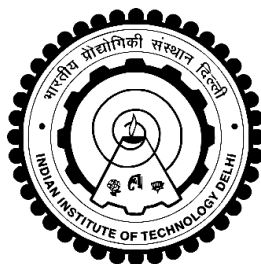


BEHAVIOR OF ROCK-SOCKETED PILES UNDER COMBINED VERTICAL AND LATERAL LOADING

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**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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**BEHAVIOR OF ROCK-SOCKETED PILES UNDER COMBINED
VERTICAL AND LATERAL LOADING**

by

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Department of Civil Engineering

Submitted

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

to the



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MARCH 2020

**DEDICATED TO MY SPIRITUAL MASTER DADASHREEJI
FOR HIS UNLIMITED LOVE AND GRACE WITH MY SENSE
OF GRATITUDE**

CERTIFICATE

This is to certify that the thesis entitled "**BEHAVIOR OF ROCK-SOCKETED PILES UNDER COMBINED VERTICAL AND LATERAL LOADING**" submitted by **Mr. Awadhesh Pratap Singh** 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

The sustained growth in global scenario has led to an increase in the development of high-end infrastructures viz., high-rise buildings, long-span bridges, transmission lines and basement retaining walls. These large infrastructures necessarily require deep foundations due to the requirements of transferring heavy structural loads and the sites having very loose/soft soils. At times, the site conditions and extremely heavy load combinations would demand the piles be socketed in to weathered soft rocks to even hard rocks. Use of rock-socketed piles become inevitable under such circumstances and these piles are subjected to combined loading rather than independent loading. This study designed and fabricated a model experimental setup for conducting 1-g model experiments on model aluminum instrumented piles embedded in synthetic rock subjected to both independent vertical-compressive and lateral loading, and combined vertical-compressive and lateral loading. Synthetic rock was prepared based on a mix design which can simulate the strength and modulus of soft rocks. 24 model tests were carried out on single pile of different socketing length of piles (L/D ratios: 6, 9 and 12). Combined loading tests were done such that the resultant of vertical-compressive and lateral loads is at a constant inclination (30° and 60°). Piles with smooth surface and rough surface were simulated for examining the effect of pile-rock roughness profile. The vertical load-settlement and the lateral load-deflection response were measured from the tests. The bending behaviour of piles under both independent and combined loading was also measured. The deflection profile of the rock-socketed pile was obtained by tracing the tested/failed piles after extracting/splitting them. The axial and lateral resistance of the rock-socketed piles are interpreted and discussed.

Numerical analysis of rock-socketed piles subjected to combined loading was also carried out using PLAXIS 3D software. The pile was idealized as a linear elastic material

whereas the rock was modeled as nonlinear material assuming elastic perfectly plastic behavior. Interface elements were used between rock and pile. The standard fixities were applied to the boundaries. The procedure of numerical analysis adopted for studying the response of rock-socketed piles under combined loading was validated using the field test data reported in the literature (for independent vertical and lateral loading). Further, the analysis is also validated using the present experimental data measured under combined loading. It is found that the pile-rock roughness profile significantly affects the axial resistance of rock-socketed piles, but its effect on lateral resistance is insignificant. It is also found that piles in rock with relative shorted embedded lengths would behave as flexible piles, compared to piles in soils. The combined loading is found to have significant effect on the response of vertical load-settlement and lateral load-deflection. The axial resistance is reduced considerably under combined loading, compared to independent loading, whereas the lateral resistance is found to increase under combined loading for shorter socketing length of piles. However, for longer flexible piles, the effect of combined loading is insignificant. The depth of fixity of rock-socketed piles measured from experimental data varies from 1 to 1.25 times pile diameter, whereas the effective pile length obtained from traced pile deflection profiles varies from 1.0 to 3.5 times the pile diameter. The numerical analysis carried out is capable of predicting the behavior of rock-socketed piles under both independent and combined loading with an excellent accuracy.

