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**ULTIMATE SHEAR RESISTANCE OF ROCK-SOCKETS IN
THE PRESENCE OF BENTONITE FILTER CAKE**

Ayodya Udara Veediya Bandara Bulathsinhala

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Department of Civil Engineering

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Declaration

I declare that this is my own research work, and this thesis does not incorporate without acknowledgement any material previously published submitted for a degree or diploma in any other university or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Signature:

Date:12.04.2025

A.U.V.B. Bulathsinhala

"The above candidate has carried out research for the PhD Thesis under my supervision. I confirm that the declaration made above by the candidate is true and correct."

Name of Supervisor: Prof. U.G.A. Puswewala

Signature of Supervisor:..... Date:12.04.2025

Name of Co-Supervisor: Dr. P.K. Wanniarachchige

Signature of Co-supervisor:.....Date:12.04.2025

Abstract

In various global regions, and notably in Sri Lanka, Bentonite slurry serves as a prominent drilling fluid and an indispensable agent in the realm of pile and diaphragm wall construction activities. The use of Bentonite slurry in these applications is based on its inherent characteristics as a Bingham fluid, replete with thixotropic properties, which imparts a support for stability enhancement within the bore hole during the intricate phases of drilling, washing, and concreting. Notably, it creates a vital barricade against side wall collapse, thereby safeguarding the structural integrity of the construction site. Moreover, Bentonite serves a dual role, not only as a structural support but also as a versatile coolant and lubricant for drilling tools, ensuring the precision and efficiency of the excavation process. However, despite the numerous advantages conferred by Bentonite slurry in facilitating the pile construction process, some research has identified adverse effects that impact pile performance. This contrast of favourable and unfavourable effects highlights the complex interplay between the unique rheological properties of Bentonite slurry, demanding further investigation to optimize its use in construction activities.

Several researchers actively involved in the oil and construction industries have undertaken extensive investigations into the Bentonite Filter cake (BFC) formation over soil and rock surfaces, as well as its consequences on the performance of piles. However, a substantial proportion of these investigations has been on the development and consequences of filter cakes over sedimentary rocks, including mudstones, siltstones, and sandstones, which are abundant in e.g. North American and Australian regions. These sedimentary rock formations have comparatively higher permeability when contrasted with crystalline rock types. The enhanced permeability of sedimentary rocks facilitates the BFC formation over their surfaces to a greater extent, thereby introducing a unique set of challenges to geotechnical engineering.

The presence of BFCs on the surfaces of sedimentary rocks produces adverse effects, particularly concerning the capacity of rock sockets to provide skin friction. Consequently, construction practices in these geological contexts necessitate the incorporation of higher safety factors to account for the inherent uncertainties that may arise due to the presence of these distinctive infill layers. These uncertainties and associated challenges require a thorough and context-specific approach to pile design and construction in regions of sedimentary rock formations, highlighting the importance of comprehensive research in mitigating potential performance issues and ensuring the structural integrity and safety of construction projects.

Countries like Sri Lanka have used the same conventional pile design practices which are used in other regions, even though it leads to a certain degree of design conservatism. This conservative approach prevails even in the face of the abundant presence of crystalline Metamorphic rocks characterized by higher strength capacities and exceptionally low permeability characteristics. The inherent geotechnical properties of these crystalline Metamorphic rocks, which hinder the formation of BFCs in comparison to sedimentary rock types, warrant a re-evaluation of the prevailing design practices.

Hence, this thesis presents a comprehensive investigation of rock socketed pile design beginning with an examination of Bentonite Filter Cake (BFC) formation over metamorphic rocks. Four distinct metamorphic rock types characterized by their major mineral compositions were collected: Biotite gneiss, Quartzofeldspathic gneiss, Garnet granulite

gneiss, and Charnockitic gneiss. These samples were taken to represent three distinct weathering grades: fresh, slightly weathered, and moderately weathered. In order to investigate the formation of BFC over metamorphic rocks, a pressure chamber was constructed to apply a Bentonite slurry pressure of 0.3 MPa over a period of 12 hours, based on data collected via a questionnaire survey providing the basis for the pressure and its duration. The findings revealed that BFC thicknesses averaged 2 mm on fresh metamorphic rocks and 4 mm on moderately weathered rocks. Among the rock types, Garnet granulite gneiss demonstrated the highest BFC thickness, measuring 2.36 mm on fresh samples, while Quartzofeldspathic gneiss exhibited the greatest thickness in both slightly and moderately weathered conditions. Nonlinear logarithmic models were developed to predict the BFC thickness after 12 hours for all rock types and their weathering grades. To complement these findings, X-Ray Diffraction (XRD) tests were conducted to determine the major mineral compositions of the rock samples across weathering grades. The results indicated no direct correlation between mineral content and BFC formation, leading to the conclusion that BFC development is independent of mineral composition.

