Bilad Alrafidain Journal for Engineering Science and Technology
https://dx.doi.org/10.56990/bajest/2026.ISCES.01

ISSN: 2073-9524
Pages:1-6

Cyclic Behavior of Sheet Pile Wall Under Seepage Anchored Conditions

Shaimaa A. Abdul Hadi[1], Hassan O. Abbas[1*]
[1]Department of Civil Engineering, University of Diyala, Diyala, Iraq

Abstract
Sheet pile walls have been considered the hoariest anchoring techniques used in civil engineering projects. In this study, experimental work was achieved on a laterally anchored sheet pile wall installed below a cycling load in sandy soil with a ratio (CLR) of 40% for 100 cycles. Several parameters were considered, including anchor rod length of (40 cm), pile length (30 cm), and angles between batter piles 100, 150, and 250). In addition, a linear load of 5 kPa applied on ground surface near sheet pile wall and a spacing between anchors of 10 cm was considered. The batter piles were installed at a distance of 40 cm from the sheet pile wall. The test results showed that the increase of angles between batter piles from 10° to 15° and 25° leads to a reduction of the lateral displacement of the sheet pile wall by 7.1% and 64.3%, respectively. Strip footing tilting and total settlement near the sheet pile wall reduced as the angles between anchored batter piles increased from 10° to 15° and 25°. The wall system, which is made from anchored sheet pile, has been exposed to cyclic load was effective and safer when the inclination angle between the batter piles is 25°.

Keywords: Sandy soil, Cyclic load, Anchored sheet pile, Seepage conditions

Article history: Recieved:*21 Jan. 2026****, Accepted:*** *20 Fab. 2026****, Published:****20 March 2026*

1. Introduction

Sheet pile walls are used to retain water-filled soils as temporary or permanent structures, to build flood barriers, to protect soil from erosion, as separation walls, under dams, to protect marine structures, to build temporary dams, and to support excavation systems. To support the backfill under horizontal pressure, sheet piles are placed in the soil on opposite sides of the wall. Sheet piles are formed by continuously connecting interlocking members to form the pile structure. In this study, cantilever sheet piles were used. They were equipped with two horizontal anchor bars driven into the sandy soil under cyclic loads. Soil stabilization techniques come in two varieties: fixed and free. There are two forms of sheet piles: the first is called a cantilever and is fully supported by its surrounding earth, while the second type is supported by a mechanical anchor in addition to the surrounding soil and is called one or more anchors [1].

The most common type is cantilever steel plates, for their fundamental structure, excellent rigidity, and easy installation. They are used at a height of six meters from the drilling line or lower [2]. The strength of the pile sheets and the strength of the wall materials can support negative pressure balance. External loads can cause changes in pressure beneath the pile walls, resulting in increased lateral forces transferred to the pile sheets, as in construction and body movement. This behavior can lead to settling and deflection, both important factors in the stability and definition of pile walls [3]. One of the most common areas where cantilever pile walls are used is in urban areas. This is due to their ease of formation and their ability to reduce excavation problems for adjacent buildings. Lateral soil pressures can be evaluated using traditional design methods for cantilever pile walls. Soil and the relationship between piles and shoring systems are key elements that have attracted the attention of engineers and geotechnical practitioners in this field. Several works were achieved on cantilever pile walls, including bending moments and lateral soil pressures [4-9].

Various anchor levels have been used. This is one of the most effective methods for reducing the impact of deformation in fixed walls. It has been shown that using larger pile sections can reduce deformation by 50%, and deformation can be reduced by 65% if a second anchor

* Corresponding author: temimi71@yahoo.com

level is incorporated. Deformation can also be reduced by placing an anchor at a height of 25% of the wall height [10]. Changing soil conditions affect the walls of cantilevered concrete piles. Increasing wall penetration depth, including increased resistance, reduces deformation and bending moments [11]. The maximum surcharge that a cantilever sheet pile wall may sustain in static states when an infinitely uniformly distributed surcharge is placed at a specific distance from the wall has been expressed. A discontinuity was seen during seismic activity, which may have resulted from the development of a plastic process separate from the surcharge. Only when the surcharge is placed farther beyond a certain critical distance does this condition occur.

