	1	6 939	6 939

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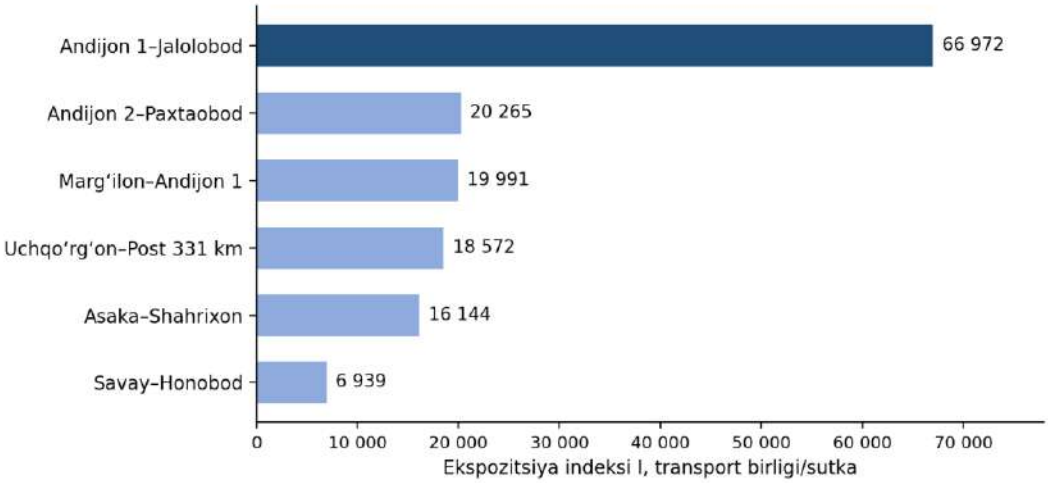

1-rasm. Uchastkalar bo'yicha xavf ekspozitsiyasi indeksi I

(2) formula bo'yicha hisoblashlar shuni ko'rsatadiki, koridor yiliga 5 mln tonna yuk tashiganda sutkasiga o'rtacha 3,9 ta yuk bilan qatnovchi poyezd (jami 7,8 ta qatnov), 15 mln tonnada 11,7 ta (23,5 ta qatnov), 20 mln tonnada esa 15,7 ta (31,3 ta qatnov) qo'shimcha harakat yuzaga keladi (3-jadval). Ya'ni koridor to'liq ishga tushganda kesishmalardan o'tuvchi poyezdlar soni sutkasiga 8–31 taga ortadi.

3-jadval

Koridor yuk hajmiga mos qo'shimcha poyezd qatnovi (q = 3 500 t) [4, 5]

Stsenariy	**Yillik hajm, mln t**	**Sutkalik hajm, t**	**Yuk bilan poyezd, sutka**	**Jami qatnov, sutka**
Dastlabki bosqich (quyi)	5	13 699	3,9	7,8
Dastlabki bosqich (yuqori)	8	21 918	6,3	12,5
Uzoq muddat	15	41 096	11,7	23,5
Ikki izli quvvat	20	54 795	15,7	31,3

Uch variant — avtomatik shlagbaum, UZP (temir yo'l kesishmasini to'sish qurilmasi) va Ballard tizimi (avtomatik va statik ustunlar) — solishtirildi (4-jadval). UZP paketi eng arzon (bitta kesishma uchun o'rtacha 83 mln so'm), Ballard tizimi eng qimmat (171 mln so'm). 21 ta kesishma uchun kapital xarajat 1 743–3 591 mln so'm, yillik ekspluatatsion xarajat amortizatsiyasiz 452–530 mln so'm.

4-jadval

Qurilma variantlarining xarajatlari (2025-yil narxlarida, mln so'm)

Variant	**1 kesishma: kapital (o'rtacha)**	**1 kesishma: yillik ekspluatatsiya**	**21 kesishma: kapital**	**21 kesishma: yillik ekspluatatsiya**
Avtomatik shlagbaum	77–115 (96)	22,1	2 016	464
UZP to'sish qurilmasi	63–103 (83)	21,5	1 743	452
Ballard tizimi	131–211 (171)	25,3	3 591	530

Hodisalar kamayishi hisobiga oldini olinadigan zarar S1 stsenariyda yiliga 3,3 ta hodisa (983 mln so'm), S2 da 3,9 ta hodisa (1 165 mln so'm) ni tashkil etadi (5-jadval). Bazaviy stsenariyda (S2) qoplanish muddati UZP uchun 2,4 yil, avtomatik shlagbaum uchun 2,9 yil,

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Ballard uchun 5,7 yil; 10 yillik sof natija mos ravishda 5 395, 4 996 va 2 760 mln so‘m. Konservativ S1 stsenariyda qoplanish 3,3–7,9 yilga uzayadi. Vaqt tejash hisobga olingan S3 stsenariyda muddat 1,0–2,2 yilgacha qisqaradi. Sezgirlik tahlili natijani zarar bahosi belgilashini ko‘rsatdi: Z = 150 mln so‘m bo‘lganda hech bir variant 10 yil ichida qoplanmaydi, Z = 450 mln so‘m bo‘lganda qoplanish 1,3–2,9 yilga tushadi.

5-jadval

Stsenariylar bo‘yicha qoplanish muddati (yil) va 10 yillik sof natija (mln so‘m), 21 ta kesishma

Stsenariy	**Yillik foyda B, mln so‘m**	**Avtomatik shlagbaum**	**UZP**	**Ballard**
S1: r = 70 %, Z = 300	983	3,9 / 3 171	3,3 / 3 570	7,9 / 934
S2 (bazaviy): r = 83 %, Z = 300	1 165	2,9 / 4 996	2,4 / 5 395	5,7 / 2 760
S3: S2 + T = 1 000	2 165	1,2 / 14 996	1,0 / 15 395	2,2 / 12 760
S2, Z = 150	583	17,0 / –830	13,3 / –431	68,5 / –3 067
S2, Z = 450	1 748	1,6 / 10 823	1,3 / 11 222	2,9 / 8 586

4. MUHOKAMA

Natijalar xavfning uchastkalar bo‘yicha keskin notekis taqsimlanganini ko‘rsatadi. Andijon 1–Jalolobod uchastkasi ekspozitsiyaning deyarli yarmini beradi va koridor Andijonga Jalolobod (Jalal-Abad) tomonidan kirib kelishi rejalashtirilgani [3, 4] uchun aynan shu yo‘nalish kelajakdagi yuklama nuqtai nazaridan ham birinchi navbatga qo‘yilishi asosli. Aksincha, Asaka–Shahrixon uchastkasida barcha 7 ta kesishma qo‘riqlanmasa-da, oqim kichik (indeks 16 144), shu sababli u keyingi bosqichga qoldirilib, oraliq chora sifatida ko‘rinish masofasini ta’minlash va belgilarni yangilash tavsiya etiladi. Andijon 2–Paxtaobod uchastkasida yuk transporti ulushi 40,1 % bo‘lgani uchun (og‘ir transportning to‘xtash masofasi uzun, kesishmani bo‘shatish vaqti ko‘p) bu uchastka indeksdan yuqori e’tiborga loyiq.

Xalqaro tajriba passiv kesishmani avtomatik to‘siq bilan jihozlash hodisalarni taxminan 83 foizga kamaytirishini ko‘rsatadi [15, 16]. Shu bilan birga qurilma o‘rnatilgach ham xavf butunlay yo‘qolmaydi: Yevropa Ittifoqida 2016-yilda kesishmalardagi to‘qnashuvlarning 60 foizi faol kesishmalarda yuz bergan, sabab ko‘pincha haydovchining to‘siq tushayotgan paytda o‘tishga urinishi [7]. Shlagbaum yo‘lning to‘liq kengligini to‘smasligi sababli haydovchi uni aylanib o‘tishi mumkin, kutish vaqti uzayganda esa signalga rioya qilish pasayadi [16]. Bu ikki holat UZP kabi qatnov qismini to‘liq to‘suvchi qurilmalar, kesishmadan o‘tish vaqtini qisqartirish va qoidabuzarliklarni foto-video qayd etish (IP-kameralar) zarurligini asoslaydi.

Iqtisodiy natijalarni ehtiyotkorlik bilan talqin qilish kerak. Birinchidan, foyda asosan oldini olingan hodisalar zararidan iborat: Z = 300 mln so‘m bo‘lganda barcha variantlar 10 yil ichida qoplanadi, Z = 150 mln so‘m bo‘lganda esa qoplanmaydi. Shu sababli Z qiymati rasmiy hisobotlar asosida aniqlashtirilishi kerak. Ikkinchidan, kesishmalarda navbatchi xodim yo‘q bo‘lgani uchun xodimlar ish haqini tejash foydaga kiritilmagan; qo‘riqlanadigan 30 ta kesishmada avtomatlashtirishning tejamkorligi alohida tadqiqot mavzusidir. Uchinchidan, vaqt tejash (T) kesishma darajasida hisoblanmagan, shu bois asosiy xulosalar S1–S2 stsenariylariga tayanadi. Odam hayoti va sog‘lig‘iga yetkazilgan zararning ijtimoiy qiymati (16 ta hodisaning 5 tasi o‘lim bilan tugagan) Z ga faqat qisman kiritilgan; to‘liq ijtimoiy baholash qurilmalar foydasini oshirishi mumkin.

Qurilmalar funksional jihatdan bir-birini to‘ldiradi: UZP shlagbaum tushirilgandan so‘ng qatnov qismini to‘liq to‘sadi, Ballard esa asosan piyoda va xizmat yo‘laklarini transportning kirib kelishidan himoya qiladi. Shu sababli 5-jadvaldagi solishtirish har bir qurilma paketini mustaqil baholaydi; keyingi bosqichda «shlagbaum», «shlagbaum + UZP», «shlagbaum + Ballard»

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kombinatsiyalarini solishtirish lozim. Hozirgi hisobga ko‘ra UZP paketi eng arzon va tez qoplanadi, Ballard tizimi esa eng qimmat, shuning uchun uni piyodalar oqimi yuqori kesishmalarda qo‘shimcha chora sifatida ko‘rish maqsadga muvofiq.

Ekspozitsiya indeksi va koridor yuklamasiga tayangan holda har bosqichda yettitadan kesishmani qamrab oluvchi uch bosqichli reja taklif etiladi. 1-bosqich (1–2 yil): Andijon 1–Jalolobod (6 ta) va Marg‘ilon–Andijon 1 (1 ta) uchastkalari. 2-bosqich (3–5 yil): Andijon 2–Paxtaobod (3 ta), Uchqo‘rg‘on–Post 331 km (3 ta) va Savay–Honobod (1 ta). 3-bosqich (5–10 yil): Asaka–Shahrixon (7 ta) hamda barcha 51 kesishmani yagona monitoring va intellektual boshqaruv tizimiga ulash. Har bir bosqichning kapital xarajati avtomatik shlagbaum variantida 672, UZP variantida 581 va Ballard variantida 1 197 mln so‘m.

Hodisalar tanlanmasi kichik (16 ta), 72 foizli ulush ishonchli intervalga ega emas. (2) Transport oqimi uchastka darajasida berilgan va kesishmalar orasida tekis taqsimlangan deb olingan; kesishma darajasidagi sanash va poyezdlar soni bilan indeks aniqlashtirilishi kerak. (3) Hodisalar kamayishi koeffitsiyentlari xorijiy (asosan AQSh) ma’lumotlariga tayanadi, «qo‘riqlanmaydigan» kesishma esa har doim ham «passiv» kesishmaga teng emas. (4) Narxlar 2025-yil bozor narxlari bo‘lib, diskontlash va valyuta kursi o‘zgarishi hisobga olinmagan. (5) Koridor yuklamasi shartli massa va tekis oqim farazlariga asoslangan.

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O‘ZBEKISTON TASHQI SAVDO TEMIR YO‘L MARSHRUTLARINING XARAJAT VA VAQT SAMARADORLIGINI QIYOSIY BAHOLASH: UMUMLASHGAN TRANSPORT XARAJATI YONDASHUVI

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Annotatsiya: *O‘zbekistonning temir yo‘lga asoslangan tashqi savdo marshrutlarini xarajat va vaqt bo‘yicha, yuk qiymatini hisobga oluvchi yagona ko‘rsatkich asosida solishtirish. Metod: janubiy, shimoliy, g‘arbiy va sharqiy yo‘nalishlardagi 12 ta marshrut bo‘yicha masofa, yetkazib berish muddati va 20–22 t yukni tashishning o‘rtacha xarajati muallif maqolasidan olindi; solishtirma ko‘rsatkichlar (doll./km, sent/t·km, km/sutka) hisoblandi; xarajat va vaqtning masofa hamda dengiz/parom bo‘g‘inlari soniga bog‘liqligi eng kichik kvadratlar usulida baholandi; jo‘natma qiymati 20, 100 va 300 ming dollar, vaqt qiymati sutkasiga 0,05–0,6 foiz bo‘lgan uch yuk sinfi uchun umumlashgan xarajat hisoblandi. Xarajat modeli (R^2 = 0,75) bo‘yicha masofaga bog‘liq bo‘lmagan qism jo‘natmaga taxminan 1 576 dollar, masofa stavkasi 0,29 doll./km, har bir dengiz yoki parom bo‘g‘ini esa qo‘shimcha 921 dollar va 4,1 sutka; vaqt modeli o‘zgaruvchanlikning 93 foizini tushuntiradi (bazaviy tezlik ≈ 442 km/sutka). Riga, Minsk va Varshava yo‘nalishlari modeldagidan 560–820 dollar arzon, Saraxs va Xorgos orqali marshrutlar esa qimmatroq. Umumlashgan xarajat bo‘yicha reyting yuk qiymatiga bog‘liq: arzon yukda Riga, o‘rta va qimmat yukda Minsk yo‘nalishi birinchi o‘rinda. Kaspiy va Qora dengiz orqali marshrutlar barcha sinflarda raqobatbardosh emas: Eron–Turkiya orqali quruqlik marshrutiga nisbatan jo‘natma uchun 450–650 dollar qimmat va 5,5 sutka uzoq. Chegara, terminal va qayta yuklash xarajatlarini qisqartirish ustuvorliklari taklif etildi.*

Kalit so‘zlar: *temir yo‘l transporti, tashqi savdo marshruti, umumlashgan transport xarajati, vaqt qiymati, qayta yuklash, transport koridori, O‘zbekiston.*

COMPARATIVE COST–TIME EFFICIENCY ASSESSMENT OF UZBEKISTAN’S RAIL-BASED FOREIGN TRADE ROUTES: A GENERALISED TRANSPORT COST APPROACH

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Abstract: *The study compares the cost and time efficiency of Uzbekistan’s rail-based foreign trade routes using a single indicator that accounts for the value of the cargo. Distance, transit time and the average cost of shipping a 20–22 t consignment were taken from the author’s dissertation for 12 routes in the southern, northern, western and eastern directions. Unit indicators (USD/km, US cents per tonne-km, km/day) were calculated; linear cost and time models*

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with distance and the number of sea/ferry legs as explanatory variables were estimated by ordinary least squares; and a generalised cost was computed for three cargo classes (consignment value of 20, 100 and 300 thousand USD; time cost of 0.05–0.6% of value per day). The cost model (R^2 = 0.75) yields a distance-independent component of about USD 1,576 per consignment, a distance rate of USD 0.29/km and a premium of USD 921 and 4.1 days for each sea or ferry leg; the time model explains 93% of the variation (base speed ≈ 442 km/day). The northern routes to Riga, Minsk and Warsaw are USD 560–820 cheaper than predicted, whereas the routes via Sarakhs and Khorgos are more expensive. The ranking by generalised cost depends on cargo value: Riga leads for low-value cargo and Minsk for medium- and high-value cargo. Routes across the Caspian and Black Seas are uncompetitive in all classes: compared with the land route via Iran and Turkey they cost USD 450–650 more and take about 5.5 days longer per consignment. Priorities for reducing border, terminal and transhipment costs are proposed.

