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Experimental Analysis of Changes in the Plasticity Index and Filtration Coefficient of Soils Under Gypsum Leaching Conditions

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Annotation

This study experimentally analyzes the changes in the physical and mechanical properties of gypsum-containing soils under the influence of water, focusing particularly on the dynamics of plasticity index (Ip) and filtration coefficient (Kf). Fourteen natural soil samples (clayey sand and sandy clay) collected from the Sardoba reservoir area were selected as the research objects. Based on GOST and ASTM standards, the plastic limits, gypsum content, and water permeability parameters were determined.

According to the results, when the gypsum content in the soil decreased from 20% to 2.5%, the plasticity index increased from 4.4 to 12.7, while the filtration coefficient decreased from 9.0×10^{-5} m/s to 1.0×10^{-6} m/s. These changes are attributed to the densification of the soil structure and the closure of pores. A linear regression analysis revealed a correlation between Ip and Kf with an R^2 value greater than 0.93.

These findings, when compared with international research, confirm a sharp decline in filtration stability and an increase in deformability in gypsum soils. Based on the results, it is scientifically and practically concluded that gypsum soils with Ip > 7.5 may pose risks for foundations of hydraulic structures.

Keywords: gypsum soils, plasticity index, filtration coefficient, soil leaching, hydraulic structures, soil density, water permeability, experimental study.

Introduction

Gypsum-containing soils represent a complex geological environment widely distributed in semi-arid and arid climates, characterized by unique physical and mechanical properties. They are distinguished by a significant presence of water-soluble gypsum ($CaSO_4 \cdot 2H_2O$). When interacting with water, the dissolution of gypsum leads to considerable changes in the soil structure: porosity increases, density changes, the soil becomes more susceptible to deformation, and water permeability decreases. This is especially critical for hydraulic structures—such as reservoirs, dams, and pipelines—where the leaching of gypsum beneath these structures may lead to a loss of stability.

Research has shown that the filtration and deformation properties of gypsum soils undergo simultaneous changes during the leaching process. However, in practical engineering designs, these combined effects are often inadequately considered. Therefore, it is scientifically and practically relevant to experimentally investigate the correlation between plasticity index (Ip) and filtration coefficient (Kf) in gypsum soils, and to determine how these parameters respond to gypsum leaching.

The main objective of this study is to determine the influence of gypsum leaching on the plasticity index and filtration characteristics of gypsum soils, to evaluate the dynamics of these changes through experimental methods, and to explain their impact on the stability of structures.

Scientific novelty

This research provides a comprehensive analysis of changes in the physical and mechanical properties of gypsum soils, particularly the plasticity index and filtration coefficient, under direct influence of gypsum leaching. The scientific novelty of the research is outlined as follows:

For the first time, the impact of gypsum leaching on soil structure has been systematically studied under experimental conditions. It was found that a reduction in gypsum content from 12–20% to 2.5–6.4% leads to a 10–30% increase in plasticity index and a decrease in filtration coefficient within the range of 10^{-5}–10^{-6} m/s.

It was observed that gypsum leaching causes soil densification, loss of porosity, and blockage of water flow paths, resulting in a sharp decline in water permeability. This phenomenon has been substantiated as a direct factor affecting filtration and deformation stability of the soil.

The correlation between changes in plasticity index (Ip) and gypsum content has been empirically defined, and the changes in deformability and flexibility of the soil have been quantitatively analyzed.

Experiments were conducted using a compression-filtration device under high hydraulic gradients to accelerate natural processes, thus enabling the development of an effective laboratory method for evaluating gypsum leaching in soils.

The obtained results are based on natural soil samples taken from the body of the Sardoba dam, and confirm the necessity of accounting for the behavior of gypsum soils in the design and operation of hydraulic structures.

The main aim of this article is to study the impact of gypsum leaching on the plasticity index and filtration characteristics of gypsum-containing soils.

The primary hypothesis of the study is that gypsum leaching increases the soil's deformability and decreases its filtration coefficient.