Furthermore, unique solutions for a restricted surcharge have been invented, making it possible to derive an expression for the maximum sustainable surcharge in static settings. A. These seismic and static solutions are independent of the surcharge's distance from the wall and stay constant even when a linearly distributed surcharge parallel to the wall is taken into account [12]. The performance of cantilever sheet piles may vary depending on the angle of internal friction. The bending moment increases with increasing internal friction angle. Soils with an angle of 39° have been shown to exhibit greater stiffness than soils with angles of 34° and 30°, and also exhibit less movement along the wall under the same vibration conditions [13]. It was found that ground subsidence represents 18 percent of the largest excavating possible when the foundation is 200 mm away, while subsidence is 2.7% when it is 800 mm away.

This emphasizes the importance of the distance between the foundation and the excavation face [14]. Contrary to the assumption of a homogeneous ground pressure distribution, they found that the effects of excess surcharge are most pronounced at the top of the wall and decrease non-linearly with depth [15]. A study was conducted using the finite element program GEO5. The results showed that the optimal anchor angle is 25°, and showed a reduction in horizontal displacement and the bending moment at the top of the wall. Therefore, the higher the friction angle, the greater the soil cohesion, the lower the bending moment, and the lower the wall displacement [16]. A soil model with relative density Dr = 50% was used to study seepage and soil failure behind the sheet pile. The soil model is stable when there is a small hydraulic pressure difference between the upper and lower sides. The sand is irreversible deformation after reaching the hydraulic pressure difference. Near the sheet pile, there is an uplift downstream and subsidence at the source.

The degree of sand particle movement or rearrangement grows the hydraulic pressure. Upstream soil surface subsidence and downstream soil surface uplift as the water level rises [17]. Installed on heterogeneous soil, sheet piles were used below the hydraulic structure cover. Intermediate piles were used in addition to the piles above and below the hydraulic structure. At the hydraulic structure's base, the discharge, uplift pressure, and exit gradient were determined. An ANN (an artificial neural network) was used to evaluate the influence of intermediate sheet piles in case of considering non-homogenous soil on leakage properties below hydraulic structure using SEEP/W. Good agreement was shown at the validation [18]. Knowledge of seismic resistance covers batter piles beating vertical piles. Smaller lateral and vertical displacements are observed as the batter's angle increases. In addition, batter piles exhibit moment values corresponding to approximately 42%, 43%, and 28% lower than the values for similar vertical pile groups for edge, corner, and center piles, respectively [19].

Calculated compared to higher load ratios, the influence of embedded lengths and spacing of piles is minor at a cyclic load ratio of 20%, and it is often considered safe from failure. Displacement values after 100 load cycles range between 6% and 8.5% of the shaft diameter. On the other hand, substantial lateral displacement occurs at cyclic load ratios of 50% and 80%, increasing rapidly as the number of cycles rises, which makes such conditions unsafe. An investigation of the influence of key parameters like batter pile length and inclination angle on the stability of anchor sheet pile group in multilayer layer under periodic loading conditions is carried out [20]. Due to a limited amount of experimental research on anchored sheet piles subjected to both cyclic load and seepage condition; therefore: this study is achieved.

2. Methodology

2.1 Soil used

For the purpose of this experiment, sand samples were taken from Karbala, Iraq. Table 1 shows the properties measured for the sand sample.

Table 1: Characteristics of sandy soil

Characteristics	Values	Standards
D30 in mm	0.26	ASTM D 422 and ASTM D 2487 (2006)
Effective size, in D10 (mm)	0.17	
Mean size, D50 in mm	0.37	
D60 in mm	0.46	
Curvature Constant, Cc	0.81	
Constant of uniformity, Cu	2.62	
Classification (USCS)	SP	
Specific Gravity, Gs	2.63	ASTM D 854 (2006)
Internal Friction angle (Ø)	36	ASTM D3040-04(2006)
γd (min.) (kN /m^3)	14.94	ASTM D 4254 - (2006)
γd (max.) (kN /m^3)	18.33	ASTM D 4253 - (2006)
,e_{max}	0.81	………

Characteristics	Values	Standards
e_{min}	0.55	……….
γd (kN/m^3)	17.03	………
Density, (Relative value) Dr.%	67	………

2.2 Sheet pile wall and batter pile

As shown in Fig. 1, the anchored sheet pile model's measurements are 500 mm in length, 495 mm in width, and 5 mm in thickness. In order to apply a cyclic load laterally, a plate of 490 mm in length, 200 mm in width, and 2 mm in thickness is set up along the sheet pile wall cantilever. As seen in Fig. 2, two batter piles which have a dimension of (30) cm in length with a diameter of 10 mm. They have been used in the assessment, along with two rods measuring 5 mm in diameter and 40 cm in length.