Key words: *rail transport, foreign trade route, generalised transport cost, value of time, transhipment, transport corridor, Uzbekistan.*

СРАВНИТЕЛЬНАЯ ОЦЕНКА СТОИМОСТНО-ВРЕМЕННОЙ ЭФФЕКТИВНОСТИ ЖЕЛЕЗНОДОРОЖНЫХ ВНЕШНЕТОРГОВЫХ МАРШРУТОВ УЗБЕКИСТАНА: ПОДХОД ОБОБЩЁННЫХ ТРАНСПОРТНЫХ ЗАТРАТ

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Аннотация *Цель исследования — сравнить железнодорожные внешнеторговые маршруты Узбекистана по стоимости и времени доставки с помощью единого показателя, учитывающего стоимость груза. По 12 маршрутам южного, северного, западного и восточного направлений из диссертации автора взяты расстояние, срок доставки и средние затраты на перевозку отправки массой 20–22 т. Рассчитаны удельные показатели (долл./км, цент/т·км, км/сут), методом наименьших квадратов оценены линейные модели затрат и времени в зависимости от расстояния и числа морских/паромных звеньев, определены обобщённые затраты для трёх классов груза (стоимость отправки 20, 100 и 300 тыс. долл.; стоимость времени 0,05–0,6 % в сутки). Модель затрат (R^2 = 0,75) даёт не зависящую от расстояния составляющую около 1 576 долл. на отправку, ставку 0,29 долл./км и надбавку 921 долл. и 4,1 сут за каждое морское или паромное звено; модель времени объясняет 93 % вариации (базовая скорость ≈ 442 км/сут). Северные маршруты на Ригу, Минск и Варшаву дешевле модельных на 560–820 долл., маршруты через Сарахс и Хоргос — дороже. Рейтинг по обобщённым затратам зависит от стоимости груза: для дешёвых грузов лидирует Рига, для средних и дорогих — Минск. Маршруты через Каспийское и Чёрное моря неконкурентоспособны во всех классах: по сравнению с сухопутным*

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маршрутом через Иран и Турцию они дороже на 450–650 долл. и дольше примерно на 5,5 сут. Предложены приоритеты снижения пограничных, терминальных и перевалочных затрат.

Ключевые слова *железнодорожный транспорт, внешнеторговый маршрут, обобщённые транспортные затраты, стоимость времени, перевалка, транспортный коридор, Узбекистан.*

1. KIRISH

Dengizga bevosita chiqish imkoniga ega bo‘lmagan mamlakatlar uchun tashqi savdo yuklarini tashish xarajati va muddati eksportning raqobatbardoshligini belgilovchi asosiy omillardan biridir. Jahon banki tadqiqotida bunday mamlakatlarda logistika xarajatlarining darajasini masofaning o‘zidan ko‘ra yetkazib berishning ishonchliligi, chegara va terminallardagi kutish vaqtlari ko‘proq belgilashi ko‘rsatilgan [1]. «2022–2026-yillarga mo‘ljallangan Yangi O‘zbekistonning taraqqiyot strategiyasi»da transport-logistika tizimini rivojlantirish va tashqi savdo uchun qulay sharoit yaratish ustuvor yo‘nalishlar qatoriga kiritilgan [2].

Yetkazib berish vaqti yuk egasi uchun alohida iqtisodiy resursdir. Djankov va hammualliflar bahosiga ko‘ra, yetkazib berishning har bir qo‘shimcha kuni savdo hajmini o‘rtacha 1 foizdan ko‘proq kamaytiradi [3]; Hummels va Schaur esa tranzitdagi bir kunning qiymati tovar qiymatining 0,6–2,1 foiziga teng boj ekvivalenti ekanini aniqlagan [4]. Maqolada Osiyo taraqqiyot banki ma’lumotlariga tayangan holda mintaqada yuk tashish vaqtini bir kunga qisqartirish savdo hajmini 5,7 foizgacha oshirishi mumkinligi qayd etilgan [5]. Demak, marshrutlarni faqat tarif yoki faqat muddat bo‘yicha solishtirish yuk egasining haqiqiy xarajatini to‘liq aks ettirmaydi.

CAREC dasturining koridorlar samaradorligini kuzatish mexanizmi chegarani kesib o‘tish vaqti, chegaradagi xarajat, koridor bo‘ylab o‘rtacha xarajat va o‘rtacha tezlikni alohida ko‘rsatkichlar sifatida baholaydi [6]. Jahon bankining Kaspiy dengizi orqali o‘tuvchi O‘rta koridor bo‘yicha hisobotida esa bu yo‘nalishda tashish muddatini 2030-yilgacha ikki baravar qisqartirish maqsadi qo‘yilgan [7]. Biroq muallifga ma’lum manbalarda O‘zbekistonning amaldagi tashqi savdo temir yo‘l marshrutlarini xarajat, vaqt va yuk qiymatini bir vaqtda hisobga olgan holda solishtiruvchi, shuningdek xarajatning masofaga bog‘liq va bog‘liq bo‘lmagan qismlarini ajratib beruvchi miqdoriy baholar uchramadi.

O‘zbekistonning temir yo‘lga asoslangan tashqi savdo marshrutlarini umumlashgan transport xarajati asosida qiyosiy baholash va xarajatni kamaytirishning ustuvor yo‘nalishlarini aniqlash.Maqoladagi marshrut ma’lumotlarini yagona ko‘rinishga keltirib, solishtirma ko‘rsatkichlarni hisoblash; (2) xarajat va vaqtning masofa hamda dengiz/parom bo‘g‘inlariga bog‘liqligini baholash; (3) yo‘nalishlarga xos ustama va chegirmalarni aniqlash; (4) uch yuk sinfi uchun marshrutlarni umumlashgan xarajat bo‘yicha reytinglash; (5) xarajatni kamaytirish ustuvorliklarini asoslash.

2. MATERIALLAR VA METODLAR

Dastlabki ma’lumotlar muallif maqolasining «O‘zbekiston Respublikasining asosiy transport yo‘laklari va tashqi savdo marshrutlari» jadvalidan olindi [5]. Unda har bir marshrut bo‘yicha masofa (km), yetkazib berish muddati (sutka) va 20–22 t yukni (bitta jo‘natma) tashishning o‘rtacha xarajati (AQSh dollari) oraliq ko‘rinishida berilgan; hisobda oraliqlarning o‘rtacha qiymati olindi. Tahlilga xarajati ko‘rsatilgan 12 ta marshrut kiritildi. Kiyev orqali o‘tuvchi yo‘nalish 2022-yildan buyon amalda foydalanilmagani sababli, Amsterdam, Parij va Madrid manzillari esa xarajat ko‘rsatilmagani uchun chiqarib tashlandi; bir xil xarajatli takroriy manzillardan (Vilnyus, Buxarest) bittasi qoldirildi.

Har bir marshrut uchun dengiz yoki parom bo‘g‘inlari soni S aniqlandi. Oqtau–Boku va Turkmanboshi–Boku parom o‘tishlari hamda Poti portidan Qora dengiz orqali tashishni o‘z ichiga

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olgan ikki marshrutda $S = 2$. Batumi–Trabzon oralig‘ida temir yo‘l bo‘lmagani uchun bu bo‘g‘in qayta yuklash bilan bajariladi, shu sababli Kavkaz–Istanbul marshrutida $S = 1$ deb olindi; qolgan marshrutlarda $S = 0$. Marshrutlar quyidagi solishtirma ko‘rsatkichlar bilan tavsiflandi:

$$c_j = C_j / L_j, \quad c'_j = 100 \cdot C_j / (m \cdot L_j), \quad v_j = L_j / T_j, \tag{1}$$

bunda C_j — j-marshrut bo‘yicha jo‘natmani tashish xarajati, doll.; L_j — masofa, km; T_j — yetkazib berish muddati, sutka; m — jo‘natma massasi (21 t); c_j — doll./km; c'_j — sent/t·km; v_j — yetkazib berish tezligi, km/sutka.

Xarajat va vaqtning tuzilmasini ajratish uchun quyidagi chiziqli modellar eng kichik kvadratlar usulida baholandi:

$$C_j = a + b \cdot L_j + d \cdot S_j + \varepsilon_j, \tag{2}$$

$$T_j = t_0 + k \cdot L_j + \tau \cdot S_j + \eta_j, \tag{3}$$

bunda a — masofaga bog‘liq bo‘lmagan xarajat (terminal operatsiyalari, chegara va hujjatlashtirish); b — masofa stavkasi, doll./km; d — bitta dengiz yoki parom bo‘g‘inining xarajat ustamasi; t_0 — masofaga bog‘liq bo‘lmagan vaqt; k — 1 km ga to‘g‘ri keladigan vaqt ($1/k$ — bazaviy tezlik); τ — bitta bo‘g‘inning vaqt ustamasi; ε_j, η_j — qoldiqlar. Qoldiqlar model hisobga olmagan yo‘nalishga xos omillarni (tarif siyosati, iz kengligi almashinuvi, tranzit davlatlar soni) ko‘rsatadi.

Vaqtni pul ko‘rinishiga keltirish uchun umumlashgan xarajat tushunchasidan foydalanildi [8]:

$$G_{jk} = C_j + \theta_k \cdot V_k \cdot T_j, \quad g_{jk} = G_{jk} / L_j, \tag{4}$$

bunda V_k — k-sinf jo‘natmaning qiymati; θ_k — vaqtning sutkalik qiymati (yuk qiymatiga nisbatan ulush). Uch sinf ko‘rib chiqildi: A — arzon yuk ($V = 20$ ming doll., $\theta = 0{,}05$ %/sutka, ya’ni yiliga taxminan 18 % kapital qiymati); B — o‘rta qiymatli yuk ($V = 100$ ming doll., $\theta = 0{,}3$ %/sutka); C — vaqtga sezgir qimmat yuk ($V = 300$ ming doll., $\theta = 0{,}6$ %/sutka, [4] dagi bahoning pastki chegarasi). Bitta dengiz/parom bo‘g‘inining umumlashgan ekvivalenti (2)–(4) dan kelib chiqadi:

$$\Delta G_k = d + \tau \cdot \theta_k \cdot V_k. \tag{5}$$

1-jadval

Tashqi savdo temir yo‘l marshrutlarining dastlabki va solishtirma ko‘rsatkichlari [5]

Kod	**Marshrut (manzil)**	***L*, km**	***T*, sutka**	***C*, doll.**	***S***	***c*, doll./km**	***c'*, sent/t·km**	***v*, km/sutka**
M1	Termiz – Mozori-Sharif	85	1,0	1 200	0	14,12	67,2	85
M2	Saraxs – Bandar-Abbos	3 065	6,5	2 500	0	0,82	3,9	472
M3	Saraxs – Mersin	4 208	13,0	3 150	0	0,75	3,6	324
M4	Saraxs – Istanbul – Sofiya (J)	5 156	14,5	4 150	0	0,80	3,8	356
M5	Beyneu – Moskva – Riga	4 781	12,0	2 150	0	0,45	2,1	398
M6	Beyneu – Moskva – Brest – Minsk	4 421	9,5	2 300	0	0,52	2,5	465
M7	Beyneu – Moskva – Brest – Varshava	4 800	11,0	2 400	0	0,50	2,4	436
M8	Beyneu – Moskva – Brest – Berlin	5 400	14,0	3 250	0	0,60	2,9	386
M9	Astraxan – Tbilisi – Batumi – Istanbul – Sofiya (K)	5 500	14,5	4 150	1	0,75	3,6	379
M10	Oqtau – Boku – Poti – Konstansa	4 558	20,0	4 600	2	1,01	4,8	228
M11	Turkmanboshi – Boku – Poti – Burgas	4 320	20,0	4 800	2	1,11	5,3	216
M12	Olmaota – Xorgos – Urumchi	1 850	5,5	2 900	0	1,57	7,5	336

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Mozori-Sharif marshruti (85 km) solishtirma reytingdan chiqarildi, chunki uning xarajati deyarli to‘liq masofaga bog‘liq bo‘lmagan qismdan iborat; u modellarni baholashda saqlab qolindi.

3. NATIJALAR

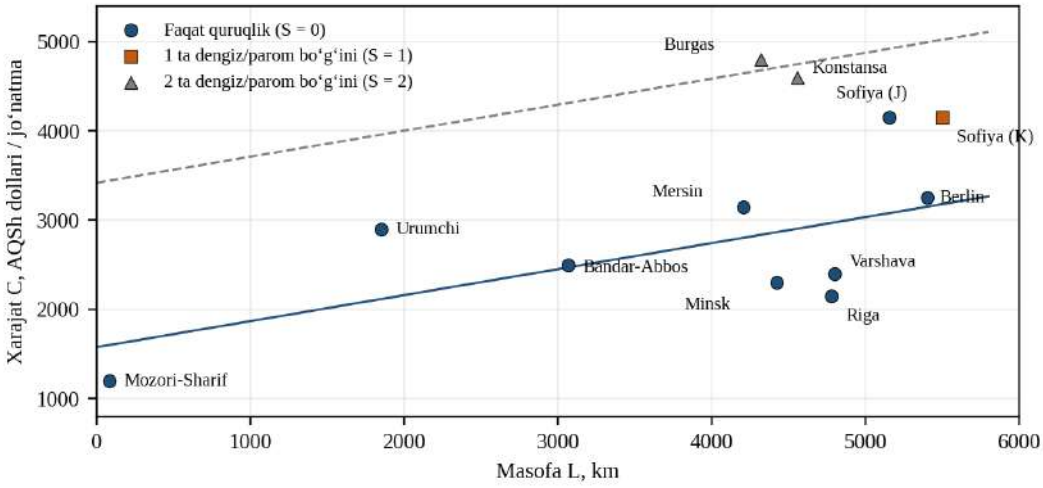
Marshrutlarning masofa bo‘yicha solishtirma xarajati 0,45 doll./km (Riga) dan 1,57 doll./km (Urumchi) gacha, ya’ni 2,1–7,5 sent/t·km oralig‘ida o‘zgaradi (1-jadval). Mozori-Sharif yo‘nalishida bu ko‘rsatkich 14,1 doll./km (67 sent/t·km) ga yetadi: 85 km masofaga 1 200 dollar sarflanishi xarajat asosan chegara va terminal operatsiyalari bilan belgilanishini ko‘rsatadi. Yetkazib berish tezligi Bandar-Abbos (472 km/sutka) va Minsk (465 km/sutka) yo‘nalishlarida eng yuqori, Kaspiy va Qora dengiz orqali o‘tuvchi marshrutlarda esa eng past (216–228 km/sutka).