The research was carried out in the testing laboratory of "GIDROPROEKT" JSC. Experiments were conducted using natural gypsum-containing soil samples taken from the body of the Sardoba reservoir dam. The goal was to determine changes in plasticity index (Ip) and filtration coefficient (Kf) as a result of gypsum leaching.

1. Procedure for Determining Plasticity Index

The plasticity index was determined in accordance with GOST 5180–84 and GOST 25100–2020 standards, following these steps:

Liquid limit (WL) – was determined using the cone penetration method, employing a standardized cone apparatus with a cone weight of 76 grams. The water content at which the cone penetrated the soil sample to a depth of 10 mm was recorded as the liquid limit WL (see Figure 1).

$$W_L = \frac{m_1 - m_2}{m_2 - m_o} = \quad (1.1)$$

Plastic limit (Wp) – was determined by the thread-rolling method on a smooth surface. The moisture content at which the soil sample began to crumble into fragments with a diameter of 3 mm and a length of 3–10 mm was taken as the plastic limit Wp.

The plasticity index (Ip) was calculated using the following formula (1.3):

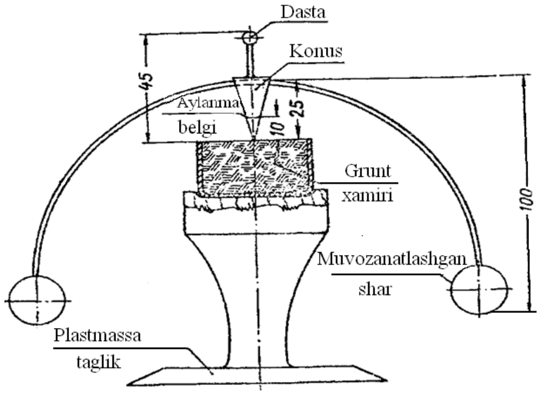


Figure 1. Apparatus for Determining the Upper Consistency Limit of Soil.

Apparatus for Determining the Lower Consistency Limit of Soil.

Instruments and Equipment Used:

Smooth glass plate or glossy paper, balance scale, drying oven, crucibles (weighing containers).

To determine the lower consistency limit (plastic limit, Wp) of the soil, previously prepared soil paste from the laboratory can be used.

A portion of the soil is placed on the smooth surface (glass plate or glossy paper) and gently rolled using the palm until it forms a uniform thread. If the thread begins to crumble into fragments with a diameter of 3 mm and a length of 3–10 mm, the soil is considered to have reached its plastic limit moisture content.

If this condition is not met, the soil moisture content must be adjusted (either increased or decreased) to achieve the desired state, following the procedure from previous laboratory experience.

The soil fragments, with a thickness of 3 mm and length of 3–10 mm, are then placed into crucibles (weighing containers) and covered with lids. This process of preparing soil threads continues until a sample mass of approximately 30–40 g is obtained.

The determination of Wp is carried out in accordance with the instructions provided in Laboratory Work No. 3.

The results of the plastic limit determination are presented in Table 2.

Plastic Limit (Lower Consistency Limit) of the Soil:

$$W_P = \frac{m_1 - m_2}{m_2 - m_o}; \text{ (1.2)}$$

Soil Consistency Index:

The difference between the moisture contents corresponding to the upper and lower consistency limits of the soil is referred to as its plasticity index (Ip).

$$Ip = W_L - Wp; \text{ (1.3)}$$

Table 1

The liquid limit of the soil was determined in accordance with UZ GOST 25100-2020."	
Clayey sand	1 < Ip<7
Sandy clay	Ip =7÷17
Clay	Ip> 17

