Comparative Analysis of Geotechnical Properties of Windblown Mesr Sand and Three Other Uniform Sand

Fardin Jafarzadeh[1]*, Zahra Mousavi[2], Aliakbar Karimzadeh[3]

Abstract

Sandy soils constitute a major portion of alluvial and aeolian surface deposits in nature. Investigation of the mechanical and behavioral characteristics of these soils is of particular importance in geotechnical engineering. For this purpose, a wide range of static and dynamic laboratory tests are conducted in soil mechanics and geotechnical laboratories using various apparatus and testing systems. These tests can generally be classified into two categories: element tests and physical model tests. Both categories require sandy soil specimens. Currently, various natural and artificial sands are used worldwide for laboratory research. In Iran, several sands are commonly employed, including natural coastal Babolsar sand and artificial Firoozkooh sand. In this paper, a wind-blown sand referred to as Mesr sand, obtainable from the Mesr Desert in Iran, is introduced. Selected properties of this sand are compared with Babolsar sand, Firoozkooh sand, and Toyoura sand, which is a well-known reference sand in geotechnical engineering.

Keywords: Sandy soil; Mesr Desert; geotechnical properties; Toyoura sand; particle shape; morphology

1. Introduction

Soils are generally classified into coarse-grained and fine-grained categories. Fine-grained soils, due to their high plasticity, typically exhibit significant cohesion and are prone to cracking under atmospheric conditions because of their high swelling and shrinkage potential [1–8]. The second category consists of coarse-grained soils, for which grain size distribution (mean grain size D_{50}), interparticle forces, particle arrangement, and soil fabric govern their mechanical behavior [9]. Consequently, grain size distribution plays a fundamental role in soil classification systems and behavioral characterization.

In addition, previous studies have emphasized the importance of another factor, particle shape, in achieving a more accurate understanding of granular soil behavior [10,11]. Particle shape significantly influences physical and mechanical properties of soils, including classification, permeability, compressibility, critical state friction angle, shear strength, underlying micromechanical processes, and other geotechnical and geological engineering aspects [12-14]. Particle shape is typically described by three independent parameters: roundness, sphericity, and regularity, although additional descriptors have also been proposed in the literature.

Accordingly, the objective of this study is to investigate the physical properties, gradation characteristics, and particle shape of four granular materials: Firoozkooh sand, Babolsar sand, Mesr Desert sand, and Toyoura sand. These materials differ in origin and formation processes, artificially crushed,

[1] Associate Professor, Department of Civil Engineering, Sharif University of Technology, Tehran, Iran
* Corresponding Author (Email: fardin@sharif.edu)
[2] MSc Graduate, Department of Civil Engineering, Sharif University of Technology, Tehran, Iran
[3] PhD Researcher, Hong Kong University of Science and Technology, Hong Kong

wind-blown, and naturally deposited, and therefore exhibit distinct physical and morphological characteristics.

2. Granular Materials with Different Particle Shapes

To provide a meaningful comparison of particle shape and geotechnical characteristics, four sands with different morphologies, Firoozkooh, Babolsar, Mesr Desert, and Toyoura sands, were selected. Particle shape has a pronounced effect on soil behavior and properties such as shear strength, settlement, and water retention capacity. Moreover, the source and formation process of these materials influence their geotechnical properties, particularly grain size distribution.

Firoozkooh sand is a commercially produced, factory-crushed sand. Due to the crushing process, its particles are highly angular, and its gradation generally covers a relatively wide range of sand sizes. Babolsar sand, obtained from the southern coast of the Caspian Sea near Babolsar city in northern Iran, is a widely used natural sand in Iran. Owing to fluvial and marine transport processes, its particles are more rounded compared to Firoozkooh sand.

Mesr Desert sand is an aeolian sand collected from the Mesr Desert in Iran (coordinates: E 54°47′43″, N 34°04′00″), located in Jandaq Rural District, Central District of Khur, and Biabanak County, Isfahan Province (Fig. 1 and Fig. 2). The sand obtained from this desert is designated as Mesr sand and is a new material specifically investigated in this study. Wind erosion removes sharp particle edges, resulting in relatively rounded grains. Additionally, wind transport leads to a gradation characterized by the absence of certain particle sizes. Toyoura sand, originating from Japan, is also a crushed sand whose particles range from sub-rounded to angular. This uniform sand is one of the most widely used reference materials in laboratory geotechnical research worldwide.

