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INFLUENCE OF PRECIPITATION ON PIT SLOPE STABILITY AT THE KALMAKYR OPEN PIT

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Abstract. *The study examines how precipitation affects pit slope stability at the Kalmakyr open pit through changes in the physical and mechanical properties of the wall rocks. Laboratory data on diorite and syenodiorite sampled at different depths are interpreted against the seasonal water regime of the deposit. The data cover tensile and uniaxial compressive strength in natural and water-saturated states, internal friction angle and cohesion. Surface water of the Almalyksay and Nakpaysay rivers and infiltration of rain and snowmelt recharge fracture groundwater, whose level peaks two to three months after heavy precipitation. Water saturation reduces the compressive strength of both rock types, and syenodiorite is the most water-sensitive and weathering-prone. Wetting of tectonic fracture zones lowers the internal friction angle and cohesion, which explains why northern wall deformations become active during wet seasons. Strength properties show no systematic change with depth, so a single strength envelope based on averaged values is justified for the pit rock mass. Stability assessments at Kalmakyr should therefore use saturated strength parameters for fracture zones and the groundwater levels expected after the lag period. Surface water control and drainage of the northern wall should be completed before the wet season.*

Annotatsiya. *Tadqiqotda yog‘ingarchilikning yonbag‘ir jinslarining fizik-mexanik xususiyatlariga ta’siri orqali Qalmoqqir ochiq koni (karyeri) bortlarining turg‘unligiga ko‘rsatadigan ta’siri o‘rganilgan. Turli chuqurliklardan olingan diorit va siyenodiorit namunalari bo‘yicha laboratoriya ma’lumotlari konning mavsumiy suv rejimi bilan qiyosiy tahlil qilingan. Ma’lumotlar tabiiy va suv bilan to‘yingan holatdagi cho‘zilish hamda bir o‘qli siqilishdagi mustahkamlik chegarasi, ichki ishqalanish burchagi va ilashish kuchini o‘z ichiga oladi. Olmaliqsoy va Nakpaysoy daryolarining yer usti suvlari hamda yomg‘ir va erigan qor suvlarining infiltratsiyasi yoriqlararo yerosti suvlarini to‘yintiradi, ularning sathi esa kuchli yog‘ingarchilikdan ikki-uch oy o‘tgach eng yuqori cho‘qqiga chiqadi. Suv bilan to‘yinish ikkala jins turining ham siqilishdagi mustahkamligini pasaytiradi, bunda siyenodiorit suvga eng ta’sirchan va nurashga moyil hisoblanadi. Tektonik yoriqlik zonalarining namlanishi ichki ishqalanish burchagi va ilashish kuchini kamaytiradi, bu esa nam mavsumlarda nurning shimoliy borti deformatsiyalarining nima sababdan faollashishini izohlaydi. Mustahkamlik xususiyatlarida chuqurlik bo‘yicha tizimli qonuniyatli o‘zgarish kuzatilmadi, shu bois karyer tog‘ jinslari massivi uchun o‘rtacha qiymatlarga asoslangan yagona mustahkamlik chegarasidan (zarbasidan) foydalanish o‘zini oqlaydi. Shunday qilib, Qalmoqqir konida turg‘unlikni baholashda yoriqlik zonalari uchun suv bilan to‘yingan holatdagi mustahkamlik parametrlari hamda kechikish davridan keyin kutiladigan yerosti suvlari sathi hisobga olinishi lozim. Shimoliy bortda yer usti suvlarini boshqarish va drenaj tadbirlari nam mavsum boshlanishidan oldin yakunlanishi zarur.*

Аннотация. *В исследовании изучается влияние атмосферных осадков на устойчивость бортов карьера Кальмакыр через изменение физико-механических свойств вмещающих пород. Лабораторные данные по диоритам и сиенодиоритам, отобранным с различных глубин, сопоставлены с сезонным водным режимом месторождения. Данные включают предел прочности на растяжение и одноосное сжатие в естественном и водонасыщенном состояниях, угол внутреннего трения и сцепление. Поверхностные воды*

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рек Алмалыксай и Накпайсай, а также инфильтрация дождевых и талых вод подпитывают трещинно-грунтовые воды, уровень которых достигает пика через два-три месяца после обильных осадков. Водонасыщение снижает прочность на сжатие обоих типов пород, при этом сиенодиорит наиболее чувствителен к воде и подвержен выветриванию. Увлажнение зон тектонической трещиноватости снижает угол внутреннего трения и сцепление, что объясняет активизацию деформаций северного борта карьера во влажные сезоны. Прочностные характеристики не демонстрируют систематических изменений с глубиной, поэтому для массива пород карьера обосновано применение единой огибающей прочности на основе осредненных значений. Таким образом, оценка устойчивости на месторождении Кальмакыр должна основываться на параметрах прочности водонасыщенных пород для зон трещиноватости и уровнях подземных вод, ожидаемых с учетом периода запаздывания. Регулирование поверхностного стока и дренаж северного борта должны быть завершены до начала влажного сезона.