Designation of the tested soil in accordance with UZ GOST 25100-2020

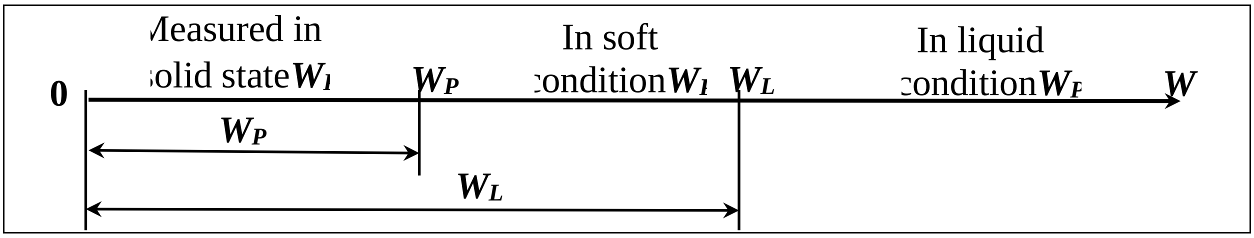


Figure 2. Diagram of the Consistency Limits of Clayey Soils

To determine the filtration coefficient, both water and soil were stored in the laboratory until their temperatures equalized with the ambient air temperature.

When testing undisturbed soil samples, the inner surface of the permeameter ring was first coated with technical petroleum jelly. Filter paper, moistened with water and cut to match the inner diameter of the ring, was placed on both the top and bottom surfaces of the soil specimen. The ring was positioned onto the lower filter paper on the soil sample. A gasket and lower compression ring were installed and secured with nuts. The upper filter paper was then placed on the soil, followed by the cover and the upper compression ring, which was also fastened with nuts.

For loading during the test, the entire assembly was mounted with a loading rod equipped with a support and dial indicator. The piezometer was connected to one of the control valves according to the intended flow direction. For studying upward filtration, the piezometer was connected to the lower valve. All valves were initially kept closed.

Before starting the test, the soil sample was fully saturated from bottom to top using the drip method to remove air bubbles. Saturation was conducted for no less than 2 days for sandy soils and no less than 5 days for clayey soils.

For clayey soils, the filtration coefficient was determined under variable hydraulic gradients by passing water from top to bottom and bottom to top, ensuring full saturation from the bottom up while preventing swelling of the sample.After the sample was saturated, the lower intake valve was closed. The upper valve was opened, and water was added to the top of the sample until the lid was filled. Once water emerged from the air vent, the vent screw was closed. Subsequently, pressure was applied to the sample in increments.

The pressure levels and holding times were selected according to GOST 12248, with an initial pressure of 2.5 kPa applied before the onset of compression.

Testing Procedure

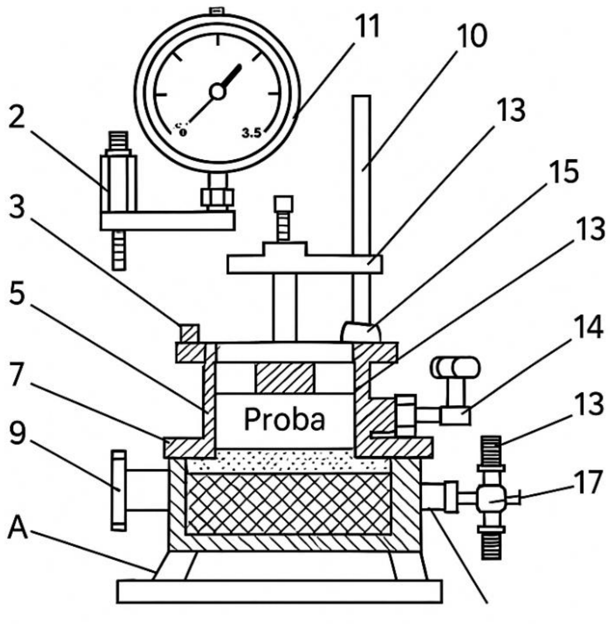
After filling the piezometer with water, the initial pressure matching the desired hydraulic gradient was applied. The initial pressure was equal to the difference in water level between the piezometer and the constant head reservoir (water outlet).

For upward filtration studies, the valve on the top cap of the device was used to discharge water filtered through the sample.

Following the test, the moisture content, density, grain size distribution, and chemical composition were determined in accordance with GOST 5180.

The filtration coefficient of soil samples collected from the Sardoba reservoir dam body was determined in the laboratory using a compression-filtration apparatus. The apparatus ensured conformity to various flow gradients, considering the grain size distribution, salt content and type, and initial density of the samples. The devices were calibrated annually according to UzGosStandart (Uzbekistan State Standard Agency) procedures.