To examine particle morphology in greater detail, scanning electron microscope (SEM) images were used for comparison (Fig. 3). SEM images of Firoozkooh, Babolsar, and Mesr sands were obtained from the Technology Services Center of Sharif University of Technology, while the Toyoura sand image was taken from Jafarzadeh and Zamanian [15,16].

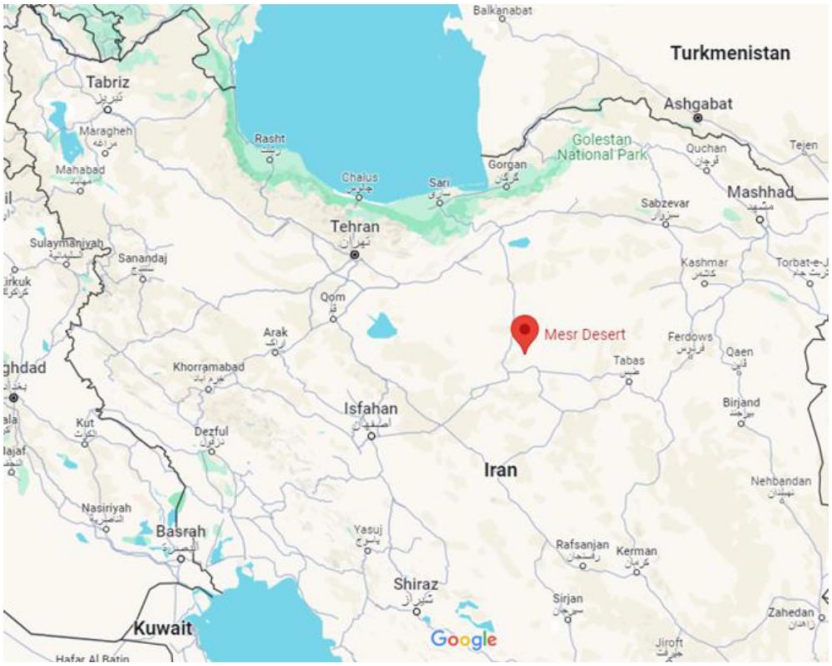

Figure 1. Location map of the Mesr Desert in Isfahan Province, Iran.

Figure 2. Photograph of sand dunes and aeolian sand deposits in the Mesr Desert.

3. Physical Properties and Morphology of Granular Materials

To evaluate the basic properties of Mesr sand and compare it with commonly used sands in Iran, standard geotechnical index tests were performed on all materials in accordance with relevant ASTM standards. The grain size distribution curves are presented in Fig. 4. As shown, Firoozkooh and Babolsar sands exhibit similar and relatively uniform gradations, whereas Mesr sand displays a less uniform gradation due to its aeolian origin.

It should be noted that, owing to the formation mechanism of this sand, the presented gradation is not necessarily representative of the entire Mesr Desert, and gradation testing should be conducted for each specific sample. Specific gravity values were also determined following standard procedures. The D_{10}, D_{50}, coefficient of uniformity (C_u), and coefficient of curvature (C_c) are summarized in Table 1. All four sands are classified as SP (poorly graded sand) according to the Unified Soil Classification System (USCS).

SEM observations (Fig. 3) indicate that Mesr sand consists of relatively rounded particles, a morphology resulting from wind-induced abrasion. Wind erosion eliminates sharp corners, producing particles that are even more rounded than those of Babolsar sand, which is a coastal sand. Such particle morphology can significantly affect soil properties, particularly shear strength, because rounded particles exhibit reduced interlocking and contact area, leading to lower shear resistance.