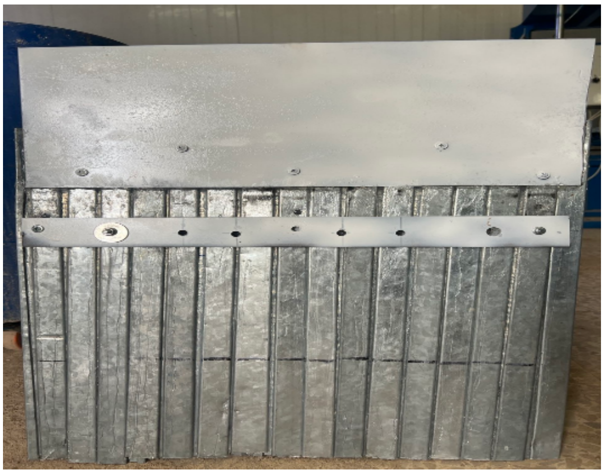

Fig. 1 Sheet pile wall with plate

Fig. 2 Batteries and Rods

2.3 Location of batter pile and wale

Wales has horizontal structural components positioned along the sheet piles, as seen in Fig. 1. The wale, which measured under dimensions of (480, 40, and, 6) mm of length, width, with thickness, respectively. To assist in distributing the sheet piles' lateral earth pressure to the anchors. Between roadways and batter piles, anchored locks are essential connections that provide effective weight transfer, stability, and duration. They enable the efficient passage of both vertical and lateral stresses from the road deck to the batter piles.

2.4 Devices and laboratory test

All devices used in this study are manufactured locally to prototype scale of 1:15 and to simulate the real problem. This study uses various types of equipment, including the following:

2.4.1 Test Container

For this research, a locally-made steel rectangular container of 100 cm in length, 50 cm in width, and 65 cm in height. Two 40 x 500 mm iron bars, each 4 mm thick, were set up across the breadth of the container to allow for easy transportation. Three coats of anti-corrosion paint were applied to the container to provide protection. To enable transportation in all directions, the container's base also has four wheels connected to its corners. A 900 × 550 mm reinforced, shatter-resistant glass panel was set up on the container's front side for testing purposes.

2.4.2 Raining device

Raining device used for preparation of sandy soil with fixed relative density of 67% as seen in Fig. 3.

Fig. 3 Raining devices

2.4.3 The loading device

As shown in Fig. 4, the loading test was made from the following parts:

- Gearbox motor system
- The Electricity Board
- A load cell
- A device for recording data
- Two dial gauges
- A linear variation displacement transducer (LVDT).

ISSN: 2073-9524
Pages:1-6

Fig. 4 Loading device

2.5 Sandy Soil Setting and Test Method

A 5 cm layer of gravel was placed to ensure that water would rise evenly to the sand layers. A layer of water-permeable fabric was also placed to isolate the gravel layer from the sand layers, as shown in the Fig. 5 and Fig. 6. Soil is placed inside a steel container that measures 1000 mm in length, 500 mm in width, and 650 mm in depth. Soil was added to the container in horizontal layers, each 100 mm deep, using a rainfall technique. A relative density of 67% has been utilized to prepare the sand dunes. After that, the container was transferred to the loading equipment. The sheet pile has been placed 30 cm away from the container's location in the passive part. The two rods were positioned with the batter piles on site, and the excavation depth was 300 mm and the embedded depth was 150 mm. As seen in Fig. 8, two rods attached to the batter piles are set up 10 cm below the soil's surface.

Fig. 5 Gravel layer at bottom of container

Fig. 6 Waterproof insulating cloth

Water is introduced into the container through a water solenoid, extending into the gravel layer. This process saturates the sand layers. The saturation height is taken into consideration, as it should be 30-35 cm above the sand layer. This process takes approximately 8-10 minutes, as shown in the Fig. 7. Water is then added from the top on one side, using a perforated water solenoid to control the water pressure so as not to deform the sand layers. The process takes 7-10 minutes, with a water height of 15 cm above the saturation level, as shown in the Fig. 8 and Fig. 9.