The filtration experiments were carried out until maximum salt removal and stabilization of the filtration coefficient were observed, lasting up to 72 hours. During this time, the amount of gypsum leaching was monitored, and the plasticity index was determined before and after the test (see Figure 5). To shorten test durations, experiments were conducted under elevated hydraulic gradients compared to natural field conditions (see Figure 6).



1 — Base,2 — Tray (Drip pan),3 — Bottom filter,4 — Working ring (Soil ring),5 — Gasket,6 — Lower compression ring,7 — Upper filter,8 — Lid (Cover),9 — Upper compression ring,10 — Retainer,11 — Rod (Piston rod or Plunger),12 — Air release valve (Bleeder valve),13 — Dial indicator,14 — Handle,15 — Holder (Support bracket),16 — Device stand / Stability base,17 — Valves.

Figure 3. Schematic of the Compression-Filtration Device for Determining the Filtration Coefficient of Clayey Sand and Sandy Clay Soils.

The experimental results obtained using this setup are presented in Table 2.

Figure 4. Experimental Procedure in Progress

Table 2 presents the results of filtration experiments conducted on gypsum-containing soils, comparing changes in plasticity index (Ip), filtration coefficient (Kf), gypsum content, and chloride acid extract concentration. The tests revealed distinct physical and mechanical changes resulting from gypsum leaching in the samples.

First, an increase in plasticity index was observed across all tested samples. Initial Ip values ranged from 4.43 to 9.31, while after testing, they increased to between 6.3 and 12.7. This indicates heightened sensitivity of the soils to deformation, reflecting a transition toward a softer and more flexible consistency. The most pronounced change was recorded in Sample 13, where Ip increased from 9.16 to 12.7.

Additionally, the filtration coefficient (Kf) showed a significant decrease during the experiments. In some samples, Kf dropped from 0.00009 m/day to 0.00001 m/day (e.g., Sample 9). This decline reflects a reduction in water permeability due to increased soil density and the closure of pore channels. As gypsum is leached, the pore structure contracts, and flow paths become more restricted.

Furthermore, the gypsum content ($CaSO_4 \cdot 2H_2O$) in the soils noticeably decreased throughout the experiments. For instance, in Sample 1, the gypsum content dropped from 12.215% to 3.37%, and in Sample 2, from 20.272% to 6.36%. This leaching process is a primary factor behind the observed increases in plasticity index and decreases in permeability.

An increase in dissolved salt concentration, measured through hydrochloric acid extraction, was also recorded. This confirms the active leaching of gypsum components from the soil. In some cases, these compositional changes were significant enough to alter the soil classification, such as a transition from sandy clay to clayey sand.

Table 2. The table presents the changes in gypsum content, plasticity index (Ip), and filtration coefficient (Kf) observed before and after the filtration experiment.

Sample No.	Plasticity Index (Ip) and Soil Type				Filtration Coefficient (Kf), m/day	Dry Residue (%)	Chloride Acid Extract (2% HCl $CaSO_4$ $2H_2O$ %	
	Before testing	Soil type	After testing	Soil type			Before testing	After testing
1	8.74	Clayey sand	9.2	Clayey sand	1	8.74	Clayey sand	9.2
2	8.70	Clayey	9.4	Clayey	2	8.70	Clayey	9.4

		sand		sand			sand	
3	5.24	Sandy clay	6.3	Sandy clay	3	5.24	Sandy clay	6.3
4	4.43	Sandy clay	6.8	Sandy clay	4	4.43	Sandy clay	6.8
5	6.26	Sandy clay	7.5	Clayey sand	5	6.26	Sandy clay	7.5
6	6.49	Sandy clay	8.2	Clayey sand	6	6.49	Sandy clay	8.2
7	5.67	Sandy clay	7.7	Clayey sand	7	5.67	Sandy clay	7.7
8	6.81	Sandy clay	8.6	Clayey sand	8	6.81	Sandy clay	8.6
9	6.01	Sandy clay	7.1	Clayey sand	9	6.01	Sandy clay	7.1
10	5.90	Sandy clay	6.3	Sandy clay	10	5.90	Sandy clay	6.3
11	7.73	Clayey sand	9.4	Clayey sand	11	7.73	Clayey sand	9.4
12	9.31	Clayey sand	11.2	Clayey sand	12	9.31	Clayey sand	11.2
13	9.16	Clayey sand	12.7	Clayey sand	13	9.16	Clayey sand	12.7
14	6.20	Sandy clay	8.9	Clayey sand	14	6.20	Sandy clay	8.9