Keywords: *Kalmakyr, slope stability, precipitation, groundwater, saturation, fractures, cohesion, friction angle.*

Kalit so‘zlar: *Qalmoqqir, bort turg‘unligi, yog‘ingarchilik, yerosti suvlari, to‘yinish, yoriqlar, ilashish kuchi, ishqalanish burchagi.*

Ключевые слова: *Кальмакыр, устойчивость откосов/бортов, осадки, подземные воды, водонасыщение, трещины, сцепление, угол трения.*

Introduction. Water is one of the main triggers of pit slope instability. Rainfall and snowmelt seep into the slope through open discontinuities. There they raise pore water pressure, reduce the effective normal stress on potential sliding surfaces and soften the rock [1–3]. Most large landslides recorded in open pits in China over the last three decades were directly related to water and occurred in the rainy season [2]. Numerical modelling of a high rock slope at the Dagushan open pit showed that the factor of safety dropped from 1.544 to 1.443 after 12 h of rainfall and did not fully recover after the rain stopped. For the same total rainfall, prolonged moderate rain was more damaging than short intense rain [2]. In a multi-aquifer pit, hydrostatic pressure reduced the calculated stability coefficient by 5–16%, depending on the mining phase and failure mode [3]. In a plane failure triggered when a tension crack filled with water during heavy rain, the factor of safety fell from about 1.9 for the dry slope to about 0.8 for the saturated slope [1].

At the Kalmakyr open pit, earlier investigations identified the main cause of northern wall deformation: rocks in tectonic fracture zones lose strength and durability as their moisture content rises. This moisture content increases mainly in the wet season, when surface and groundwater inflow grows. Surface water is associated with the Almalyksay and Nakpaysay rivers. Groundwater forms by infiltration of rain, snowmelt and river water and accumulates mainly in fractured ground and vein-type fractures. Fracture groundwater is recharged predominantly by atmospheric precipitation. Its level reaches a maximum two to three months after heavy precipitation, so the most unfavourable hydrogeological state of the slopes lags behind the rainfall itself. On the north-western and north-eastern walls, the degree of wetting depends on how close the rivers are and on the number of fractures that conduct river water. For this reason, deformations concentrate on the northern wall in wet seasons.

Slope stability is assessed using strength properties determined on borehole samples. The most important of these are the loss of strength of rocks and clays on wetting, the internal friction angle and cohesion. For landslide zones of the northern wall, strength values should be taken lower than those derived from routine geological data, and the influence of fracture zones and water should be reconsidered. To characterise tectonic fracture zones, samples were taken from open

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deformation fractures at different benches. The tests showed that the internal friction angle decreases as moisture content increases, which matches the higher deformation rate of the wall during periods of heavy precipitation. Cohesion also decreases on wetting. In the fracture zones, however, its contribution is small compared with friction and may be neglected in some cases. This is consistent with the common practice of designing against sliding on discontinuities with zero or near-zero cohesion [1].

Uniaxial compressive strength showed no systematic change with depth, so averaged test values were adopted as design properties (Table 1). All rocks lost strength on water saturation. The ratio of saturated to natural compressive strength, Ks, averages 0.92 for diorite (strength loss 6–8%) and 0.89 for syenodiorite (strength loss 6–15%). The lowest value, 0.85, was recorded in the upper interval of syenodiorite, which also has the lowest friction angle. Syenodiorite is therefore the rock most susceptible to weathering and to precipitation-induced weakening. Rock strength decreases as porosity increases. The degree of jointing decreases with depth, but vertical fractures persist, so infiltration pathways from the surface remain open at depth.

Table 1

Average physical and mechanical properties of the Kalmakyr pit wall rocks relevant to slope stability

Rock	Sampling depth, m	Tensile strength, MPa	UCS, natural, MPa	UCS, saturated, MPa	Ks	Friction angle φ, °	Cohesion C, MPa
Diorite	up to 50	19	108	101.2	0.94	39	22.4
Diorite	50–100	21.05	104.1	95.7	0.92	38	28.5
Diorite	100–150	21	97	89	0.92	37	26.6
Syenodiorite	50–100	20.1	82	70	0.85	34	23
Syenodiorite	100–150	18	105	99	0.94	39	27
Syenodiorite	150–200	20	92.4	83	0.90	37	23
Syenodiorite	200–250	21	87	75	0.86	38	23

Note: Ks = UCS saturated / UCS natural.

Precipitation therefore governs the stability of the Kalmakyr pit walls through three coupled mechanisms:

- the rocks lose strength on saturation;
- the friction angle and cohesion fall in wetted tectonic fracture zones;
- fracture groundwater rises with a delay after precipitation.

Because the strength of the rock mass does not change significantly with depth, a common strength envelope based on averaged properties can be adopted for the whole pit. This simplifies stability assessment of different benches. For fracture zones of the northern wall, the envelope should be built from saturated-state parameters. Groundwater pressures should correspond to the period of maximum water level, two to three months after heavy precipitation. The most direct means of reducing precipitation-induced deformations are surface runoff control and drainage of the northern wall, with drainage performance checked before each wet season.

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