(2) model bo‘yicha masofaga bog‘liq bo‘lmagan xarajat a = 1 576 doll., masofa stavkasi b = 0,291 doll./km, bitta dengiz/parom bo‘g‘inining ustamasi d = 921 doll.; barcha koeffitsiyentlar statistik ahamiyatli (2-jadval). Natijaga ko‘ra 4–5 ming km masofada ham jo‘natma xarajatining 52–57 foizi, 1 850 km (Urumchi) da esa qariyb 75 foizi masofaga bog‘liq bo‘lmagan qismga to‘g‘ri keladi. Bitta dengiz yoki parom bo‘g‘ini xarajat bo‘yicha taxminan 3 200 km qo‘shimcha temir yo‘l masofasiga teng. (3) vaqt modeli yanada aniq: bazaviy tezlik $1/k \approx 442$ km/sutka, har bir bo‘g‘in esa 4,1 sutka qo‘shadi, bu 1 800 km ga yaqin temir yo‘l masofasini bosib o‘tish vaqtiga teng (1-rasm).

2-jadval

Xarajat (2) va vaqt (3) modellarini baholash natijalari (n = 12; qavs ichida standart xato)

Ko‘rsatkich	**Xarajat modeli, *C***	**Vaqt modeli, *T***
Ozod had (a / t_0)	1 576 doll. (498)	1,0 sutka (1,4)
Masofa koeffitsiyenti (b / k)	0,291 doll./km (0,119)	0,00226 sutka/km (0,00033)
Dengiz/parom bo‘g‘ini (d / τ)	921 doll. (241)	4,1 sutka (0,66)
Bazaviy tezlik $1/k$	—	≈ 442 km/sutka
R^2 / tuzatilgan R^2	0,745 / 0,689	0,925 / 0,908



1-rasm. Jo‘natma xarajatining masofaga bog‘liqligi: uzluksiz chiziq — (2) model S = 0 da, uzuq chiziq — S = 2 da

Model qoldiqlari yo‘nalishlar bo‘yicha aniq farqlanadi (3-jadval). Shimoliy yo‘nalishdagi Riga, Minsk va Varshava marshrutlari modeldagidan 564–819 dollar arzon, Berlin esa model chizig‘iga yaqin. Saraxs orqali Eron va Turkiyaga chiquvchi marshrutlar qimmat: Mersin +348, Sofiya (J) +1 071 dollar. Xorgos orqali Urumchi marshruti +785 dollar ustamaga ega. Kaspiy dengizi orqali ikki marshrut model bilan deyarli mos keladi (–147 va +122 dollar), ya’ni ularning yuqori xarajati to‘liq dengiz/parom bo‘g‘inlari bilan tushuntiriladi. Vaqt bo‘yicha eng katta chetlanishlar Kavkaz–Istanbul marshrutida (–3,0 sutka) va Mersin yo‘nalishida (+2,5 sutka) kuzatiladi.

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3-jadval

Marshrutlarning haqiqiy va model bo‘yicha xarajati hamda yetkazib berish muddati

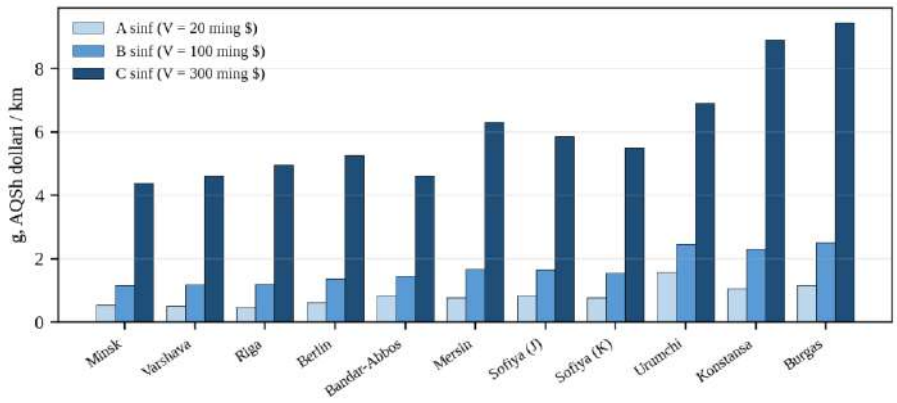
Kod	Manzil	*C*, doll.	Model *C*, doll.	*ε*, doll.	*T*, sutka	Model *T*, sutka	*η*, sutka
M1	Mozori-Sharif	1 200	1 601	–401	1,0	1,2	–0,2
M2	Bandar-Abbos	2 500	2 469	+31	6,5	7,9	–1,4
M3	Mersin	3 150	2 802	+348	13,0	10,5	+2,5
M4	Sofiya (J)	4 150	3 079	+1 071	14,5	12,7	+1,8
M5	Riga	2 150	2 969	–819	12,0	11,8	+0,2
M6	Minsk	2 300	2 864	–564	9,5	11,0	–1,5
M7	Varshava	2 400	2 975	–575	11,0	11,9	–0,9
M8	Berlin	3 250	3 150	+100	14,0	13,2	+0,8
M9	Sofiya (K)	4 150	4 100	+50	14,5	17,5	–3,0
M10	Konstansa	4 600	4 747	–147	20,0	19,5	+0,5
M11	Burgas	4 800	4 678	+122	20,0	19,0	+1,0
M12	Urumchi	2 900	2 115	+785	5,5	5,2	+0,3

(4) formula bo‘yicha umumlashgan xarajat va marshrutlar reytingi 4-jadval va 2-rasmda keltirilgan. A sinfda vaqt qiymati sutkasiga atigi 10 dollarni tashkil etadi va reyting amalda tarif bo‘yicha shakllanadi: Riga (0,47), Varshava (0,52) va Minsk (0,54 doll./km) yetakchi. B sinfda (sutkasiga 300 doll.) eng qisqa muddatli Minsk yo‘nalishi birinchi o‘ringa chiqadi, Bandar-Abbos esa sakkizinchi o‘rindan beshinchiga ko‘tariladi. C sinfda (sutkasiga 1 800 doll.) vaqt xarajati umumlashgan xarajatning 77–91 foizini tashkil etadi; Bandar-Abbos uchinchi o‘ringa chiqadi, Riga esa to‘rtinchiga tushadi. (5) formula bo‘yicha bitta dengiz/parom bo‘g‘inining ekvivalenti A sinf uchun 962, B uchun 2 148, C uchun 8 283 dollarni tashkil etadi.

4-jadval

Yuk sinflari bo‘yicha solishtirma umumlashgan xarajat *g*, doll./km, va marshrutning o‘rni

Kod	Manzil	A sinf: *g*	O‘rin	B sinf: *g*	O‘rin	C sinf: *g*	O‘rin
M2	Bandar-Abbos	0,84	8	1,45	5	4,63	3
M3	Mersin	0,78	5	1,68	8	6,31	8
M4	Sofiya (J)	0,83	7	1,65	7	5,87	7
M5	Riga	0,47	1	1,20	3	4,97	4
M6	Minsk	0,54	3	1,16	1	4,39	1
M7	Varshava	0,52	2	1,19	2	4,62	2
M8	Berlin	0,63	4	1,38	4	5,27	5
M9	Sofiya (K)	0,78	6	1,55	6	5,50	6
M10	Konstansa	1,05	9	2,33	9	8,91	10
M11	Burgas	1,16	10	2,50	11	9,44	11
M12	Urumchi	1,60	11	2,46	10	6,92	9



2-rasm. Yuk sinflari bo‘yicha marshrutlarning solishtirma umumlashgan xarajati *g*

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Janubi-sharqiy Yevropa (Bolgariya, Ruminiya) yo‘nalishida to‘rtta muqobil marshrutni solishtirish alohida e’tiborga loyiq. Kaspiy va Qora dengiz orqali o‘tuvchi M10 va M11 marshrutlari Eron–Turkiya orqali quruqlik marshrutiga (M4) nisbatan jo‘natma uchun 450–650 dollar qimmat va 5,5 sutka uzoq, ya’ni hech bir yuk sinfida undan ustun kelmaydi. C sinfda bu farq jo‘natmaga 10 350–10 550 dollarni tashkil etadi; [3] dagi bahoga ko‘ra 5,5 sutkalik farq savdo hajmini kamida 5,5 foizga kamaytirishi mumkin.

4. MUHOKAMA

Birinchi muhim natija — xarajatning katta qismi masofaga bog‘liq emasligi. Transport xarajati terminal va harakat (masofa) qismlaridan iborat bo‘lib, masofa ortishi bilan solishtirma xarajat kamayishi umume’tirof etilgan [9]; O‘zbekiston marshrutlarida esa 4–5 ming km masofada ham qat’iy qism xarajatning yarmidan ko‘pini tashkil etadi. Shu sababli masofaviy tarifni pasaytirishdan ko‘ra chegara, terminal va hujjatlashtirish xarajatlarini qisqartirish samaraliroq bo‘lishi mumkin: a ni 20 foizga (≈ 315 doll.) kamaytirish 4 500 km masofada masofa stavkasini 24 foizga kamaytirish bilan teng natija beradi. Bu xulosa CAREC monitoringida chegaradagi vaqt va xarajatga alohida e’tibor berilishi bilan mos keladi [6]. Ayniqsa, Mozori-Sharif va Urumchi kabi qisqa va o‘rta masofali yo‘nalishlarda chegara o‘tkazish punktlari va iz kengligi almashinuvi nuqtalarini modernizatsiya qilish ustuvor vazifa sifatida qaralishi lozim.

Ikkinchi natija dengiz va parom bo‘g‘inlariga taalluqli. Har bir bunday bo‘g‘in 921 dollar va 4,1 sutka qo‘shadi. Kaspiy–Qora dengiz marshrutlari Eron–Turkiya marshruti bilan tenglashishi uchun M10 misolida A sinf yukda har bir bo‘g‘in xarajatini taxminan 253 dollarga (d ning 27 foizi) kamaytirish, B sinfda xarajat o‘zgarmagan holda har bir bo‘g‘indagi vaqtni 3,5 sutkaga (τ ning 86 foizi), C sinfda esa 2,9 sutkaga (τ ning 70 foizi) qisqartirish talab etiladi. Demak, O‘rta koridor uchun e’lon qilingan tashish muddatini ikki baravar qisqartirish maqsadi [7] amalga oshsa, bu marshrutlar o‘rta va qimmat yuklar uchun raqobatbardosh bo‘lishi mumkin; arzon yuklar uchun esa asosiy omil tarif bo‘lib qoladi.

Uchinchidan, shimoliy yo‘nalishdagi 564–819 dollarlik chegirma va Saraxs orqali marshrutlardagi 348–1 071 dollarlik ustama model hisobga olmagan omillarni ko‘rsatadi. Saraxs nuqtasida 1 520 va 1 435 mm iz kengligi almashinuvi hamda ikki davlat hududi orqali tranzit bunday ustamaning ehtimoliy sabablari hisoblanadi; bu farazni chegara xarajatlari bo‘yicha alohida ma’lumotlar bilan tekshirish lozim. Shimoliy yo‘nalishlarning arzonligi esa tashqi xatarlar va sanksiyaviy cheklovlar hisobga olinmagan holda olingan; ular modelga kiritilsa, reyting o‘zgarishi mumkin.

To‘rtinchidan, reytingning yuk qiymatiga bog‘liqligi marshrutlarni yuk turlari bo‘yicha tabaqalashtirish zarurligini ko‘rsatadi. Arzon ommaviy yuklar uchun eng past tarifli shimoliy marshrutlar, vaqtga sezgir qimmat yuklar uchun esa eng tez marshrutlar maqbul. C sinf yukda yetkazib berish muddatini bir sutkaga qisqartirish jo‘natmaga 1 800 dollar tejaydi; bu kafolatlangan jadval asosida qatnaydigan tezlashtirilgan konteyner poyezdlari uchun tarif ustamasini iqtisodiy jihatdan asoslash imkonini beradi.

Tadqiqotning cheklovlari: (1) xarajatlar maqola jadvalidan olingan, manbada sanasi ko‘rsatilmagan va ular 2021–2022-yillar atrofidagi tarif darajasini aks ettiradi deb hisoblanadi; (2) tanlanma kichik (n = 12), shu sababli koeffitsiyentlar taxminiy xarakterga ega; (3) oraliq qiymatlarning o‘rtachasi olingan, yetkazib berish muddatining barqarorligi (dispersiyasi) hisobga olinmagan; (4) V va θ qiymatlari stsenariy tarzida tanlangan; (5) Bandar-Abbos, Mersin, Riga va Qora dengiz portlaridan keyingi dengiz bo‘g‘ini tahlilga kiritilmagan; (6) S o‘zgaruvchisi parom va dengiz bo‘g‘inlarini, shuningdek iz kengligi almashinuvini alohida ajratmaydi.