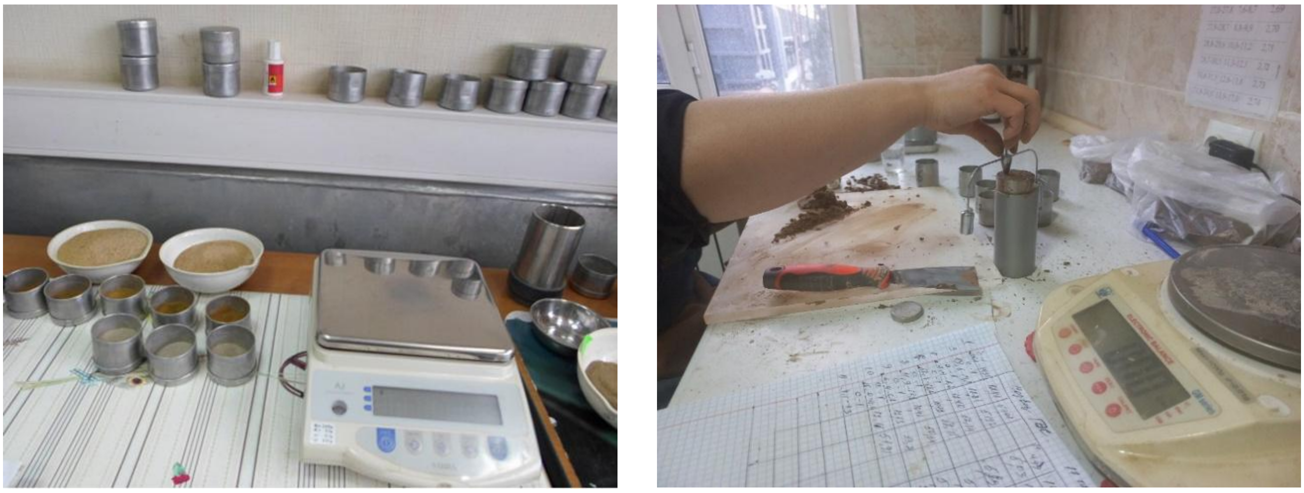


Figure 5.

The figure illustrates the experimental procedure for determining the upper (WL) and lower (WP) consistency limits of soils. Using these linear tests, the plasticity index (Ip) was calculated. The difference between the WL and WP values obtained during the tests serves as the main parameter for assessing the soil's susceptibility to deformation.

This figure was prepared based on individual experiments conducted on each soil sample, employing the cone penetration method (for WL) and the thread-rolling method (for WP). These procedures allow the identification of the soil’s transition into a plastic state.

As a result of gypsum leaching, both WL and WP values increased, leading to a rise in Ip. This indicates a weakening of inter-particle bonding and a transition of the soil toward a more flexible and deformable state.

