

BEHAVIOUR OF ROCK-SOCKETED PILES UNDER AXIAL STATIC AND CYCLIC LOADING

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**DEPARTMENT OF CIVIL ENGINEERING
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**BEHAVIOUR OF ROCK-SOCKETED PILES
UNDER AXIAL STATIC AND CYCLIC LOADING**

by

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Submitted

in the fulfillment of the requirement of the Degree of Doctor of Philosophy

to the



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DEDICATED TO MY BELOVED PARENTS

CERTIFICATE

This is to certify that the thesis entitled "**BEHAVIOR OF ROCK-SOCKETED PILES UNDER AXIAL STATIC AND CYCLIC LOADING**" submitted by **Mr. AMIT JAIN** to the Indian Institute of Technology Delhi, is a record of the bonafide research work carried out by him under our supervision and guidance. This thesis work, in our opinion, has reached the standard, fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and the results presented in this thesis have not been submitted, in part or full, to any other university or institute, for the award of any degree or diploma.

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ABSTRACT

Significant development on infrastructural growth happens in India recently among the various infrastructural sectors such as tall buildings, longest span bridges in high altitude regions (like Chenab bridge), transmission towers and deep basement walls etc. These structures may demand deep foundations for transferring heavy vertical compressive loads, lateral/moment loads and uplift loads at the project sites with poor soil conditions coupled with shallow bed rock levels. When soil cover at these sites is very shallow thick and poor, large magnitude of loads acting in different directions, pile foundations used for supporting these structures may need be socketed into weathered rocks to even hard rocks. The loads coming on these structures and eventually to the rock-socketed piles may act cyclically and dynamically depending on the nature of loading conditions and project locations in seismically active regions. Under such circumstances, it is imperative to understand the response of piles socketed into rock under cyclic and/or dynamic loading as well and design the piles accordingly, in addition to designing those pile for static loading.

In this study, a comprehensive experimental program is designed involving testing of model rock-socketed piles embedded in synthetic weak rock conditions under both static and cyclic axial loading. Model aluminum piles were instrumented to measure the axial strain along the pile length. Synthetic rock blocks were casted considering the different cement-sand mix ratios (1:6 (SR16) and 1:8 (SR18)) which are targeted to simulate weak and soft rock conditions. 72 model experiments (36 static loading tests and 36 cyclic loading tests) were carried out on model pile having of L/D ratios: 6, 9 and 12, indicating different socketing length of piles. In static loading tests, the tests were carried out under different rate of loading by varying the strain rate. The vertical load-settlement response was measured from the static loading tests. It is found that the load carrying capacity of rock-socketed piles increases with an increase in strain rate. The axial pile capacity values

were estimated as per IS code formulae and the values are found to have close agreement with the measured axial pile capacity values under static loading. Cyclic loading tests were conducted by varying different frequencies of loading and Cyclic Loading Ratio (CLR=0.25 and 0.50). The static load ratio (SLR) was maintained in all cyclic loading tests. The accumulated settlement is found to increase with cyclic loading and the effect is prominent upto 100 number of cycles, beyond which the further increase in cyclic settlement is insignificant. The frequency of loading, socketing length and cyclic loading ratio is found to affect the settlement of rock-socketed piles; however, a detailed further study is needed simulating wide range of rock conditions and loading conditions.

Numerical analysis of model-scale dimensions of rock-socketed piles subjected to static and cyclic loading was performed using finite element software, *Plaxis3D*. The model aluminium pile was modelled to behave as linear elastic material using an embedded beam element. Synthetic rock was idealized as a nonlinear material assuming elastic perfectly plastic behavior, using Mohr-Coulomb criterion. Boundary conditions were modelled as per the conventional conditions. The procedures of numerical analysis adopted for studying the response of rock-socketed piles under combined loading was validated using the present model experimental data. The numerical analysis carried out is able to predict the response of piles socketed in weak rocks under static and cyclic loading with a very good accuracy. Numerical analyses were also carried out considering the prototype dimensions of rock-socketed pile and actual rock conditions/properties. Numerical analysis using even the simple Mohr-Coulomb criterion is able to predict the response of rock-socketed pile in weak rock under axial static loading., However, the predicted response of rock-socketed pile under cyclic loading seems to have more error using such simple Mohr-Coulomb criterion. Further work is needed analysing the response of rock-socketed piles under cyclic loading.

सार

भारत में हाल ही में विभिन्न अवसंरचना क्षेत्रों जैसे ऊंची इमारतें, उच्च ऊंचाई वाले क्षेत्रों में सबसे लंबे स्पैन वाले पुल (जैसे चेनाब पुल), ट्रांसमिशन टावर और गहरी बेसमेंट दीवारें आदि में अवसंरचना विकास पर महत्वपूर्ण विकास हुआ है। इन संरचनाओं को भारी ऊर्ध्वाधर संपीड़न भार, पार्श्व/क्षण भार और परियोजना स्थलों पर उथली चट्टान के साथ खराब मिट्टी की स्थिति वाले अपलिफ्ट भार को स्थानांतरित करने के लिए गहरी नींव की आवश्यकता हो सकती है। जब इन साइटों पर मिट्टी का आवरण बहुत उथला मोटा और खराब होता है, तो विभिन्न दिशाओं में कार्य करने वाले भार की बड़ी मात्रा, इन संरचनाओं को सहारा देने के लिए उपयोग किए जाने वाले ढेर नींव को अपक्षयित चट्टानों से लेकर कठोर चट्टानों तक में सॉकेट करने की आवश्यकता हो सकती है। इन संरचनाओं और अंततः चट्टान-सॉकेट वाले ढेर पर आने वाले भार लोडिंग स्थितियों की प्रकृति और भूकंपीय रूप से सक्रिय क्षेत्रों में परियोजना स्थानों के आधार पर चक्रीय और गतिशील रूप से कार्य कर सकते हैं। ऐसी परिस्थितियों में, चक्रीय और/या गतिशील लोडिंग के तहत चट्टान में सॉकेट किए गए ढेर की प्रतिक्रिया को समझना और स्थिर लोडिंग के लिए उन ढेरों को डिजाइन करने के अलावा, तदनुसार ढेर को डिजाइन करना अनिवार्य है।