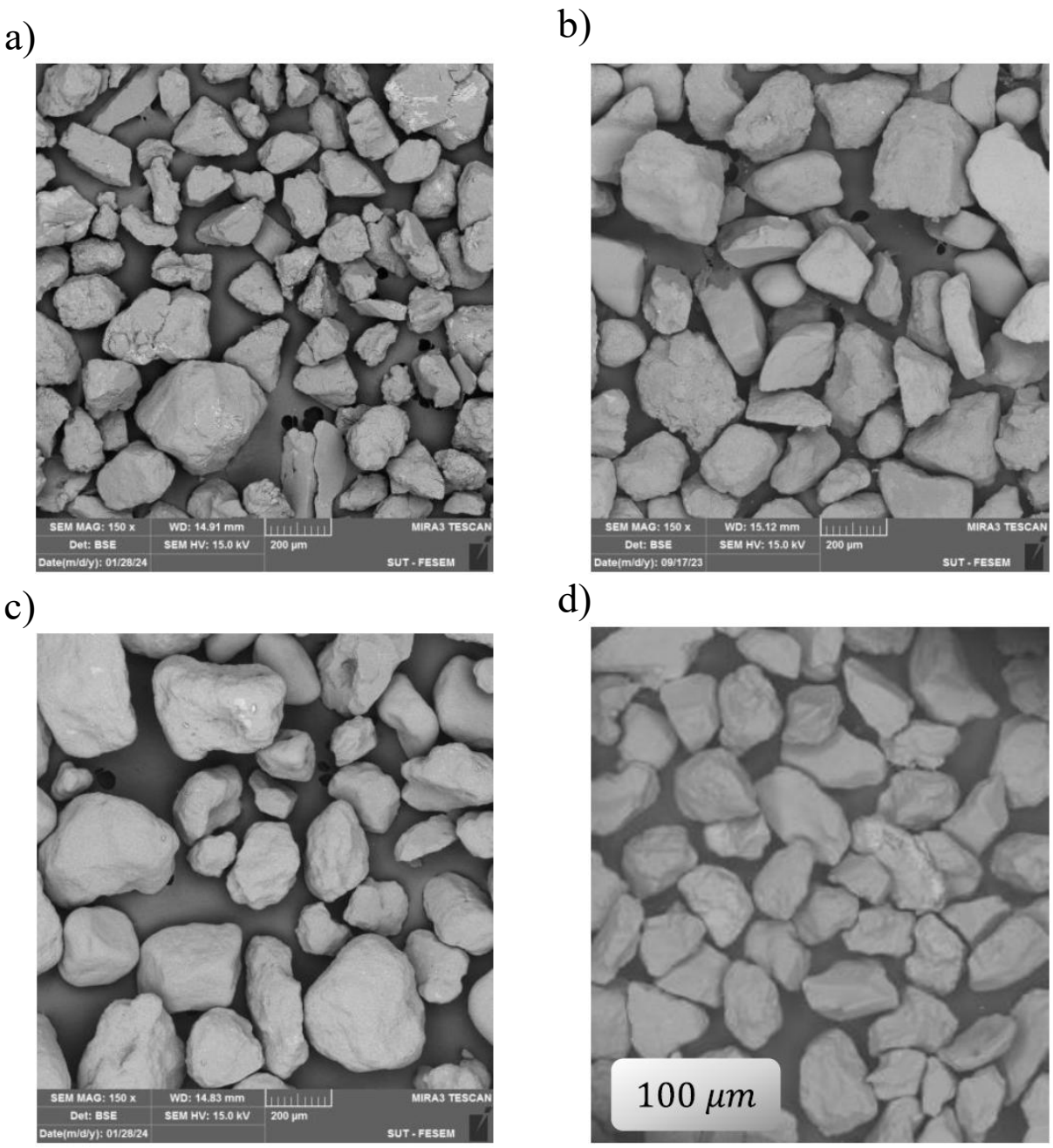

Figure 3. SEM images of the materials used in this study: (a) Firoozkooh sand, (b) Babolsar sand, (c) Mesr sand, (d) Toyoura sand [13].