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PROSPECTS FOR THE APPLICATION OF Ti–Cr, TiN AND TiB_2 SYSTEMS FOR STRENGTHENING SUPERHARD MATERIALS

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Abstract: *The article examines the main approaches to improving the performance properties of superhard materials based on cubic boron nitride (cBN) and titanium-containing compounds. The primary focus is on forming Ti–Cr coatings on the surface of cBN particles, obtaining TiB2–TiN composites, as well as cBN composites with combined binders. Based on published data, the influence of temperature, composition, and treatment conditions on the phase composition, microstructure, hardness, density, and strength of materials has been demonstrated. The possibilities of vacuum deposition and magnetron spraying as promising methods for surface hardening have been considered. The work is of an overview nature and can serve as an introductory theoretical basis for further research in the field of surface treatment technologies.*

Key words: *cubic boron nitride; cBN, TiN, TiB2; Ti–Cr coating; PVD; magnetron spraying; surface hardening; superhard materials*

ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ Ti–Cr, TiN И TiB_2 СИСТЕМ ДЛЯ УПРОЧНЕНИЯ СВЕРХТВЁРДЫХ МАТЕРИАЛОВ

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Аннотация *В статье рассмотрены основные подходы к повышению эксплуатационных свойств сверхтвёрдых материалов на основе кубического нитрида бора (cBN) и титансодержащих соединений. Основное внимание уделено формированию Ti–Cr покрытий на поверхности частиц cBN, получению композитов TiB_2–TiN, а также cBN-композитов с комбинированными связующими. На основе опубликованных данных показано влияние температуры, состава и условий обработки на фазовый состав, микроструктуру, твёрдость, плотность и прочность материалов. Рассмотрены возможности вакуумного осаждения и магнетронного распыления как перспективных методов поверхностного упрочнения. Работа носит обзорный характер*

и может служить вводной теоретической основой для дальнейших исследований в области технологий обработки поверхностей.

Ключевые слова *кубический нитрид бора; cBN; TiN; TiB_2; Ti–Cr покрытие; PVD; магнетронное распыление; поверхностное упрочнение; сверхтвёрдые материалы*

1. INTRODUCTION

Modern mechanical engineering places increasingly high demands on cutting, abrasive, and tool materials. These materials are expected to combine high hardness, wear resistance, thermal stability, and the ability to retain their properties under high contact loads. Cubic boron nitride (cBN) is one of the most important superhard materials. Although it is less hard than diamond, it has high thermal and chemical stability and is therefore widely used for machining steels and other ferrous materials [3].

The performance of cBN depends not only on the properties of the grain itself, but also on the condition of its surface, the quality of bonding with the matrix, and the structure of the interfacial zone. Therefore, surface modification of cBN with metallic and ceramic layers is considered a promising direction. Titanium is of particular interest because it can interact with boron and nitrogen to form hard TiB_2 and TiN phases. Chromium, in turn, can improve oxidation resistance and the thermal stability of the surface layer [2, 5].

Another important direction is the production of bulk TiB_2–TiN ceramic composites. TiB_2 is characterized by high hardness and wear resistance, while TiN has long been used as a protective and wear-resistant coating. The combination of these phases makes it possible to obtain materials suitable for high-temperature operation and significant mechanical loading [1]. For thin-film systems, PVD processes and magnetron sputtering are of particular interest because they allow control of coating composition, thickness, and multilayer architecture [6, 7].

The aim of this paper is to summarize, in an accessible form, the results of studies on Ti–Cr coatings, TiB_2–TiN composites, and cBN composites with binders, and to define their significance for the further development of surface strengthening technologies.

1. TiB_2–TiN composites and the influence of synthesis conditions

In the study by M. M. Liu et al., TiB_2–TiN composites were produced from titanium and hexagonal boron nitride powders at a high pressure of 5.0 GPa and temperatures ranging from 1400 to 1800 °C [1]. The authors investigated phase composition, microstructure, density, and hardness. The main reaction can be represented as $3Ti + 2BN \rightarrow TiB_2 + TiN$. At the same time, intermediate phases such as $TiN_{0.26}$, Ti_2N, TiB, and Ti_3B_4 were also formed, and their amount depended on the temperature and holding time.

As the temperature increased, the reaction became more complete and the amount of residual BN decreased. The highest relative density reached 96.2%. The maximum Vickers hardness was 17.9 GPa at 1800 °C with a holding time of 30 min [1]. These results show that temperature directly affects phase formation and the size of structural elements and, through them, the mechanical properties of the material.

Such systems are of interest not only as bulk ceramics. Thin-film nitride and boride coatings are also widely discussed in the literature. The review by PalDey and Deevi shows that PVD coatings based on TiN and complex nitrides are extensively used to improve tool wear resistance and thermal stability [7]. The addition of alloying elements and the formation of multilayer structures make it possible to control hardness, oxidation resistance, and tribological properties.

Thus, the results obtained for TiB_2–TiN may serve as a basis for selecting compositions for future coatings. If hard phases provide a positive effect in a bulk material, the same concept can

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be applied to a surface layer where high hardness must be combined with sufficient adhesion to the substrate.

2. Ti–Cr coatings on cBN surfaces

The study that is most closely related to surface engineering is the work by Y. Jiang, L. Fang, and W. Yang, devoted to the deposition of a Ti–Cr coating on cBN particles by vacuum vapor deposition [2]. The work is published as a preprint, so its results should be regarded as promising but still requiring further independent verification. Nevertheless, it presents a clear technological route and compares several Ti/Cr ratios.

Before coating, the cBN particles were chemically cleaned and then mixed with Ti and Cr powders. The process was carried out at a vacuum level of about 10^{-2} Pa and a temperature of approximately 850 °C, with a holding time of about three hours [2]. The authors used SEM and XRD together with computational modeling of the deposition process. According to their interpretation, TiN first forms on the cBN surface, after which Ti and Cr participate in the formation of a combined surface layer.

The highest compressive strength of the particles was obtained at a Ti:Cr mass ratio of 1:1 [2]. After heat treatment, increasing the Cr content also had a positive influence on strength retention, which was associated with reduced titanium oxidation. These results are consistent with the general understanding of chromium as an element capable of improving the oxidation resistance of protective coatings.

The importance of titanium-containing surface layers is also supported by other studies. Daoush et al. obtained TiN coatings on cBN through preliminary titanium deposition followed by heat treatment, resulting in nanoscale layers of Ti-containing compounds on the surface [4]. Chang et al. also showed that Ti coatings on cBN may contain TiB_2, TiN, and metallic Ti and can improve particle strength and the bonding quality between cBN and a metallic matrix [5].

Therefore, Ti and Cr represent a promising pair for cBN surface modification. A transition from conventional vacuum deposition to DC/RF magnetron sputtering can provide wider possibilities for controlling coating composition, process power, working pressure, gas atmosphere, and layer thickness.

3. cBN composites with AlN–Al–Ni binders

In the work by L. Li et al., cBN composites were produced under high-pressure and high-temperature conditions using a mixed AlN–Al–Ni binder [3]. The concept of this composition is to combine the advantages of metallic and ceramic binders. Metallic components promote densification and improve bonding between grains, while ceramic phases help retain high hardness.

The authors varied the binder content from 11 to 17 wt.% and the sintering temperature from 1350 to 1550 °C. At 17 wt.% binder, the relative density reached 99.6%, flexural strength reached 661 MPa, and fracture toughness reached 7.19 $MPa \cdot m^{1/2}$. At the same time, the maximum hardness of 47.92 GPa was obtained at 13 wt.% binder [3]. This result demonstrates that a single composition does not necessarily provide the maximum value of every property at the same time.

A similar conclusion was reported by Yang et al., who compared cBN composites with Al- and TiC-based binders [8]. The composition and amount of the binder phase affect density, microstructure, and mechanical properties; therefore, the priority property—hardness, strength, fracture toughness, or wear resistance—should be defined in advance when designing the material.

This principle is directly relevant to surface engineering. A coating should not be evaluated only by hardness. Even a very hard layer may be ineffective if it has poor adhesion, excessive brittleness, or low oxidation resistance. Therefore, promising Ti–Cr–N, TiN, CrN, and TiB_2-containing coatings should be studied using a combined set of characteristics.

4. Prospects of PVD and magnetron sputtering methods

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Physical vapor deposition (PVD) makes it possible to form thin coatings in vacuum while precisely controlling many process parameters. Magnetron sputtering is one of the most widely used PVD techniques. Its main advantage is the possibility of depositing metallic, nitride, and multicomponent layers with relatively accurate control of composition and thickness [6, 7].

In the study by Otaño-Rivera et al., cBN films were produced by magnetron sputtering, and the effects of Al additions and AlN interlayers on the stability of the cubic phase and adhesion were investigated [6]. It was shown that even small changes in composition can strongly influence the stability of the cBN phase. This highlights the importance of accurate control of technological parameters during coating deposition.

The practical importance of surface metallization is also confirmed by studies on abrasive materials. Wang et al. showed that a titanium coating on diamond grits improved their strength, oxidation resistance, and retention in a metallic bond [10]. Although diamond and cBN are different materials, the general concept is similar: a surface layer creates a more favorable interface between the superhard particle and the surrounding matrix.

In addition to PVD, electrochemical methods are also important. Feng et al. demonstrated the possibility of forming nickel coatings on fine diamond particles by electroplating using a rotating electrode [9]. Such studies show that the choice of technology depends on the required coating material, sample geometry, and research objectives. For an educational and research laboratory, combining magnetron sputtering with electroplating processes makes it possible to study different mechanisms of surface layer formation.

A promising direction for further work is a comparative study of single-layer and multilayer Ti, Cr, TiN, CrN, and Ti–Cr–N systems. Possible process variables include DC/RF power, Ar and N_2 flow rates, working pressure, substrate temperature, and deposition time. The resulting coatings can then be evaluated in terms of structure, hardness, adhesion, wear resistance, and corrosion resistance.

CONCLUSION

The analysis of published studies shows that Ti-, Cr-, nitride-, and boride-based systems are of considerable interest for strengthening superhard materials. High-pressure synthesis of TiB_2–TiN makes it possible to obtain dense and hard ceramic materials, while modification of cBN surfaces with titanium and Ti–Cr layers can improve particle strength and interaction with the binder phase [1, 2, 4, 5].

At the same time, composition optimization should be based on a combination of properties. Studies of cBN composites demonstrate that maximum hardness may be achieved at one binder content, while maximum strength and fracture toughness may occur at another [3, 8]. Therefore, promising coatings should be evaluated simultaneously by mechanical, structural, and service-performance parameters.

For further development of this research area, PVD and DC/RF magnetron sputtering are particularly promising. These methods allow the production of single-layer and multilayer coatings with controlled composition and provide a basis for systematic studies of the influence of technological parameters on surface properties. The reviewed literature may be used as an introductory theoretical basis for a master's thesis and as a foundation for subsequent computational or experimental research.

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August-September 2026
ISSN: 2791-3651

THE EFFECT OF PARTICLE SIZE DISTRIBUTION, MOISTURE CONTENT AND TEMPERATURE ON THERMAL SHOCK AND CRACKING OF IRON ORE PELLETS DURING DRYING

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Abstract: *The article examines the patterns of failure of green iron ore pellets at the drying stage. The causes of surface cracking and volumetric (explosive) destruction of pellets are analyzed; they are associated with the mismatch between the intensity of water vapor generation and its filtration through the pore space. Experimental data are summarized on the share of cracked pellets depending on the size class (16–5 mm) and drying temperature (300–600 °C) for fluxed and non-fluxed raw material, on the compressive strength of dried pellets, and on the thermal shock temperature at residual moisture of 3.0–9.4 %. It is shown that the thermal stability of pellets decreases as their diameter and moisture content increase. Recommendations are formulated for the temperature regime of the first drying zone of an induration machine.*

Key words: *iron ore pellets, drying, thermal stability, crack formation, thermal shock, size class, moisture, compressive strength*

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Volume 5 | Issue 52-53 |
August-September 2026
ISSN: 2791-3651

ВЛИЯНИЕ ГРАНУЛОМЕТРИЧЕСКОГО СОСТАВА, ВЛАЖНОСТИ И ТЕМПЕРАТУРЫ НА ТЕРМОУДАР И РАСТРЕСКИВАНИЕ ЖЕЛЕЗОРУДНЫХ ОКАТЫШЕЙ ПРИ СУШКЕ

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Аннотация *В статье рассмотрены закономерности разрушения сырых железорудных окатышей на стадии сушки. Проанализированы причины поверхностного растрескивания и объёмного (взрывообразного) разрушения окатышей, связанные с несоответствием интенсивности образования водяного пара и его фильтрации через поровое пространство. Обобщены экспериментальные данные о доле окатышей с трещинами в зависимости от класса крупности (16-5 мм) и температуры сушки (300-600 °C) для офлюсованного и неофлюсованного сырья, о прочности высушенных окатышей на сжатие, а также о температуре теплового шока при остаточной влажности 3,0-9,4 %. Показано, что термостойкость окатышей снижается с увеличением их диаметра и влажности. Сформулированы рекомендации по температурному режиму первой зоны сушки обжиговой машины.*

Ключевые слова *железорудные окатыши, сушка, термостойкость, растрескивание, тепловой шок, класс крупности, влажность, прочность на сжатие*

1. INTRODUCTION

Pellets made from finely ground iron ore concentrates are one of the main components of the charge of blast furnaces and direct reduction units. The quality of the finished product is largely determined not only by the parameters of balling and induration, but also by how defect-free the green pellets pass through the initial stage of heat treatment – drying. It is at this stage that intensive

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heating, evaporation and moisture migration occur simultaneously in the pellet, making it most vulnerable to mechanical damage.

The most important technological characteristic of green pellets is thermal stability – the ability to withstand heating at the highest possible rate of heat supply without cracking or complete destruction. This concept combines two phenomena: crack formation, in which the integrity of the granule is preserved but defects appear on its surface, and temperature (thermal) shock, accompanied by instantaneous destruction of the pellet [1, 2]. The mechanical properties of pellets obtained as a result of heat treatment depend on the temperature level, holding time, heating and cooling rates, as well as on the chemical and mineral composition of the charge [2, 3].

The physical picture of the processes occurring in a pellet during intensive heating is shown schematically in Fig. 1. Heat from the hot gas reaches the surface, and the outer layer dries first. The boundary between the dry shell and the wet core – the evaporation front – gradually moves toward the center. The vapor formed escapes outward through the pore system; if the pores cannot remove it in time, pressure in the core rises, and radial and tangential stresses arise in the shell, leading to cracks or destruction.