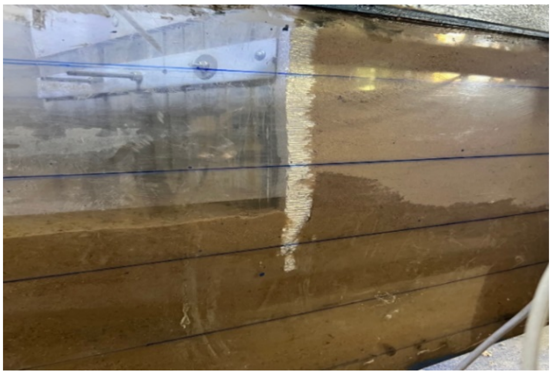

Fig. 7 Saturation process

To determine the sheet pile wall's lateral displacement, an LVDT is set up. For eight minutes and thirty-three seconds, the plate is exposed to cyclic loading that ranges from 1 to 100 cycles at a frequency of 0.2 Hz. As shown in Fig. 12, the load is placed on top of the sheet pile wall.

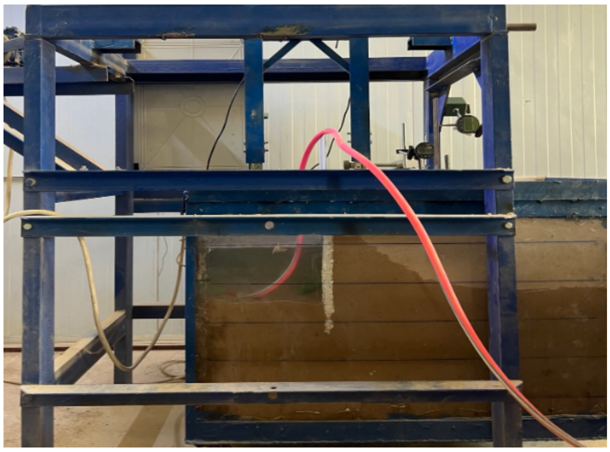

Fig. 8 Seepage process

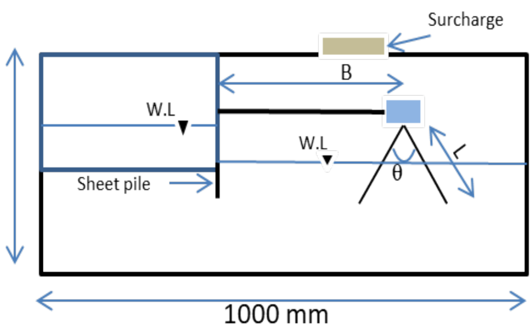

Fig. 9 Cross section for batter pile modeling

ISSN: 2073-9524
Pages:1-6

Fig. 1. Cyclic load test following the preparation of the sheet pile wall and soil

3. Results and Discussion

This section looks at the effects of a lateral cyclic load on the lateral displacement of the sheet pile wall on the sand. Dense sandy soils with a relative density of 67% that have been leveled with a rainfall mechanism were used for the testing. This study looks into a number of factors, including:

1. The batter piles length (300 mm).
2. The pile angle (10°,15°,25°).
3. Spacing of 100 mm between rods.

The ground, 300 mm from the sheet pile, has a 5 kPa surcharge applied to it. All model results are also evaluated against a reference model, the anchor sheet pile wall with a wale, to facilitate comparisons. The free height of the sheet pile wall, expressed by the value of H, is equivalent to the passive failure displacement of 0.005H, or 1.5 mm.

3. 1 Lateral displacement of sheet pile walls

Fig. 11 shows the relationship between cycle number and lateral she anchored sheet Pile wall. It is clear from this figure the increase in number of cycles leads to an increase in lateral displacement, and the increase of angle between anchored Piles caused to reduce lateral displacement of sheet pile Wall. The percent of reduction of lateral displacement of Sheet Pile wall reached 7.1% and 64.30% When the angle between anchored Pile changer from 10° to 15° and 25°. The inclination angles 10° and is between anchored Piles caused lateral displacement of sheet pile to exceed the failure Passive limit but the angle of 25° give lateral displacement below the failure limits.