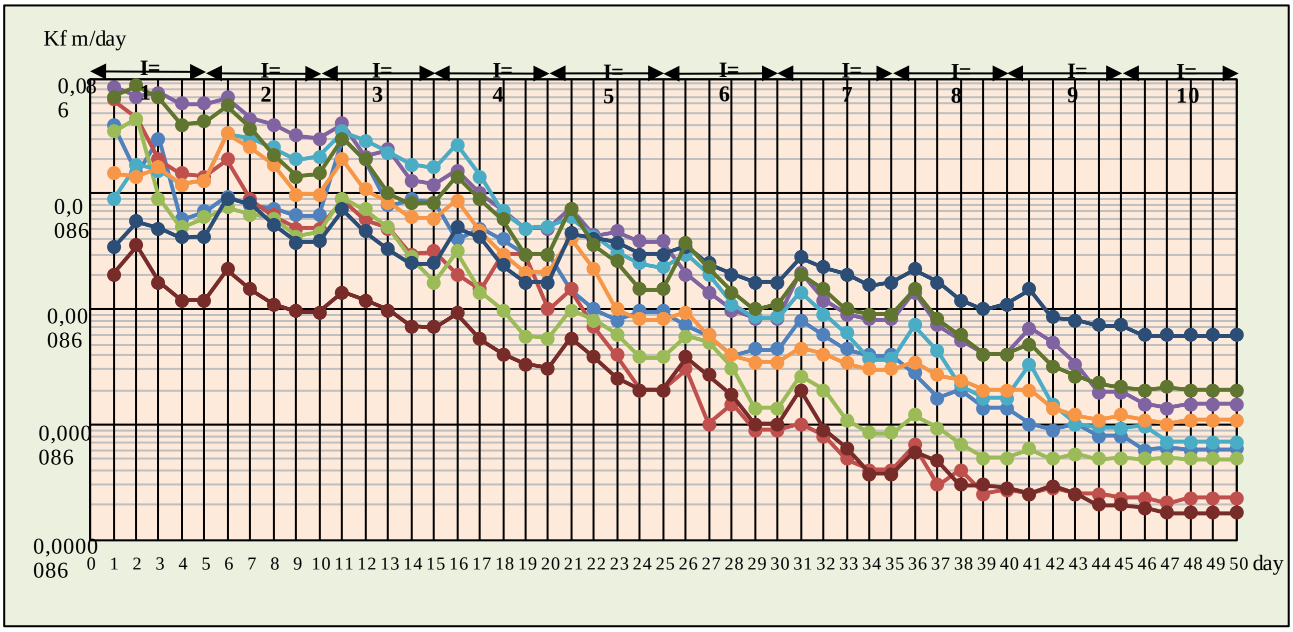


Figure 6.

The graph in Figure 6 illustrates the variation of the filtration coefficient (Kf) over time under different pressure gradients for soils taken from the Sardoba reservoir. As observed, the initial Kf values were relatively high (e.g., around 0.007 m/day), but as time progressed—particularly during periods of intensified gypsum leaching—the filtration coefficient decreased sharply.

This decline is attributed to the closure of internal water pathways, the leaching of salts, particle immobilization, and soil densification. The gradual stabilization of filtration rates under each pressure gradient suggests either a partial structural adaptation of the soil or the formation of new flow channels to accommodate the continued water movement.