To assess the impact of BFC on the shear behaviour at the rock-concrete interface, a direct shear apparatus was fabricated at the University of Moratuwa (UOM) after a thorough literature review on similar apparatus. Direct shear tests were conducted under constant normal loading (CNL) conditions for all four rock types under a range of Bentonite infill conditions. Accordingly, Garnet granulite gneiss exhibited the highest shear strength, while Biotite gneiss displayed the lowest. Considering these findings, Biotite gneiss was selected for further shear testing, and samples were transported to the University of Wollongong (UOW), NSW, Australia for additional testing under CNL conditions. The tests confirmed the accuracy of the results given by the apparatus at the University of Moratuwa and established the base friction angle for the Biotite gneiss-concrete interface as 38.53°.

To further explore the effects of rough surface profiles, the least rough Biotite gneiss profile obtained from pile cores was converted into an equivalent triangular profile with a 3.5 mm asperity height and 80° asperity angles. This profile was tested at UOW under constant normal stiffness (CNS) boundary conditions of 8.5 kN/mm. The highest shear strength recorded was 3.53 MPa for a clean joint at initial normal stress of 0.705 MPa. The critical infill thickness where Bentonite began to govern shear behaviour was determined to be 4.5 mm. A new hyperbolic model was developed to estimate shear strength capacity for varying infill thicknesses of between 0 to 5.5 mm. In subsequent testing, a setup involving a thick steel pipe was used to apply higher CNS conditions of 215 kN/mm. Under these conditions, the maximum shear strength capacity of 9.76 MPa was achieved for the clean Biotite gneiss-concrete joint, while the lowest capacity of 2.86 MPa occurred with a 5.5 mm Bentonite infill. A new hyperbolic model was also developed to predict the maximum shear strength capacity under these higher CNS conditions.

Finally, data from 15 field load tests were utilized to analyse mobilized skin friction from the socketed regions of piles. These results were compared to the newly developed model, which was used to optimize skin friction design for pile rock sockets. Based on the findings, it is recommended to adopt the new model with a safety factor of 2.5, which would result in a potential reduction of construction costs for rock sockets by more than half.

Keywords: Bentonite slurry, Bentonite Filter Cake (BFC), Crystalline Metamorphic rocks, Ultimate shear resistance, Rock-concrete interface, Constant Normal Stiffness, (CNS) Constant Normal Loading (CNL), Shear strength capacity, Rock sockets.

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List of Publications

1. Bulathsinhala, A. U. V. B., & Puswewala, U. G. A. (2022). The Effect of Quartz and Feldspar Minerals on Formation of BFC over Gneissic Bedrocks in Sri Lanka. *ENGINEER*, 55(04), 01-08.
2. Bulathsinhala, A. U. V. B., & Puswewala, U. G. A. Measurement of shear strength capacity of metamorphic rock–concrete interface of pile sockets: a laboratory study. In *International Research Conference* (p. 59).
3. Bulathsinhala, A. U. V. B., & Puswewala, U. G. A. (2024). Formation of BFC over Crystalline Metamorphic Rocks by Means of a Pressure Chamber: A Laboratory Study. *Journal of Testing and Evaluation*, 52(1)

List of Abbreviations

BFC:	Bentonite Filter Cake
CNL:	Constant Normal Loading
CNS:	Constant Normal Stiffness
JRC:	Joint Roughness Coefficient
JCS:	Compressive Strength of Joint Surface
ISRM:	International Society for Rock Mechanics
ASTM:	American Society for Testing and Materials
PET:	Polygon Editing Tool
2D:	Two Dimensions
3D:	Three Dimensions
LVDT:	Linear Variable Differential Transformer
SRC:	Shaft Resistance Co-efficient
UCS:	Unconfined Compressive Strength