3.2 Vertical Displacement of strip footing

The relationship between the exponential number and total settlement of strip footing near an anchored sheet pile wall under cyclic load is shown in Fig. 12. The overall settlement of the strip footing increases as the number of cycles increases. The total settlements of the strip footing decreased as the inclination between anchor piles increased. The total settlement was less than allowed when the inclination angles between piles were 15° and 25°, while it was more than permitted when the angle was 10°.

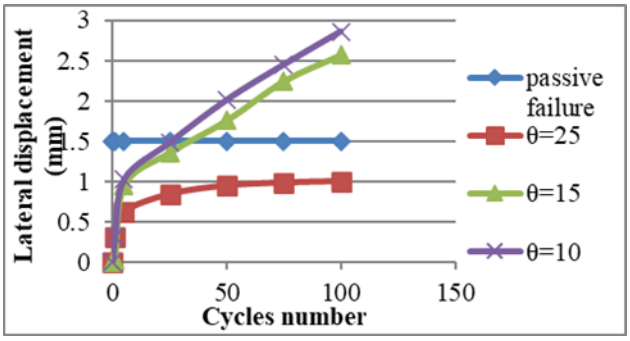

Fig. 11 The lateral displacement of anchored sheet pile wall

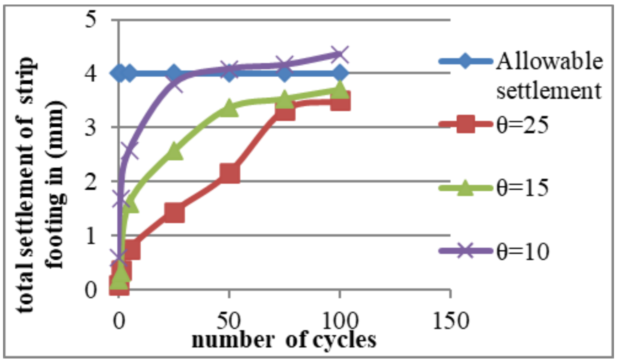

Fig. 12 The vertical displacement of the strip footing

3.3 Tilting of strip footing

Fig. 13 gives the number of cycles versus tilting of strip footing for different angles between piles 10°,15°, and 25°. The increase in angles leads to a decrease in tilting of strip footing. All angles between piles gave tilting below tolerable limits, but angle 25° gave minimum tilting as compared to angles 10° and 15°. During the passive cyclic load, the pore water pressure generated between particles of sandy soil which caused a reduction in shear strength of soil. The reduction of lateral displacement of sheet pile wall when subjected to cyclic load during seepage when increasing angle between batter piles may be due to increase in anchorage resistance between piles and soil. The increase of angle between batter piles leads to put the pile location to be far away from failure zone generated near sheet pile wall.

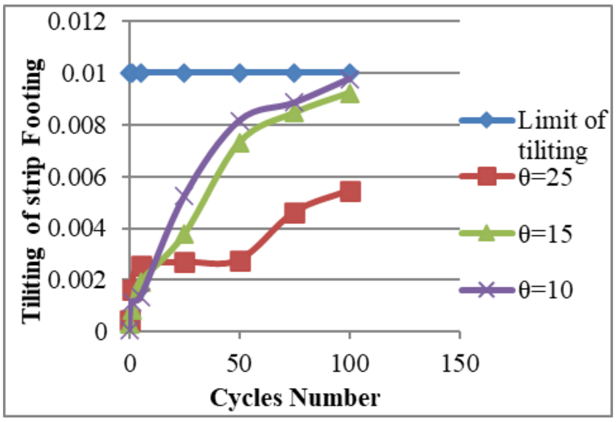

Fig. 13 Tilting of strip footing

4. Conclusions

The main conclusions are as follows:

1. The increase of angles between batter piles from 10° to 15° and 25° lead to decreasing the sheet pile wall's lateral displacement by 7.1% and 64.3%, respectively.
2. The incrementing of angles between anchored batter piles from 10° to 15° and 25° caused a reduction in tilting and settlement of the strip footing near the sheet pile wall.
3. The inclination angle of 25° between batter piles provided best stability of the anchored sheet pile wall subjected to cyclic load and seepage condition.
4. Pore water pressure generated between particles of sandy soil due to passive cyclic load plays a significant influent on whole system of anchored sheet pile wall.