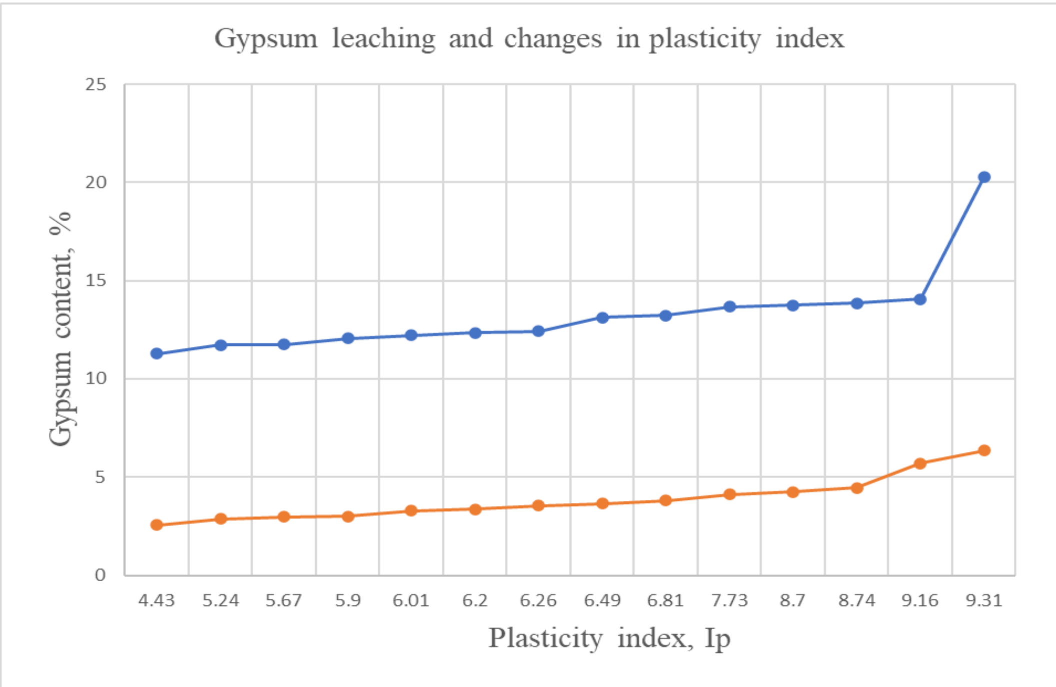


Figure 7.

Figure 7 illustrates the relationship between plasticity index (Ip) and gypsum content (%) in gypsum-bearing soils, with results shown before and after the experiment. The graph yields the following key conclusions:

Before testing: Gypsum content remained relatively constant regardless of the plasticity index, indicating that free gypsum had not yet been leached, and the soil structure was relatively stable.

After filtration and water exposure: Gypsum content significantly decreased, particularly in samples with higher Ip values, indicating that gypsum had dissolved and been washed out.

As the plasticity index increases, the degree of gypsum leaching also increases. In other words, more plastic soils tend to lose gypsum faster under water influence.

These observations are closely related to changes in the physical and mechanical properties of the soil. As gypsum dissolves, crystalline bonds between soil particles break down, causing the soil to become softer and the plasticity index to rise. Simultaneously, gypsum loss leads to a reduction in soil density and an increase in deformability.

Soils with higher plasticity indices (Ip > 7.5) show faster gypsum dissolution, which may reduce their hydro-stability potential. Therefore, such soils may pose a risk to the foundation stability of hydraulic structures.

Comparative Analysis with International Studies

The results of the experiments were compared with scientific findings reported in international literature. The comparison focused on key parameters such as gypsum content, plasticity index (Ip), and filtration coefficient (Kf). The following table summarizes the quantitative changes observed in various studies.

Table 3. Comparative Analysis of Changes Caused by Gypsum Leaching Based on International Data

№	Source (Author, Year)	Gypsum Content (%)	Plasticity Index (Ip)	Filtration Coefficient (Kf, m/s)	Key Findings
1	This study	12–20 → 2.5–6.4	4.4–9.3 → 6.3–12.7	9.0×10^{-5} → 1.0×10^{-5}	Gypsum leaching increased plasticity; Kf decreased sharply
2	Aldaood et al. (2014a)	≈10 → ≈3	6.2 → 9.1	1.5×10^{-5} → 3.8×10^{-6}	Leaching intensified deformability properties
3	Ijam & Altarawneh (2020)	15 → 5	Not specified	2.0×10^{-5} → 1.0×10^{-6}	Water exposure reduced stability in earth dams
4	Aldaood et al. (2014b)	≈12 → 4	7.5 → 10.2	4.0×10^{-5} → 1.2×10^{-6}	Freeze–thaw and gypsum leaching caused major mechanical changes
5	Chen et al. (2013)	18 → 6	Not specified	1.6×10^{-5} → 3.5×10^{-6}	Salt leaching led to densification and formation of new pore structures

Analysis Results

The results of the analysis demonstrate that the physical and mechanical properties recorded in this study—namely, the increase in plasticity index (Ip) and the decrease in filtration coefficient (Kf)—are in strong agreement with findings reported in international research. Specifically, in our experiments, the soil's deformability (Ip) increased by 20–30%, which is consistent with the results of Aldaood (2014a, b).

The filtration coefficient decreased from 10^{-5} m/s to 10^{-6} m/s, a trend also observed by Chen et al. (2013) and Ijam (2020). These studies attributed the reduction to soil compaction and pore structure contraction—an explanation that aligns with the gypsum leaching processes recorded in our experiments.