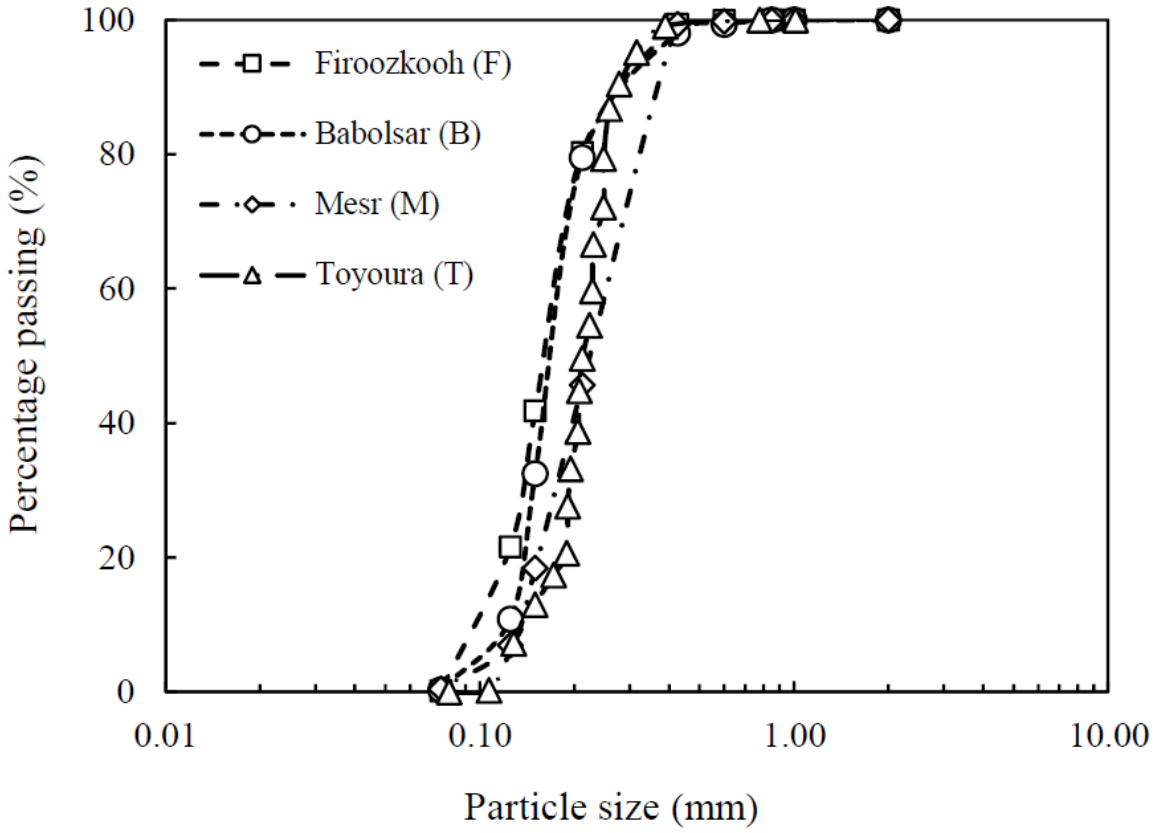

Figure 4. Grain size distribution curves of the tested sands.

Table 1. Basic geotechnical properties of the tested sands

Material symbol	Material name	G_s	Grain size distribution indices			
			$D_{10}(mm)$	$D_{50}\ (mm)$	C_u	C_c
F	Firoozkooh sand	2.65	0.095	0.167	1.860	1.216
B	Babolsar sand	2.79	0.130	0.179	1.415	1.017
M	Mesr sand	2.66	0.147	0.228	1.741	0.861
T	Toyoura sand	2.65	0.140	0.212	1.714	1.074

4. Conclusions

In this study, for the first time, a uniform aeolian sand obtained from the central desert of Iran, referred to as Mesr sand, was introduced and characterized. The index properties, particle shape, and geotechnical characteristics of this sand were compared with three other sands: Firoozkooh sand, Babolsar sand (Iran), and Toyoura sand (Japan). SEM images revealed that Mesr sand particles are more rounded than those of the other sands. Furthermore, grain size distribution tests demonstrated that, due to its formation process, Mesr sand exhibits lower gradation uniformity compared to the other sands.

5. References

[1] M. Jabbarzadeh, H. Sadeghi, S. Tourchi and A.G. Darzi, "Thermo-hydraulic analysis of desiccation cracked soil strata considering ground temperature and moisture dynamics under the influence of soil-

atmosphere interactions," *Geomechanics for Energy and the Environment*, p.100558, 2024. https://doi.org/10.1016/j.gete.2024.100558

[2] S. Tourchi, M. Jabbarzadeh, H. Sadeghi and A.A. Lavasan, "Thermo-hydro-mechanical modelling of rock cliff-atmosphere interaction: the case of the Pozary test site in Czechia," In *EGU,* Copernicus Meetings, Austria*,* 2024. https://doi.org/10.5194/egusphere-egu24-20407