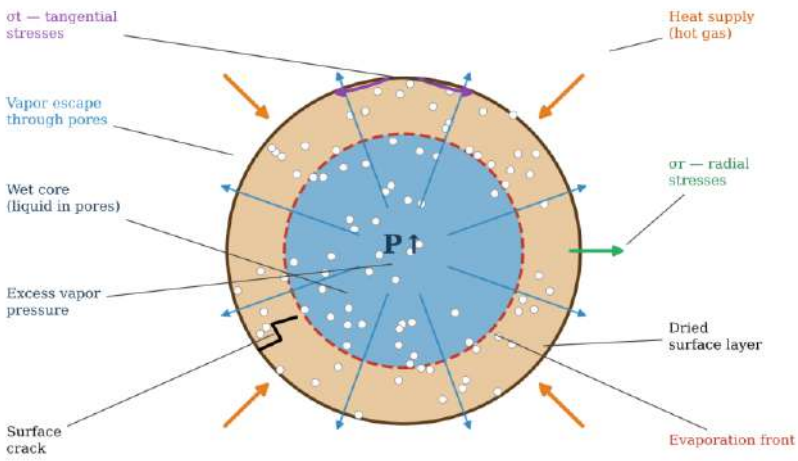

Figure 1. Drying scheme of a green pellet: moisture distribution, vapor escape paths and stresses in the shell

The appearance of cracks at the drying stage has a number of negative consequences: the strength of pellets decreases, the yield of fines during transportation and handling increases, and the gas permeability of the bed on the induration machine and in the blast furnace deteriorates. Therefore, determining the maximum permissible drying temperatures for pellets of different size and moisture content remains a relevant task for pelletizing plants seeking to increase the productivity of induration units without impairing product quality.

The aim of this work is to summarize and analyze experimental data on the effect of particle size distribution, drying temperature and residual moisture on crack formation, strength and thermal shock temperature of fluxed and non-fluxed iron ore pellets, and to formulate practical recommendations on the drying regime.

2. MATERIALS AND METHODS

The object of the study was green fluxed and non-fluxed pellets produced from magnetite concentrate. Before testing, the pellets were screened into four size classes: 16-12.5; 12.5-11.2; 11.2-8 and 8-5 mm. Samples weighing about 200 g were formed from each class.

The general scheme of the experimental studies is shown in Fig. 2.

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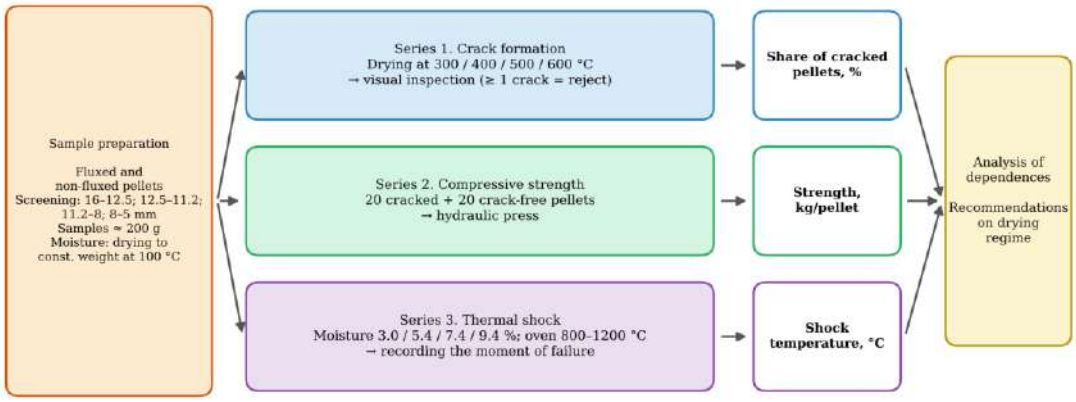

Figure 2. Scheme of the experimental studies

The study included three series of experiments. In the first series, pellet samples of each class were dried in a laboratory furnace at fixed temperatures of 300, 400, 500 and 600 °C. The initial moisture content was determined by the standard gravimetric method – drying the samples to constant weight at 100 °C. After drying, each pellet was inspected visually; a pellet was considered to have failed the thermal load if at least one crack was detected, regardless of its size and orientation. Based on the inspection results, the share of cracked pellets (%) was calculated for each combination of "pellet type – size class – temperature".

In the second series, the compressive strength of dried pellets was determined. For this purpose, 20 pellets without cracks and 20 pellets with cracks were selected from each class and crushed on a hydraulic press according to the standard method [6]. The result was expressed as the average breaking load in kilograms per pellet.

In the third series, the thermal shock temperature was determined. Wet pellets were placed in a drying oven preheated to a specified temperature in the range of 800-1200 °C, and the moment of their destruction was recorded visually. The shock temperature was taken as the minimum ambient temperature at which explosive destruction of the pellets occurred. Tests were performed for pellets with a moisture mass fraction of 3.0; 5.4; 7.4 and 9.4 %; moisture was controlled by the same gravimetric method. The obtained dependences were processed graphically; the values given in the figures and table were taken from the experimental curves and are approximate.

3. MAIN PART

In the initial period of drying, moisture evaporates mainly in the near-surface layer of the pellet, and the vapor escapes relatively freely. As the inner layers heat up, evaporation spreads deep into the granule. If the intensity of vapor generation exceeds the throughput capacity of the porous structure, excess vapor pressure builds up inside the pellet. A moderate excess leads to the formation of surface cracks; with a sharp rise in temperature, when the vapor generation rate continues to increase while the rate of its filtration through the pores remains practically unchanged, the pressure becomes sufficient for instantaneous destruction of the granule, i.e. for thermal shock [1, 4].

Under a severe drying regime, a complex stress state forms in a spherical body, which can conveniently be described by two components: radial (normal) stresses directed along the radius and tangential stresses acting perpendicular to it. Exceeding the strength limit for tangential stresses causes surface cracking in different directions, whereas exceeding it for radial stresses leads to detachment and destruction of the outer shell of the pellet, which is observed as shock. The thermal conductivity of the charge components also plays a significant role: a material with higher thermal conductivity heats up faster and becomes a source of vapor earlier.

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The nature of mass transfer depends on the ratio of the thermal conductivity coefficients of the solid skeleton λ_s and the liquid λ_l [4]. When $\lambda_s > \lambda_l$, a so-called piston mode of moisture removal is possible, in which the evaporation front quickly moves inward, creating significant excess pressures; drying in this case proceeds at high intensity, but with an increased risk of destruction. When $\lambda_s \approx \lambda_l$, moisture removal approaches the laws of evaporation from a free surface and is "softer".

The thermal stability of pellets is also affected by the binder composition. It is known that increasing the proportion of bentonite in the charge lowers the temperature at which cracking begins, since the number of closed pores that hinder the escape of vapor increases; the bentonite additive has little effect on the shock temperature [5]. A generalization of literature data shows that the tendency of pellets to fail increases with a decrease in porosity and particle size of the concentrate, a widening of the particle size distribution range, an increase in pellet diameter and moisture content, as well as with an increase in drying temperature and rate [1, 3, 5].

The results of the first series of experiments for fluxed pellets are shown in Fig. 3. For all size classes, the share of cracked pellets increases monotonically with increasing drying temperature, but the absolute values differ significantly.

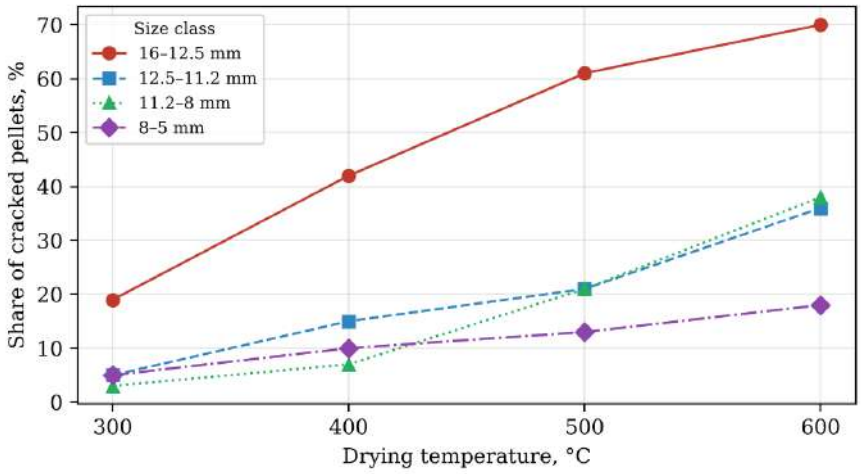

Figure 3. Share of cracked fluxed pellets versus drying temperature for different size classes (plotted from experimental data)

The pellets of the coarse class 16-12.5 mm proved to be the most sensitive to heating: already at 300 °C approximately every fifth pellet has cracks, and at 600 °C – about 70 %. For the 12.5-11.2 and 11.2-8 mm classes, the share of defective pellets does not exceed 5 % at 300 °C, but increases to 35-40 % by 600 °C. The fine class 8-5 mm showed the best thermal stability: even at 600 °C the share of cracked pellets was less than 20 %. Thus, other things being equal, an increase in pellet size leads to a decrease in their thermal stability.

The explanation of this pattern is related to the length of the path that vapor must travel from the evaporation zone to the surface. In a large pellet, this path is longer and the resistance of the pore structure is higher, so the time required to evacuate the vapor increases, and at the same heating rate vapor generation outpaces filtration. For non-fluxed pellets the qualitative picture is similar: the share of crack-free pellets increases as their size and drying temperature decrease. At the same time, non-fluxed pellets are generally more prone to cracking: at 600 °C the share of defective pellets of the coarse class approaches 80 %, and at 500 °C – 60 %. Even at 300 °C, coarse non-fluxed pellets crack in about half of the cases, while for the 8-5 mm class crack formation at

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this temperature is practically absent. Consequently, the size distribution of pellets is one of the determining factors of their behavior during drying.

Data on the compressive strength of fluxed pellets without cracks are given in Table 1.

Table 1.

Compressive strength of dry fluxed pellets without cracks, kg/pellet

Size class, mm	300 °C	400 °C	500 °C	600 °C
16-12.5	≈ 7	≈ 19	≈ 33	≈ 41
12.5-11.2	≈ 5	≈ 12	≈ 21	≈ 31
11.2-8	≈ 7	≈ 11	≈ 15	≈ 22

As can be seen from Table 1, the strength of pellets increases with increasing drying temperature: for the 16-12.5 mm class it increases approximately 6 times (from 7 to 41 kg/pellet) when moving from 300 to 600 °C. Strengthening is associated with the onset of oxidation of magnetite to hematite, whose crystal lattice has a denser packing, which promotes the formation of strong intergranular bonds. It should be emphasized that this pattern applies only to pellets that have retained their integrity; pellets with cracks failed at significantly lower loads. Therefore, the gain in strength with increasing drying temperature can only be realized provided that the heating regime does not cause mass crack formation.

The results of the third series of experiments are presented in Fig. 4. For all size classes, the shock temperature decreases with increasing residual moisture of the pellets.

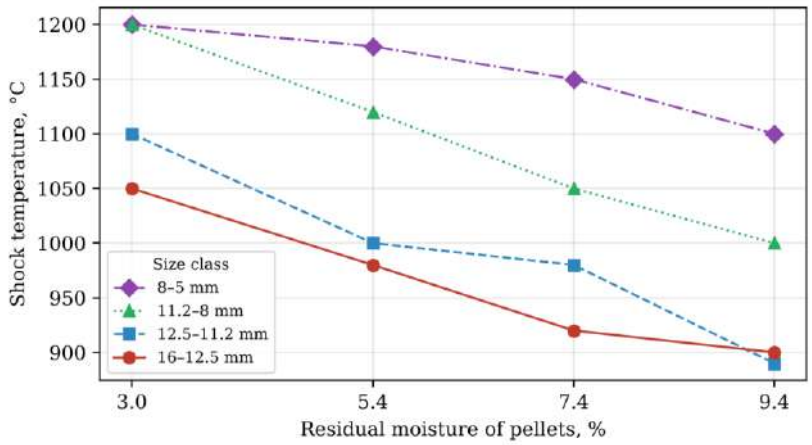

Figure 4. Thermal shock temperature versus residual moisture of pellets of different size classes (plotted from experimental data)

Pellets of finer classes withstand higher temperatures without destruction. At a moisture content of 3 %, the shock temperature for the 8-5 and 11.2-8 mm classes reaches about 1200 °C, while for the 12.5-11.2 and 16-12.5 mm classes it is 1050-1100 °C. With an increase in moisture to 9.4 %, the shock temperature decreases to 1000-1100 °C for fine pellets and to 890-900 °C for coarse ones. Thus, an increase in moisture from 3 to 9.4 % lowers the shock temperature by 100-200 °C on average.

The obtained dependences are consistent with the mechanism considered. The more moisture a pellet contains, the larger the volume of vapor formed during sharp heating and the higher the pressure in its pores; destruction therefore occurs at a lower ambient temperature. For small-diameter pellets, the distance the vapor must travel is short, and the time of its formation does not exceed the time required for its removal, which ensures their increased resistance to thermal shock.

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On travelling grate induration machines, pellets successively pass through the drying, preheating and firing zones, with the temperature of the heat carrier increasing from zone to zone. The data obtained make it possible to reasonably limit the gas temperature in the first drying zone, taking into account the type of pellets and their size distribution. At the same time, the results emphasize the importance of stabilizing pellet size at the balling stage: narrowing the size range and reducing the proportion of the +12.5 mm class lowers the risk of crack formation and allows drying to be intensified. In addition, controlling the residual moisture of pellets at the exit from the drying zone makes it possible to prevent their destruction during the transition to high-temperature zones [3, 7].

4. CONCLUSION

The main cause of crack formation and thermal shock of green pellets is the excess of the water vapor generation rate over the rate of its removal through the pore structure; cracks are caused mainly by tangential stresses, while explosive destruction is caused by radial stresses.

The share of cracked pellets increases with increasing drying temperature and pellet size. For fluxed pellets of the 16–12.5 mm class it reaches about 70 % at 600 °C, while for the 8–5 mm class it does not exceed 20 %. Non-fluxed pellets are more sensitive to heating than fluxed ones.

The strength of dry crack-free pellets increases with increasing drying temperature due to oxidation of magnetite to hematite; however, this effect is realized only in the absence of crack formation.

The smaller the pellet size, the higher the thermal shock temperature: for the 8-5 mm fraction it is approximately one and a half times higher than the corresponding value for the 12.5-11.2 mm fraction. As residual moisture increases from 3 to 9.4 %, the shock temperature decreases by 100-200 °C.

Under production conditions, it is recommended to keep the heat carrier temperature in the first drying zone below 300 °C for non-fluxed pellets; for fluxed pellets it can be increased to 320-350 °C. The residual moisture of pellets during the transition from the drying zone to the preheating zone should not exceed 3-4 %, which prevents their destruction.