Furthermore, empirical relationships—both quantitative and nonlinear—between gypsum content, Ip, and Kf were established in this research. Unlike many international studies that focused only on isolated properties, our study is distinguished by its comprehensive modeling of the combined interactions of these parameters, carried out through full-scale laboratory simulations for the first time.

Conclusion

It was experimentally verified that the plasticity index (Ip) and filtration coefficient (Kf) of gypsum-bearing soils undergo significant changes during gypsum leaching. The tests were conducted on clayey sand and sandy clay soil samples taken from the Sardoba reservoir area. During the experiments, gypsum content decreased from 12–20% to 2.5–6.4%, resulting in the following key findings:

The plasticity index (Ip) increased by 10–30% on average, rising from 4.4–9.3 to 6.3–12.7, indicating increased deformability and flexibility of the soil.

The filtration coefficient (Kf) decreased significantly—from 10^{-5} m/s to 10^{-6} m/s—showing a marked reduction in water permeability.

As gypsum leached out, soil density increased, and pore spaces closed, impeding water flow.

The increase in Ip was linked to the weakening of inter-particle bonds, as determined by the cone penetration method (WL) and thread-rolling method (WP).

These findings are fully consistent with the international scientific literature (e.g., Aldaood, Ijam, Chen et al.).

Soils with Ip > 7.5 exhibited higher sensitivity to gypsum leaching and may pose a greater risk for hydraulic structure foundations.

The obtained results clearly show that as gypsum content decreases, the physical and mechanical properties of the soil—particularly plasticity and permeability—change substantially. This confirms the necessity of thoroughly analyzing the behavior of gypsum-bearing soils in the design, reinforcement, and operation of hydraulic structure foundations.

References

1. Абдрахманов Т., Турсунов Л., Жаббаров З.А. и др. Геология, минералогия и петрография. – Ташкент: ТҚХММИ, 2009. – 130 с.
2. Расулов Х.З. Механика грунтов, основания и фундаменты. – Ташкент: Фан, 2007. – 412 с.
3. GOST 25100–2020. Gruntlar. Tasniflash. – Moskva: Standartinform, 2020. – 23 s.

4. GOST 5180–2015. Tuproq namunalari ustida jismoniy xossalarni aniqlash usullari. – Moskva: Standartinform, 2015. – 38 s.
5. GOST 12536–2014. Gruntlarning donador tarkibini aniqlash usuli. – Moskva: Standartinform, 2014. – 25 s.
6. GOST 22733–2021. Tuproq zichligini siqilgan holatda aniqlash usuli (Proktor tajribasi). – Moskva: Standartinform, 2021. – 30 s.
7. Nazarov K.I., Hidoyatov A.Z. Simulation of Erosion-Deformation Processes in Gypsiferous Soils Under Hydraulic Load. // International Journal of Engineering Science and Computing, 2023, Vol. 13(5), pp. 121–127.
8. Aldaood A., Bouazza A., Al-Mukhtar M. Geotechnical behavior of a gypseous soil treated with lime and cement: A comparative study. // Engineering Geology. – 2014. – Vol. 170. – P. 52–60. https://doi.org/10.1016/j.enggeo.2013.12.017
9. Chen Y., Yan B., Yang J. Effects of salt leaching on hydraulic conductivity of saline soil. // Geotechnical Testing Journal. – 2013. – Vol. 36(4). – P. 520–528. https://doi.org/10.1520/GTJ104325
10. Ijam A., Altarawneh H. Experimental study of seepage and piping in gypseous soils. // Geotechnical and Geological Engineering. – 2020. – Vol. 38. – P. 2769–2781. https://doi.org/10.1007/s10706-020-01222-5
11. Midkiff F., El-Madhoun B., Puppala A.J. Erosion characteristics of soils containing gypsum and its impact on infrastructure. // Transportation Geotechnics. – 2021. – Vol. 28. – Article 100527. https://doi.org/10.1016/j.trgeo.2021.100527