इस अध्ययन में, एक व्यापक प्रयोगात्मक कार्यक्रम तैयार किया गया है जिसमें स्थैतिक और चक्रीय अक्षीय लोडिंग दोनों के तहत सिंथेटिक कमजोर चट्टान की स्थितियों में एम्बेडेड मॉडल रॉक-सॉकेट वाले ढेर का परीक्षण शामिल है। ढेर की लंबाई के साथ अक्षीय तनाव को मापने के लिए मॉडल एल्यूमीनियम ढेर को यंत्रीकृत किया गया था। विभिन्न सीमेंट-रेत मिश्रण अनुपातों (1:6 (SR16) और 1:8 (SR18)) को ध्यान में रखते हुए सिंथेटिक रॉक ब्लॉकों को कास्ट किया गया था, जो कमजोर और नरम चट्टान की स्थितियों का अनुकरण करने के लिए लक्षित हैं। 72 मॉडल प्रयोग (36 स्थैतिक लोडिंग परीक्षण और 36 चक्रीय लोडिंग परीक्षण) L/D अनुपात वाले मॉडल पाइल पर किए गए: 6, 9 और 12, जो पाइल की विभिन्न सॉकेटिंग लंबाई को दर्शाते हैं। स्थैतिक लोडिंग परीक्षणों में अक्षीय ढेर क्षमता मूल्यों का अनुमान आईएस कोड सूत्रों के अनुसार लगाया गया और पाया गया कि ये मान स्थैतिक लोडिंग के तहत मापी गई अक्षीय ढेर क्षमता मूल्यों के साथ करीब से मेल खाते हैं। लोडिंग की विभिन्न आवृत्तियों और चक्रीय लोडिंग अनुपात (सीएलआर=0.25 और 0.50) को बदलकर चक्रीय लोडिंग परीक्षण किए गए। सभी चक्रीय लोडिंग परीक्षणों में स्थैतिक लोड अनुपात (एसएलआर) बनाए रखा गया। संचित निपटान चक्रीय लोडिंग के साथ बढ़ता पाया गया और प्रभाव 100 चक्रों तक प्रमुख है, जिसके बाद चक्रीय निपटान में आगे की वृद्धि नगण्य

है। लोडिंग की आवृत्ति, सॉकेटिंग लंबाई और चक्रीय लोडिंग अनुपात रॉक-सॉकेट वाले ढेर के निपटान को प्रभावित करते पाए गए हैं; हालांकि, रॉक स्थितियों और लोडिंग स्थितियों की विस्तृत श्रृंखला का अनुकरण करने के लिए एक विस्तृत आगे के अध्ययन की आवश्यकता है।

स्थैतिक और चक्रीय लोडिंग के अधीन चट्टान-सॉकेट वाले ढेरों के मॉडल-स्केल आयामों का संख्यात्मक विश्लेषण, परिमित तत्व सॉफ्टवेयर, प्लैक्सिस 3डी का उपयोग करके किया गया था। मॉडल एल्युमीनियम पाइल को एक एम्बेडेड बीम तत्व का उपयोग करके रैखिक लोचदार सामग्री के रूप में व्यवहार करने के लिए तैयार किया गया था। मोहर-कूलम्ब मानदंड का उपयोग करके, लोचदार पूर्ण प्लास्टिक व्यवहार को मानते हुए सिंथेटिक रॉक को एक गैर-रैखिक सामग्री के रूप में आदर्श बनाया गया था। पारंपरिक स्थितियों के अनुसार सीमा स्थितियों को मॉडल किया गया था। संयुक्त लोडिंग के तहत रॉक-सॉकेट किए गए ढेर की प्रतिक्रिया का अध्ययन करने के लिए अपनाई गई संख्यात्मक विश्लेषण की प्रक्रियाओं को वर्तमान मॉडल प्रायोगिक डेटा का उपयोग करके मान्य किया गया था। किए गए संख्यात्मक विश्लेषण बहुत अच्छी सटीकता के साथ स्थैतिक और चक्रीय लोडिंग के तहत कमजोर चट्टानों में सॉकेट किए गए ढेर की प्रतिक्रिया की भविष्यवाणी करने में सक्षम है। रॉक-सॉकेट किए गए ढेर के प्रोटोटाइप आयामों और वास्तविक रॉक स्थितियों/गुणों पर विचार करते हुए संख्यात्मक विश्लेषण भी किए गए थे। सरल मोहर-कूलम्ब मानदंड का उपयोग करके संख्यात्मक विश्लेषण भी अक्षीय स्थैतिक लोडिंग के तहत कमजोर चट्टान में रॉक-सॉकेट किए गए ढेर की प्रतिक्रिया की भविष्यवाणी करने में सक्षम है। हालांकि, चक्रीय लोडिंग के तहत रॉक-सॉकेट किए गए ढेर की अनुमानित प्रतिक्रिया में ऐसे सरल मोहर-कूलम्ब मानदंड का उपयोग करके अधिक त्रुटि होती है। चक्रीय भार के अंतर्गत चट्टान-सॉकेट वाले ढेरों की प्रतिक्रिया का विश्लेषण करने के लिए आगे और कार्य करने की आवश्यकता है।

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