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Volume 5 | Issue 52-53 |
August-September 2026
ISSN: 2791-3651

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Annotatosiya: *Ushbu maqolada 2023-yilda Turkiyada sodir bo‘lgan kuchli zilzilalar ta’sirida uzluksiz temirbeton ko‘prik va yo‘l o‘tkazgichlarning seysmik holati hamda konstruktiv elementlarida yuzaga kelgan shikastlanish xususiyatlari tahlil qilingan. Xususan, ko‘prik tayanchlari, oraliq qurilmalari, tayanch qismlari va poydevorlarining zilzila vaqtida o‘zaro ta’siri, seysmik yuklarning konstruksiya bo‘ylab taqsimlanishi hamda zilzilabardoshlikka ta’sir etuvchi omillar ko‘rib chiqilgan. Turkiyadagi zilzilalar tajribasi, jumladan, Nurdağı viadugida kuzatilgan shikastlanishlar asosida konstruksiyalarning seysmik ta’sirga javob xususiyatlari yoritilgan. Shuningdek, grunt, poydevor, tayanch va oraliq qurilmalarning o‘zaro bog‘liq ishlashini hisobga olish, real zilzila akselerogrammalaridan foydalanish, seysmik izolyatsiya tizimlari va tayanch qismlarining samarali parametrlarini tanlash masalalariga alohida e’tibor qaratilgan. Tadqiqot natijalari ko‘prik va yo‘l o‘tkazgichlarning seysmik xavfsizligini oshirish, hisoblash usullarini takomillashtirish hamda kuchli zilzilalar sharoitida konstruksiyalarning ishonchliligini ta’minlash bo‘yicha muhim ilmiy-amaliy xulosalar chiqarishga xizmat qiladi.*

Kalit so‘zlar: *uzluksiz temirbeton ko‘prik, yo‘l o‘tkazgich, zilzila, seysmik ta’sir, zilzilabardoshlik, konstruktiv shikastlanish, ko‘prik tayanchi, oraliq qurilma, poydevor, seysmik izolyatsiya, real zilzila yozuvlari, Nurdağı viadugi*

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August-September 2026
ISSN: 2791-3651

SEISMIC DAMAGE CHARACTERISTICS OF CONTINUOUS REINFORCED CONCRETE BRIDGES AND OVERPASSES UNDER STRONG EARTHQUAKES AND ISSUES IN IMPROVING THEIR EARTHQUAKE RESISTANCE

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Abstract: *This article analyzes the seismic performance of continuous reinforced concrete bridges and overpasses subjected to the strong earthquakes that struck Türkiye in 2023, with particular emphasis on the damage patterns observed in their structural components. The study examines the interaction between bridge piers, superstructures, bearings, and foundations during seismic events, the distribution of seismic loads throughout the structural system, and the factors affecting earthquake resistance. Based on the experience of the 2023 Türkiye earthquakes, including the damage observed at the Nurdağı viaduct, the seismic response characteristics of bridge structures are discussed. Particular attention is given to considering the interaction between soil, foundations, piers, and superstructures; using real earthquake accelerograms in structural analysis; and selecting effective parameters for seismic isolation systems and bridge bearings. The findings provide a basis for developing important scientific and practical recommendations aimed at improving the seismic safety of bridges and overpasses, refining structural analysis methods, and ensuring the reliability of bridge structures under strong earthquake conditions.*

Key words: *continuous reinforced concrete bridge, overpass, earthquake, seismic effects, earthquake resistance, structural damage, bridge pier, superstructure, foundation, seismic isolation, real earthquake records, Nurdağı viaduct*

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Volume 5 | Issue 52-53 |
August-September 2026
ISSN: 2791-3651

ХАРАКТЕРИСТИКИ СЕЙСМИЧЕСКОГО ПОВРЕЖДЕНИЯ НЕПРЕРЫВНЫХ ЖЕЛЕЗОБЕТОННЫХ МОСТОВ И ЭСТАКАД ПРИ СИЛЬНЫХ ЗЕМЛЕТРЯСЕНИЯХ И ВОПРОСЫ ПОВЫШЕНИЯ ИХ СЕЙСМОСТОЙКОСТИ

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Аннотация *В данной статье анализируются сейсмические характеристики непрерывных железобетонных мостов и эстакад, подвергшихся воздействию сильных землетрясений, произошедших в Турции в 2023 году, с особым акцентом на закономерности повреждений, наблюдаемые в их конструктивных компонентах. В исследовании рассматриваются взаимодействие мостовых опор, надстроек, подшипников и фундаментов при сейсмических явлениях, распределение сейсмических нагрузок по всей конструктивной системе и факторы, влияющие на сейсмостойкость. На основе опыта землетрясений 2023 года в Турции, включая повреждения, наблюдаемые на виадуке Нурдаг, обсуждаются сейсмические характеристики мостовых конструкций. Особое внимание уделяется рассмотрению взаимодействия грунта, фундаментов, опор и надстроек; использованию реальных акселерограмм землетрясений в конструктивном анализе; выбору эффективных параметров систем сейсмоизоляции и подшипников мостов. Полученные результаты служат основой для разработки важных научно-практических рекомендаций, направленных на повышение сейсмической безопасности мостов и путепроводов, совершенствование методов структурного анализа и обеспечение надежности мостовых конструкций в условиях сильного землетрясения.*

Ключевые слова *непрерывный железобетонный мост, эстакада, землетрясение, сейсмические эффекты, сейсмостойкость, повреждение конструкции, опора моста, надстройка, фундамент, сейсмоизоляция, реальные записи о землетрясениях, виадук Нурдагы*

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Kirish

Jahonda bugungi kunda avtomobil yo‘llaridagi ko‘priklar va yo‘l o‘tkazgichlarning zilzilabardoshligini oshirish, seysmik xavf yuqori bo‘lgan hududlarda yirik ko‘priklarni hisoblash hamda loyihalash usullarini takomillashtirish masalalariga alohida e’tibor qaratilmoqda. Mazkur yo‘nalishda ko‘priklarning konstruktiv elementlarini “grunt – tayanch – tayanch qismi – oraliq qurilma” konsepsiyasi asosida o‘zaro bog‘liq va bir-biriga ta’sir ko‘rsatuvchi yaxlit tizim sifatida tadqiq etish muhim ahamiyat kasb etadi. Shuningdek, transport inshootlarida seysmoizolyatsiya texnologiyalarini qo‘llash samaradorligini asoslash, haqiqiy zilzila yozuvlari asosida uzluksiz temirbeton avtomobil ko‘priklarini seysmik ta’sirlardan himoyalashning samarali usullarini ishlab chiqish hamda seysmik himoyalovchi tayanch qismlarining maqbul parametrlarini aniqlash dolzarb ilmiy vazifalar sirasiga kiradi. Shu bilan birga, ko‘p tayanchli ko‘prik inshootlarining seysmik ta’sir ostidagi dinamik xususiyatlarini o‘rganish, ularning zilzilabardoshligini baholash mezonlari va hisoblash usullarini takomillashtirish hamda konstruksiyalarning ishonchliligi va ekspluatatsion xavfsizligini ta’minlashga qaratilgan ilmiy-amaliy tadqiqotlarni rivojlantirish bugungi kunning ustuvor yo‘nalishlaridan biri hisoblanadi [3, 9].

Zilzila — Yer qobig‘i yoki yuqori mantiyada sodir bo‘ladigan tektonik siljishlar, tog‘ jinslarining yorilishi va uzilishi natijasida yuzaga keluvchi, elastik seysmik to‘lqinlar orqali turli masofalarga tarqaladigan yer osti silkinishlari hamda yer yuzasining tebranishlari jarayonidir [1].

Kuchli zilzilalar ko‘priklarning konstruktiv yaxlitligi va normal ekspluatatsiya holatiga jiddiy ta’sir ko‘rsatib, ayrim hollarda ularning shikastlanishi yoki butunlay ishdan chiqishiga sabab bo‘lishi mumkin. Shu sababli avtomobil yo‘llaridagi ko‘priklar va boshqa sun’iy inshootlarning zilzilabardoshligini ta’minlash, seysmik ta’sirlar ostida ularning mustahkamligi va barqarorligini oshirish muhim ilmiy-amaliy masalalardan biri hisoblanadi. Ko‘prik inshootlari o‘zaro bog‘langan ko‘plab konstruktiv elementlardan tashkil topgan bo‘lib, ularning seysmik xavfsizligini ta’minlashda, ayniqsa, tayanchlar va tayanch qismlari muhim o‘rin tutadi. Ushbu elementlarning seysmik yuklar ta’siridagi ishlash xususiyatlarini chuqur o‘rganish, ularning o‘zaro ta’sirini baholash hamda konstruktiv parametrlarini to‘g‘ri tanlash ko‘priklarning zilzilabardoshligini oshirish va favqulodda vaziyatlarda ishonchli ishlashini ta’minlashga xizmat qiladi [2-3].

Magnitudasi 8,2 ni tashkil etgan va 143 ming kishini halok bo‘lishiga sabab bo‘lgan Yaponiyadagi Tokio (1923y.) zilzilasining keltirgan seysmik zararini baholash mumkin. Zizlilani Tokio sh. va uning atrofiga keltirgan zarari 3 mlrd dollarni tashkil etdi (1923 y. narxlarida). Zilzila va sunami natijasida Yaponiyada avtoyo‘llar 582 joyidan, ko‘priklar esa 32 joyidan shikastlanganligi aniqlandi. Yo‘llarda ko‘plab yoriqlar paydo bo‘lgan, ayrim holatlarda esa yo‘l polotnolari va ko‘priklar butunlay buzilib ketgan [9].

2020-yil ma’lumotlariga ko‘ra, zilzilalar natijasida jami iqtisodiy yo‘qotishlar 1,904 trln. AQSH dollari va suv toshqinlari hamda tropik siklonlardan keyin 3-o‘rinni egallaydi. Zilzilalarning umumiy iqtisodiy yo‘qotishlari taxminan 2 trillion AQSH dollarini tashkil etganligi sababli, zilzilalar natijasida o‘lim darajasi 2020-yil ma’lumotlariga ko‘ra taxminan 4500 kishini tashkil etadi (1-rasm) [9]. Iqtisodiy yo‘qotishlardan tashqari, tabiiy ofatlardan o‘lim darajasi ham juda dolzarbdir (1-rasm).

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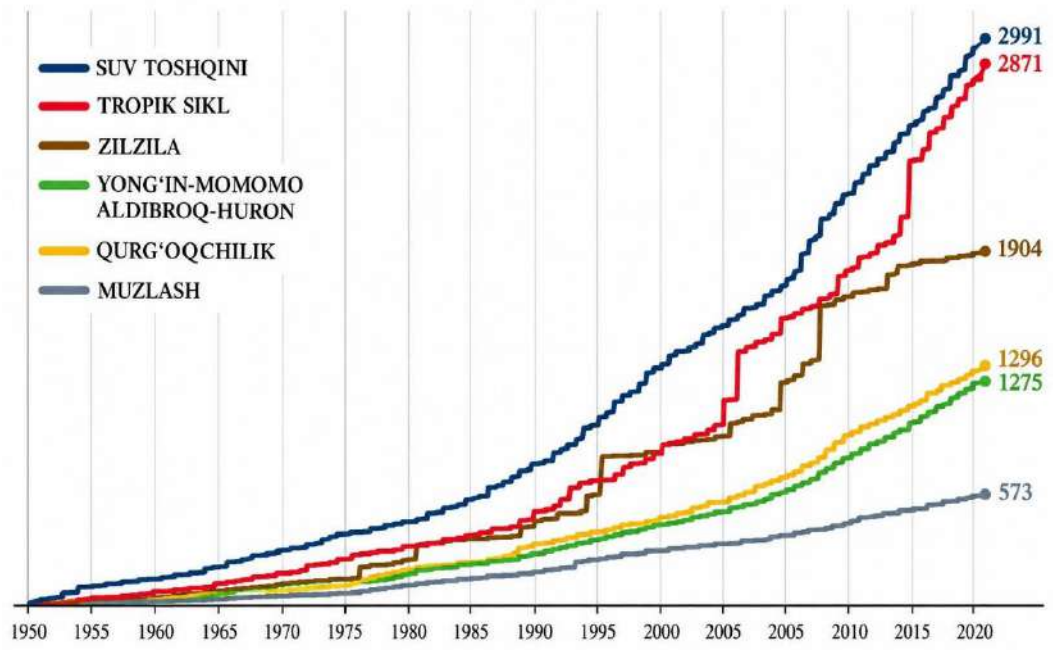
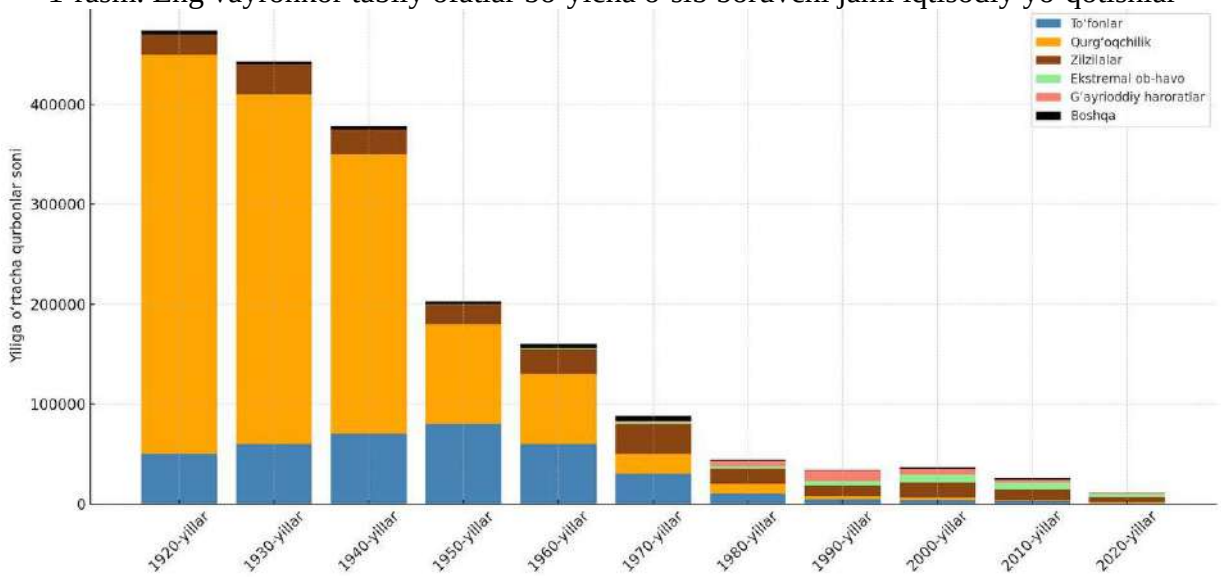


1-rasm. Eng vayronkor tabiiy ofatlar bo'yicha o'sib boruvchi jami iqtisodiy yo'qotishlar



2-rasm. Tabiiy ofatlardan o'limning o'rtacha darajasi

Natijalar tahlili shuni ko'rsatadiki, zilzilalar natijasida iqtisodiy yo'qotishlar yig'indisi o'sib boruvchi xarakterga ega bo'lib, eng katta sakrashlar 1994-1996-yillar oralig'ida kuzatilgan (Koba zilzilasi, Yaponiya, 1995-yil 17-yanvar, Rixter shkalasi bo'yicha 7,3 magnitudali, qurbonlar soni 6434 kishi, iqtisodiy zarar 102,5 mlrd. AQSH dollari), 2008-2012 yy. (Sichuan zilzilalari, Xitoy, 2008 yil 12 may, Rixter shkalasi bo'yicha 7,9 magnituda, qurbonlar soni 69197 kishi, iqtisodiy zarar 1,37 mln. AQSH dollari; Fukusima zilzilalari, Yaponiya, 2011-yil 11-mart, Rixter shkalasi bo'yicha 9,1 magnitudali, qurbonlar soni 19747 kishi, iqtisodiy zarar 309 mlrd. AQSH dollari) [1]. 2023-yilda kuchli zilzilalarda halok bo'lganlar soni 1-jadvalda keltirilgan.