5. Acknowledgements

Special thanks is expressed by the author to the University of Diyala, College of Engineering, for providing the tools and classroom conditions necessary to finish this project. Additionally, thanks are given to everyone who helped this research succeed in an indirect way.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

References

[1] Sivakumar BGL, Munwar BB. Optimum Design of Cantilever Sheet Pile Walls in Sandy Soils Using Inverse Reliability Approach. Computers and Geotechnics 2008; 35(2):134-143.

[2] Eskandari L, Kalantari B. Basic Types of Sheet Pile Walls and their Application in the Construction Industry - A Review. Electronic Journal of Geotechnical Engineering EJGE. 2011; 16(1): 1533-1541.

[3] Singh AP, Chatterjee K. Ground Settlement and Deflection Response of Cantilever Sheet Pile Wall Subjected to Surcharge Loading. Indian Geotechnical Journal 2020; 50:540-549.

[4] King GJW. Analysis of Cantilever Sheet-Pile Walls in Cohesionless Soil. Journal of Geotechnical Engineering ASCE 1995; 121(9):629- 635.

[5] Madabhushi SPG, Chandrasekaran VS. Rotation of Cantilever Sheet Pile Walls. Journal of Geotechnical Engineering ASCE 2005; 131(2):202-212.

[6] Bowles JE. Foundation Analysis and Design. 5th ed. McGraw Hill, New York; 2012.

[7] Conti R, Viggiani GM. A New Limit Equilibrium Method for the Pseudostatic Design of Embedded Cantilevered Retaining Walls. Soil Dynamics and Earthquake Engineering 2013; 50:143-150.

[8] Callisto L. Capacity Design of Embedded Retaining Structures. Géotechnique 2014; 64(3):204-214.

[9] Conti R, Viggiani GMB, Burali DF. Some Remarks on the Seismic Behavior of Embedded Cantilevered Retaining Walls. Geotechnical Earthquake Engineering: Géotechnique Symposium in Print 2015; 64(1):40-50.

[10] Bilgin, Ö. and M.B. Erten, Analysis of anchored sheet pile wall deformations, in Contemporary topics in ground modification, problem soils, and geo-support. 2009. p. 137-144. https://doi.org/10.1061/41023(337)18

[11] Amer, H.A.R., Effect of Wall penetration depth on the behavior of sheet pile walls. 2013, University of Dayton.

[12] Caltabiano S, Cascone E, Maugeri M (2012) Static and seismic limit equilibrium analysis of sliding retaining walls under different surcharge conditions. Soil Dyn Earthq Eng 37:38–55 17.

[13] Georgiadis M, Anagnostopoulos C (1998) Lateral pressure on sheet pile walls due to strip load. J Geotech Geoenviron Eng. 124(1):95–98.

[14] Aparna SNK (2019) Evaluation of model sheet pile wall adjacent to a strip footing—an experimental investigation. Int J Geotech Eng. https://doi.org/10.1080/19386362.2019.1581459

[15] Dave TN, Dasaka SM (2012) "Transition of earth pressure on rigid retaining walls subjected to surcharge loading". Int J Geotech Eng 6:427–435 18. Steenfelt JS,

[16] Moamen A (2020)" Numerical Analysis Of Anchored Sheet Pile Walls". Journal of Al-Azhar University Engineering Sector, 15(55), April, 2020, 594-603.

[17] Tsutomu T. and Arnold V. Seepage failure of sand behind sheet piles – the mechanism and practical approach to analyze. Soils and foundation Japanese geotechnical society. 39(3), 27 – 35, June 1999.

[18] Asmaa A. Effect of Intermediate Sheet Piles in Non-Homogenous Soil on Seepage Properties under Hydraulic Structure Using SEEP/W Program. Tikrit Journal of Engineering Sciences. 23 (3) (2016) 79-90

[19] A. H. Jassim and B. S. Albusoda, “An Experimental Investigation of Batter Pile Performance under Seismic Activity,” Transp. Infrastructure. Geotechnical, 12(1) , p. 55, Jan. 2025, doi: 10.1007/s40515-024-00511-6.

[20] Hassan. O. and Azhar. S, “Investigation of lateral cyclic load capacity of screw pile group in multi clay layer,” Arab. J. Geosci., 16 (9), p. 511, Sep. 2023, doi: 10.1007/s12517-023-11635-3