[3] M.J. Ghandilou, S. Tourchi and H. Sadeghi, "Numerical investigation of cyclic wetting and drying of Boom clay based on the Barcelona Expansive Model," In *84th EAGE Annual Conference & Exhibition*, vol. 2023, No. 1, pp. 1-5, 2023. https://doi.org/10.3997/2214-4609.202310400

[4] M.J. Ghandilou, S. Tourchi, A.G. Darzi and H. Sadeghi, "Numerical modeling of volumetric behavior of unsaturated expansive soil under wetting and drying cycles," In *5th Iranian Conference on Geotechnical Engineering*, 2023. https://www.researchgate.net/publication/377265206

[5] M. Jabbarzadeh and H. Sadeghi, "A Novel Analytical-Statistical-Numerical Framework for Investigating the Thermo-Hydro-Mechanical Behavior of Heterogeneous Subsidence Phenomena, Moisture and Temperature Variations in Cracked Soils Under Soil-Atmosphere Interaction", *Sharif Journal of Mechanical Engineering*, 41(1), pp. 13-28, 2025. https://doi.org/10.24200/j40.2024.65047.1718

[6] S. Tourchi, M. Jabbarzadeh, and H. Sadeghi, "Thermo-hydro-mechanical analysis of soil strata suffered from desiccation cracking," *XVIII European Conference on Soil Mechanics and Geotechnical Engineering*, p.1362-1367, 2024. https://www.researchgate.net/publication/384285071

[7] M. Jabbarzadeh, Z. Mousavi, "Coupled multi-physics modeling of spatio-temporal behavior of embankment subjected to freeze-thaw cycles considering layered construction phases", *Cold Regions Science and Technology.,* p.104652., 2025. https://doi.org/10.1016/j.coldregions.2025.104652

[8] Z. Mousavi, M. Jabbarzadeh, F. Jafarzadeh, H. Sadeghi, "Hydromechanical behavior of unsaturated sandy soils with different particle shapes under loading–unloading paths: Numerical simulation and experimental validation", *Transportation Geotechnics*., *52*, p.101560. 2025. https://doi.org/10.1016/j.trgeo.2025.101560

[9] Santamarina, J.C. and Cho, G.C., 2004. Soil behaviour: The role of particle shape. In Advances in geotechnical engineering: The Skempton conference: Proceedings of a three day conference on advances in geotechnical engineering, organised by the Institution of Civil Engineers and held at the Royal Geographical Society, London, UK, on 29–31 March 2004 (pp. 604-617). Thomas Telford Publishing.

[10] M.A. Hosseini and P. Tahmasebi, "A novel graph-based 3D breakage method for angular particles with an image-based DEM," *International Journal of Rock Mechanics and Mining Sciences*, 174, p.105640, 2024. https://doi.org/10.1016/j.ijrmms.2024.105640

[11] Z. Mousavi and M. Jabbarzadeh, "3D DEM-based analysis of cylindrical rock specimen failure and micro-fracturing: impact of stiffness and tensile strength." *Discover Geoscience*, *3*(1), pp.1-21., 2025. https://doi.org/10.1007/s44288-025-00126-5

[12] M.A. Hosseini and P. Tahmasebi, "On the influence of the natural shape of particles in multiphase fluid systems: Granular collapses," *Computers and Geotechnics*, 162, p.105654, 2023. https://doi.org/10.1016/j.compgeo.2023.105654

[13] Z. Lu, A. Yao, A. Su, X. Ren, Q. Liu, and S. Dong, "Re-recognizing the impact of particle shape on physical and mechanical properties of sandy soils: a numerical study," *Engineering geology*, 253, pp.36-46, 2019. https://doi.org/10.1016/j.enggeo.2019.03.011

[14] Z. Mousavi, F. Jafarzadeh, "Experimental insights into particle shape and suction effects on compression and shear behavior of sandy soils", *Transportation Geotechnics,* p.101761, 2025. https://doi.org/10.1016/j.trgeo.2025.101761

[15] Z. Mousavi and F. Jafarzadeh, "The influence of gradation on shear behavior of Glass Beads: A DEM study", In *14th National Conference on Civil Engineering*, 2024. https://www.researchgate.net/publication/380667931

[16] F. Jafarzadeh, and M. Zamanian, "Effect of stress direction on the undrained monotonic and cyclic behavior of dense sands," Scientia Iranica, 27(2), pp.551-565, 2020. https://doi.org/10.24200/sci.2018.20318