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1-jadval

2023-yilda kuchli zilzilalarda halok bo‘lganlar soni

Reyting	Qurbonlar soni	Magnituda	Sana	Zilzila sodir bo‘lgan hudud
1.	59,259	7.8.	6.02.2023 y.	Turkiya, Qahramanmarash
		7.5.		
2.	2,960	6.8.	8.09.2023 y.	Marokash, Al-Hauz
3.	1,482.	6.3.	7.10.2023 y.	Afg‘oniston Hirot
4.	153.	5.7.	3.11.2023 y.	Nepal, Karnali
5.	151.	5.9.	18.12.2023 y.	Xitoy, Gansu
6.	21.	6.5.	21.03.2023 y.	Afg‘oniston, Badaxshon
7.	18.	6.8.	18.03.2023 y.	Ekvador, Guayas
8.	13.	6.3.	20.02.2023 y.	Turkiya, Hatay
9.	11.	6.7.	17.11.2023	Filippin, Sokksargen

2023-yilda zilzilalar oqibatida 64,1 mingdan ortiq odam halok bo‘ldi, bu 2010-yildan beri eng yuqori ko‘rsatkichdir.

2023-yil 6-fevralda Turkiyaning janubi-sharqiy hududlarida taxminan to‘qqiz soatlik vaqt oralig‘ida ikkita kuchli zilzila sodir bo‘ldi. Birinchi zilzilaning magnitudasi 7,8 ni tashkil etib, uning epitsentri Gaziantep viloyatining Shehitkamil hududi yaqinida, ikkinchi zilzila esa 7,5 magnituda bilan Qahramonmarash viloyatining Ekinözü hududida qayd etildi.

3-rasm. Turkiyaning Qahramanmarash viloyatidagi ro‘y bergan zilzilaning ta’sir hududi

Ushbu kuchli seysmik hodisalardan keyin hududda magnitudasi 6,7 gacha yetgan takroriy silkinishlar ham kuzatildi. Mazkur zilzilalar katta hududda sezilarli tebranishlarni yuzaga keltirib, binolar, transport infratuzilmasi va muhandislik inshootlarining seysmik mustahkamligini baholash masalasini dolzarb qilib qo‘ydi [4] (3 va 4-rasm).

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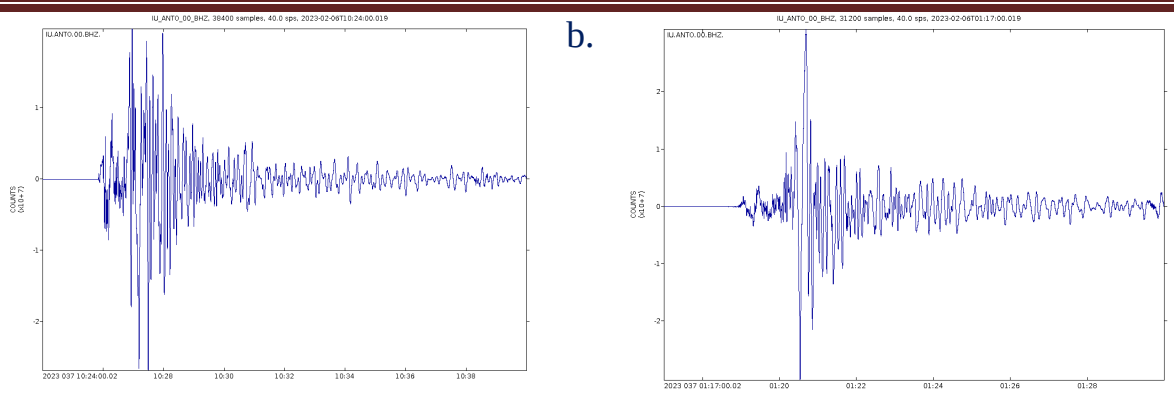
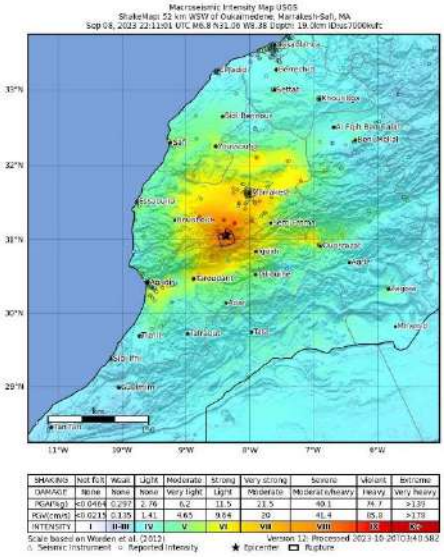
a b.



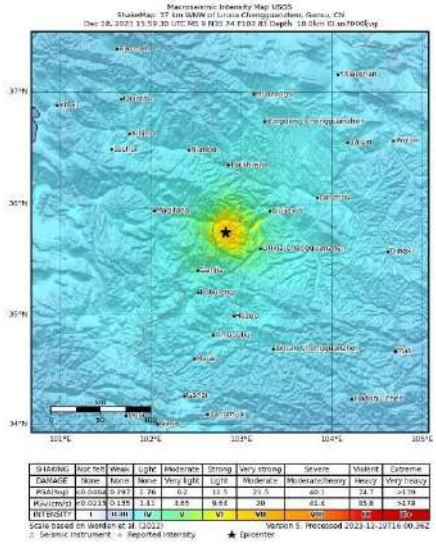
4-rasm. Qahramonmarashdagi 7,5 magnitudali (a) va Gaziantepadagi 7,8 magnitudali (b) zilzilalar seysmogrammalari

Xalqaro tibbiyot korpusining 2023-yil 8-martdagi vaziyat hisobotida keltirilgan ma’lumotlarga ko‘ra, 2023-yil 6-fevralda Turkiya va Suriyada sodir bo‘lgan kuchli zilzilalar oqibatida halok bo‘lganlar soni 50 ming kishidan oshgan. Jumladan, Turkiyada 45 968 nafar, Suriyada esa 7 259 nafar inson hayotdan ko‘z yumgan. Ushbu fojiali hodisa keng ko‘lamli vayronagarchiliklarga sabab bo‘lib, aholi turar joylari bilan bir qatorda transport infratuzilmasi va muhandislik inshootlarining seysmik xavfsizligini ta’minlash masalasi naqadar muhim ekanini yana bir bor namoyon etdi [4, 9].

Bundan tashqari, 2023-yil 8-sentabr kuni Marokashning Marrakesh–Safi mintaqasida magnitudasi 6,8 ga teng bo‘lgan kuchli zilzila sodir bo‘ldi. Zilzila epitsentri Marrakesh shahridan taxminan 72 km janubi-g‘arbda joylashgan bo‘lib, yer silkinishlari katta hududda vayronagarchiliklarni keltirib chiqardi (5-rasm). Tabiiy ofat natijasida tarixiy obidalar va turli infratuzilma obyektlari, jumladan, binolar hamda transport tizimining ayrim elementlari zarar ko‘rdi. Mavjud ma’lumotlarga ko‘ra, zilzila oqibatida 2 946 kishi halok bo‘lgan, iqtisodiy zarar esa taxminan 12 milliard AQSH dollariga baholangan. Mazkur hodisa kuchli seysmik ta’sirlar sharoitida muhandislik inshootlarining konstruktiv mustahkamligi, barqarorligi va ishonchliligini ta’minlash zarurligini yana bir bor ko‘rsatdi.



5-rasm. Marokashning Marrakesh - Safi mintaqasidagi ro‘y bergan zilzilaning ta’sir



6-rasm. Xitoyning Gansu provinsiyasidagi ro‘y bergan zilzilaning ta’sir hududi

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Shuningdek, 2023-yil 18-dekabr kuni Xitoy Xalq Respublikasining Gansu provinsiyasidagi Jishishan (Jishishan Bao'an, Dongxiang va Salar muxtor okrugi) hududida magnitudasi turli manbalarda 5,9–6,2 oralig'ida qayd etilgan zilzila sodir bo'ldi. Asosiy seysmik hodisadan so'ng magnitudasi 3,0 ga yetgan to'qqizta takroriy silkinish (aftershok) kuzatildi. Ushbu zilzila mintaqadagi bino va muhandislik inshootlariga seysmik ta'sir ko'rsatib, hududning tabiiy ofatlarga tayyorgarligi hamda qurilish konstruksiyalarining zilzilabardoshligini ta'minlash masalalariga e'tiborni kuchaytirdi. Mazkur hodisa seysmik xavf mavjud hududlarda transport inshootlarini loyihalash, hisoblash va ekspluatatsiya qilishda zilzila ta'sirlarini chuqur tahlil qilish zarurligini ko'rsatadi (6-rasm). Zilzila Xitoyning Gansu va Sinxay provinsiyalari chegarasida joylashgan, aholi zich istiqomat qiladigan hududlarda jiddiy vayronagarchiliklarni keltirib chiqardi. Tabiiy ofat oqibatida 150 nafardan ortiq kishi halok bo'ldi, ko'plab bino va inshootlar zarar ko'rdi. Ushbu hodisa 2014-yilda Yunnan provinsiyasida yuz bergan Ludian zilzilasidan keyin Xitoyda qayd etilgan eng ko'p qurbonlarga sabab bo'lgan zilzilalardan biri sifatida baholandi. Mazkur fojia seysmik xavf yuqori bo'lgan hududlarda nafaqat turar joy binolari, balki ko'priklar, yo'l o'tkazgichlar va boshqa muhim transport inshootlarining zilzilabardoshligini ta'minlash, ularning konstruktiv ishonchliligini oshirish hamda favqulodda vaziyatlar oqibatlarini kamaytirishga qaratilgan muhandislik yechimlarini takomillashtirish zarurligini ko'rsatdi [5].

2024-yil 1-yanvar kuni Yaponiyaning Ishikava prefekturasida, Noto yarimorolida magnitudasi 7,6 ga teng bo'lgan kuchli zilzila sodir bo'ldi. Zilzila, ayniqsa, Vadzima va Sudzu shaharlarida katta vayronagarchiliklarni keltirib chiqardi. Tabiiy ofat oqibatida ko'plab bino va inshootlar shikastlandi, transport infratuzilmasi faoliyatida uzilishlar yuzaga keldi hamda qurbonlar soni 200 nafardan oshdi. Ushbu zilzila seysmik xavf yuqori bo'lgan hududlarda muhandislik inshootlarining zilzilabardoshligini ta'minlash, konstruktiv elementlarning dinamik ta'sirlarga chidamliligini oshirish va transport aloqalarining uzluksizligini saqlash masalalarining naqadar muhimligini yana bir bor namoyon etdi (7-rasm) [6].

2025-yil 28-mart kuni Myanmaning Sikayn hududida moment magnitudasi (Mw) 7,7 ga teng bo'lgan kuchli zilzila sodir bo'ldi. Mazkur seysmik hodisa keng hududda kuchli yer tebranishlarini yuzaga keltirib, bino va inshootlar hamda transport infratuzilmasiga jiddiy xavf tug'dirdi. Ushbu zilzila seysmik faol mintaqalarda joylashgan muhandislik inshootlarining, xususan, ko'priklar va yo'l o'tkazgichlarning zilzilabardoshligini ta'minlash, ularning dinamik yuklar ta'siridagi xatti-harakatlarini baholash hamda konstruktiv himoya choralarini takomillashtirish zarurligini yana bir bor ta'kidladi. (8-rasm). Mazkur zilzilaning intensivligi Merkalli shkalasi bo'yicha IX darajaga yetdi. Kuchli yer silkinishlari Myanma va qo'shni Tailand hududlarida katta vayronagarchiliklarga sabab bo'lib, binolar, muhandislik inshootlari va transport infratuzilmasiga jiddiy zarar yetkazdi. Asosiy zilziladan keyin 169 ta takroriy seysmik silkinish (aftershok) qayd etildi. Mavjud ma'lumotlarga ko'ra, tabiiy ofat oqibatida Myanmada kamida 5 300 kishi, Tailandda esa 36 kishi halok bo'lgan. Ushbu hodisa kuchli zilzilalar sharoitida ko'priklar va boshqa transport inshootlarining konstruktiv mustahkamligini ta'minlash, seysmik ta'sirlarni hisoblash usullarini takomillashtirish hamda infratuzilmaning favqulodda vaziyatlarga chidamliligini oshirish zarurligini yana bir bor ko'rsatdi. [7-9].

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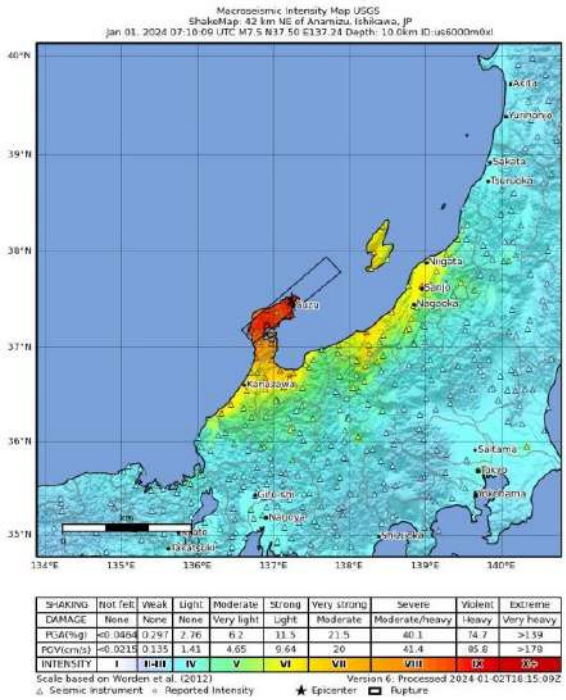
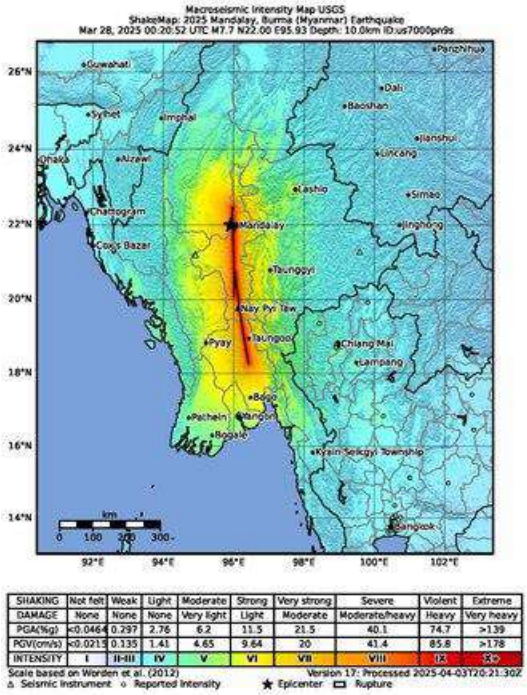


7-rasm. Yaponiyaning Ishikava prefekturasidagi ro‘y bergan zilzilaning ta’sir hududi



8-rasm. Myanmaning Sikayn okrugidagi ro‘y bergan zilzilaning ta’sir hududi

2024-yil 1-yanvar kuni Yaponiyaning Ishikava prefekturasida, Noto yarimorolida magnitudasi 7,6 ga teng bo‘lgan kuchli zilzila sodir bo‘ldi. Zilzila, ayniqsa, Vadzima va Sudzu shaharlarida katta vayronagarchiliklarni keltirib chiqardi. Tabiiy ofat oqibatida ko‘plab bino va inshootlar shikastlandi, transport infratuzilmasi faoliyatida uzilishlar yuzaga keldi hamda qurbonlar soni 200 nafardan oshdi. Ushbu zilzila seysmik xavf yuqori bo‘lgan hududlarda muhandislik inshootlarining zilzilabardoshligini ta’minlash, konstruktiv elementlarning dinamik ta’sirlarga chidamliligini oshirish va transport aloqalarining uzluksizligini saqlash masalalarining naqadar muhimligini yana bir bor namoyon etdi (7-rasm) [6].

2025-yil 28-mart kuni Myanmaning Sikayn hududida moment magnitudasi (Mw) 7,7 ga teng bo‘lgan kuchli zilzila sodir bo‘ldi. Mazkur seysmik hodisa keng hududda kuchli yer tebranishlarini yuzaga keltirib, bino va inshootlar hamda transport infratuzilmasiga jiddiy xavf tug‘dirdi. Ushbu zilzila seysmik faol mintaqalarda joylashgan muhandislik inshootlarining, xususan, ko‘priklar va yo‘l o‘tkazgichlarning zilzilabardoshligini ta’minlash, ularning dinamik yuklar ta’siridagi xatti-harakatlarini baholash hamda konstruktiv himoya choralarini takomillashtirish zarurligini yana bir bor ta’kidladi. (8-rasm). Mazkur zilzilaning intensivligi Merkalli shkalasi bo‘yicha IX darajaga yetdi. Kuchli yer silkinishlari Myanma va qo‘shni Tailand hududlarida katta vayronagarchiliklarga sabab bo‘lib, binolar, muhandislik inshootlari va transport infratuzilmasiga jiddiy zarar yetkazdi. Asosiy zilziladan keyin 169 ta takroriy seysmik silkinish (aftershok) qayd etildi. Mavjud ma’lumotlarga ko‘ra, tabiiy ofat oqibatida Myanmada kamida 5 300 kishi, Tailandda esa 36 kishi halok bo‘lgan. Ushbu hodisa kuchli zilzilalar sharoitida ko‘priklar va boshqa transport inshootlarining konstruktiv mustahkamligini ta’minlash, seysmik ta’sirlarni hisoblash usullarini takomillashtirish hamda infratuzilmaning favqulodda vaziyatlarga chidamliligini oshirish zarurligini yana bir bor ko‘rsatdi. [7-9].

Kuchli zilzilalar natijasida transport infratuzilmasi obyektlari, jumladan, ko‘priklar va yo‘l o‘tkazgichlarning konstruktiv elementlari turli darajada shikastlanishi mumkin. Xususan, 2023-yil 6-fevralda Turkiyada sodir bo‘lgan Qahramonmarash zilzilalari avtomobil yo‘llari

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infratuzilmasiga sezilarli ta’sir ko‘rsatib, ayrim ko‘prik inshootlarida shikastlanishlar yuzaga kelishiga sabab bo‘ldi. Bunday holatlar ko‘priklarning seysmik yuklar ta’siridagi ishlash xususiyatlarini, konstruktiv elementlarining mustahkamligini hamda tayanch va tayanch qismlarining zilzila vaqtida tutgan o‘rnini chuqur o‘rganish zarurligini ko‘rsatadi.

Shu munosabat bilan, mazkur maqolada Turkiyada sodir bo‘lgan zilzilalar ta’sirida shikastlangan Nurdağı viaduki va Asi ko‘prigining texnik holati hamda konstruktiv xususiyatlari tahlil qilinadi. Ushbu inshootlarni o‘rganish orqali seysmik ta’sirlarning ko‘prik konstruksiyalariga ta’sir mexanizmlarini aniqlash, yuzaga kelishi mumkin bo‘lgan shikastlanish sabablarini baholash va kelgusida shunga o‘xshash transport inshootlarining zilzilabardoshligini oshirishga qaratilgan muhandislik yechimlarini takomillashtirish masalalariga e’tibor qaratiladi.

Nurdağı viaduki — Turkiyaning janubiy qismidagi past tog‘li hududda joylashgan yirik ko‘prik inshooti bo‘lib, uning konstruksiyasida diametri 3 m va balandligi taxminan 24 m bo‘lgan temirbeton tayanchlardan foydalanilgan. Viaduk ikkita mustaqil, har biri beshta oraliqdan tashkil topgan ko‘prik konstruksiyasidan iborat. Inshootning yuk ko‘taruvchi tizimida oldindan zo‘riqtirilgan temirbeton elementlar hamda eng uzun oraliqda po‘lat oraliq qurilma konstruksiyasi qo‘llanilgan.

Mazkur viaduk 2023-yil 6-fevralda Turkiyada sodir bo‘lgan, moment magnitudasi Mw 7,8 ga teng zilzila epitsentridan 29,1 km masofada joylashgan. Shunga qaramay, inshoot zilzila vaqtida yuzaga kelgan yer yorig‘i chizig‘idan 161 m dan kam masofada joylashgani uning seysmik ta’sirlarga duchor bo‘lish xavfini yanada oshirgan. Bunday sharoitda gruntning siljishi, yer yuzasidagi deformatsiyalar hamda kuchli seysmik tebranishlarning ko‘prik tayanchlari va oraliq qurilmalariga ta’sirini o‘rganish alohida ilmiy ahamiyatga ega. Nurdağı viaduki misolida yirik ko‘priklarning zilzilabardoshligini baholashda nafaqat epitsentrgacha bo‘lgan masofa, balki faol tektonik yoriqlarga nisbatan joylashuvi va grunt sharoitlarini ham hisobga olish zarurligi namoyon bo‘ladi [8].

Katta konsolli temir-beton tayanchlardan birining ko‘tarilish yo‘lida kutilmagan plastik deformatsiyalar qayd etildi (9 – 12- rasmlar). Nazariy hisob-kitoblarga ko‘ra, ko‘prik tayanchida eng katta eguvchi moment, odatda, uning poydevor bilan tutashgan quyi qismida yuzaga kelishi kutiladi. Biroq, mazkur holatda deformatsiyaning tayanchning yuqoriroq qismida kuzatilgani alohida e’tiborga loyiqdir. O‘tkazilgan tahlillar shikastlanishlar, asosan, ko‘ndalang yo‘nalishdagi egilish ta’sirida yuzaga kelganini ko‘rsatadi. Tayanchning ikki tomonida beton qatlamining sinishi va ko‘chishi, bir tomonda vertikal armaturalarning egilishi, shuningdek, ko‘ndalang armaturalarning sezilarli deformatsiyalanishi hamda o‘z vazifasini yo‘qotishi qayd etilgan. Bunday shikastlanishlar tayanchga ko‘ndalang yo‘nalishda ta’sir etgan seysmik yuklar natijasida ikki yo‘nalishda ham katta eguvchi momentlar hosil bo‘lganidan dalolat beradi.

9-rasm. Nurdagi viadukining konstruktiv elementlari ko‘rinishlari: plastik deformatsiyalangan temir-beton tayanch va yig‘ma beton hamda po‘lat oraliq qurilmalar

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10-rasm. Nurdagi viadukining diametri 3 m bo‘lgan temir-beton tayanchida kuzatilgan plastik deformatsiyalar

11-rasm. Nurdag‘i viadukidagi chetki tayanchda kuzatilgan shikastlanishlar

12-rasm. Nurdag‘i viadukining diametri 3 m bo‘lgan temir-beton tayanchining yaqinlashuv yo‘li (ko‘tarma) bilan birikkan chetki zonasida kuzatilgan plastik deformatsiya turlari

Bundan tashqari, poydevor elementlarida ham shikastlanishlar aniqlangan. Bu holat kuchli zilzila vaqtida grunt, poydevor va tayanch konstruksiyalari o‘rtasidagi murakkab o‘zaro ta’sirning natijasi bo‘lishi mumkin. Shu sababli ko‘priklarning seysmik mustahkamligini baholashda faqat tayanchlarning yuqori qismlaridagi deformatsiyalarni emas, balki poydevorlarning ishlash xususiyatlari, armaturalarning holati va butun konstruktiv tizimning o‘zaro ta’sirini ham kompleks ravishda hisobga olish zarur [9].

Ko‘priklarni zilzilabardosh qilib loyihalash va qurish bo‘yicha xalqaro tajriba shuni ko‘rsatadiki, ushbu yo‘nalishda sezilarli yutuqlarga erishilgan bo‘lsa-da, kuchli seysmik ta’sirlar sharoitida konstruksiyalarning ishonchli ishlashini ta’minlash bilan bog‘liq qator muammolar hanuz dolzarbligicha qolmoqda. Amaldagi me’yoriy hujjatlarda ko‘priklar va yo‘l o‘tkazgichlarning seysmik ta’sirlarga chidamliligini hisoblash hamda ularni antiseysmik kuchaytirish bo‘yicha belgilangan usullar barcha murakkab seysmik vaziyatlarda

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konstruksiyalarning shikastlanmasdan ishlashini to‘liq kafolatlay olmaydi. Shu bois hisoblash usullarini takomillashtirish, haqiqiy zilzila yozuvlari asosida dinamik tahlillarni amalga oshirish va ko‘prikning barcha konstruktiv elementlari o‘rtasidagi o‘zaro ta’sirni hisobga olish muhim ilmiy-amaliy vazifalardan biri hisoblanadi.

2023-yil 6-fevralda Turkiyada sodir bo‘lgan kuchli zilzilalar oqibatlari ushbu masalalarning amaliy ahamiyatini yaqqol namoyon etdi. Zilzilalar natijasida ko‘plab ko‘priklar va yo‘l o‘tkazgichlarda turli darajadagi shikastlanishlar kuzatilgan bo‘lsa-da, ularning qulash holatlari turar joy binolariga nisbatan kamroq qayd etildi. Ayrim inshootlarda, jumladan, ko‘rib chiqilgan ko‘prik misolida, kuchli tebranishlar ta’sirida oraliq qurilmaning tayanch qismidan siljishi yoki ajralishi kuzatilgan, biroq ushbu holat bo‘yicha insonlar jabrlangani qayd etilmagan. Bunday shikastlanishlar ko‘priklarning seysmik xavfsizligini ta’minlashda oraliq qurilmaning tayanchlarda ishonchli saqlanishi, tayanch qismlarining siljishga qarshi xususiyatlari va konstruksiyaning umumiy dinamik javobi muhim o‘rin tutishini ko‘rsatadi.

Turkiya tajribasi shuni anglatadiki, ko‘priklarni zamonaviy muhandislik talablari asosida loyihalash, sifatli qurilish materiallaridan foydalanish, konstruktiv yechimlarni to‘g‘ri tanlash va qurilish jarayonida me’yoriy talablarning bajarilishini ta’minlash kuchli zilzilalar oqibatlarini kamaytirishda muhim omillardir. Shu bilan birga, hatto yuqori muhandislik standartlari asosida qurilgan inshootlarda ham seysmik ta’sirlar natijasida ayrim shikastlanishlar yuzaga kelishi mumkin. Shuning uchun ko‘priklarning zilzilabardoshligini faqat konstruksiyaning mustahkamligi bilan emas, balki uning deformatsiyalanish qobiliyati, tayanch qismlarining ishlash xususiyatlari, poydevor va grunt bilan o‘zaro ta’siri hamda zilziladan keyingi ekspluatatsion yaroqliligi bilan birgalikda baholash zarur.

Xulosa

Xulosa qilib aytganda, Turkiyada sodir bo‘lgan kuchli zilzilalar tajribasi uzluksiz temirbeton ko‘prik va yo‘l o‘tkazgichlarning seysmik holatini chuqur o‘rganish, ularning zaif konstruktiv elementlarini aniqlash hamda zilzilabardoshlikni oshirishga qaratilgan samarali muhandislik yechimlarini ishlab chiqish zarurligini tasdiqlaydi. Ayniqsa, “grunt – tayanch – tayanch qismi – oraliq qurilma” tizimining yaxlit ishlashini hisobga olgan holda hisoblash usullarini takomillashtirish, seysmoizolyatsiya texnologiyalarini qo‘llash va tayanch qismlarining maqbul parametrlarini asoslash kelgusidagi tadqiqotlarning ustuvor yo‘nalishlari bo‘lib xizmat qiladi. Mazkur yondashuvlar ko‘priklarning seysmik ishonchliligini oshirish, transport qatnovining uzluksizligini saqlash va kuchli zilzilalar oqibatida yuzaga kelishi mumkin bo‘lgan iqtisodiy hamda ijtimoiy talafotlarni kamaytirishga yordam beradi.

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Свидетельство о постановке на учет периодического печатного издания, информационного агентства и сетевого издания Эл № KZ26VPY00048061 от 15 апреля 2022 г.

Редакционная коллегия:

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Выпуск №5 (52-53) (август-сентябрь, 2026). Сайт: https://mspes.ru
ИП «Исакова У.М.». Республика Казахстан, г. Нур-Султан, 2026