सारांश

वैश्विक परिदृश्य में निरंतर वृद्धि के कारण उच्च-अंत अवसंरचना के विकास में वृद्धि हुई है, ऊंची इमारतों, लंबी अवधि के पुलों, ट्रांसमिशन लाइनों और तहखाने की दीवारों को बनाए रखना। भारी संरचनागत भारों को स्थानांतरित करने और बहुत ढीली / मुलायम मिट्टी वाली साइटों की आवश्यकताओं के कारण इन बड़ी अवसंरचनाओं को आवश्यक रूप से गहरी नींव की आवश्यकता होती है। कई बार, साइट की स्थिति और अत्यधिक भारी भार संयोजन, ढेर नरम सॉकेट में भी सॉकेट किए जाने की मांग करेंगे। ऐसी परिस्थितियों में रॉक-सॉकेटेड पाइल कठोर रॉक में अपरिहार्य हो जाते हैं और इन पाइल को स्वतंत्र लोडिंग के बजाय संयुक्त लोडिंग के अधीन किया जाता है। इस अध्ययन में मॉडल एल्यूमीनियम इंस्ट्रूमेंट पाइल पर 1-जी मॉडल प्रयोगों के संचालन के लिए एक मॉडल प्रायोगिक सेटअप तैयार किया गया है। सिंथेटिक रॉक दोनों स्वतंत्र ऊर्ध्वाधर-संपीड़ित और पार्श्व लोडिंग के अधीन है, और ऊर्ध्वाधर-संकुचित और पार्श्व लोडिंग संयुक्त है। सिंथेटिक रॉक एक मिक्स डिजाइन के आधार पर तैयार किया गया था जो नरम चट्टानों की ताकत और मापांक को अनुकरण कर सकता है। 24 मॉडल परीक्षण अलग-अलग लंबाई के पाइल (एल / डी अनुपात: 6, 9 और 12) के एकल पाइल पर किए गए थे। संयुक्त लोडिंग परीक्षण ऐसे किए गए थे कि ऊर्ध्वाधर-संपीड़ित और पार्श्व भार का परिणाम निरंतर झुकाव (30° और 60°) पर है। पाइल-रॉक खुरदरापन के प्रभाव की जांच के लिए चिकनी सतह और खुरदरी सतह वाले पाइलों का अनुकरण किया गया। ऊर्ध्वाधर भार-निपटान और पार्श्व भार-विक्षेपण को परीक्षणों से मापा गया। स्वतंत्र और संयुक्त लोडिंग के तहत पाइल के झुकने वाले व्यवहार को भी मापा गया। रॉक-सॉकेटेड पाइल का डिफेक्शन प्रोफाइल परीक्षण / असफल पाइल को निकालने / विभाजित करने के बाद ट्रेस करके प्राप्त किया गया था। रॉक-सॉकेटेड पाइल के अक्षीय और पार्श्व प्रतिरोध की व्याख्या और चर्चा की जाती है।

संयुक्त लोडिंग के अधीन रॉक-सॉकेटेड पाइल्स का संख्यात्मक विश्लेषण भी PLAXIS 3 डी सॉफ्टवेयर का उपयोग करके किया गया था। पाइल को एक लीनियर इलास्टिक मैटीरियल के रूप में आदर्श बनाया गया था, जबकि रॉक को नैलिनियर मटीरियल के रूप में तैयार किया गया था, जिसमें इलास्टिक पूरी तरह से प्लास्टिक का व्यवहार था। रॉक और पाइल के बीच इंटरफ़ेस तत्वों का उपयोग किया गया था। मानक निर्धारण सीमाओं के लिए लागू किए गए थे। संयुक्त लोडिंग के तहत रॉक-सॉकेटेड पाइल की प्रतिक्रिया का अध्ययन करने के लिए अपनाया गया संख्यात्मक विश्लेषण की प्रक्रिया को साहित्य में रिपोर्ट किए गए फ़ील्ड परीक्षण डेटा (स्वतंत्र ऊर्ध्वाधर और पार्श्व लोडिंग के लिए) का उपयोग करके मान्य किया गया था। इसके अलावा, संयुक्त लोडिंग के तहत मापा गया वर्तमान प्रायोगिक डेटा का उपयोग करके विश्लेषण को भी मान्य किया गया है। यह पाया गया है कि पाइल-रॉक खुरदरापन प्रोफ़ाइल रॉक-सॉकेटेड पाइल्स के अक्षीय प्रतिरोध को काफी प्रभावित करता है, लेकिन पार्श्व प्रतिरोध पर इसका प्रभाव नगण्य है। यह भी पाया जाता है कि सापेक्ष शॉर्टेड एंबेडेड लंबाई वाली चट्टान में पाइल मिट्टी में पाइल की तुलना में लचीले पाइल के रूप में व्यवहार करेगा। संयुक्त लोडिंग में ऊर्ध्वाधर भार-निपटान और पार्श्व भार-विक्षेपण की प्रतिक्रिया पर महत्वपूर्ण प्रभाव पाया जाता है। अक्षीय प्रतिरोध स्वतंत्र लोडिंग की तुलना में संयुक्त लोडिंग के तहत काफी कम हो जाता है, जबकि पार्श्व प्रतिरोध कम लोडिंग पाइल्स के लिए संयुक्त लोडिंग के तहत वृद्धि के लिए पाया जाता है। हालांकि, लंबे समय तक लचीले पाइल के लिए, संयुक्त लोडिंग का प्रभाव नगण्य है। प्रायोगिक डेटा से मापी गई रॉक-सॉकेटेड पाइल्स की शुद्धता की गहराई 1 से 1.25 गुना के व्यास से भिन्न होती है, जबकि ट्रेस किए गए पाइल विक्षेपण प्रोफ़ाइल से प्राप्त प्रभावी पाइल की लंबाई 1.0 से 3.5 गुना के व्यास से भिन्न होती है। संख्यात्मक विश्लेषण एक स्वतंत्र सटीकता के साथ स्वतंत्र और संयुक्त लोडिंग दोनों के तहत रॉक-सॉकेटेड पाइल के व्यवहार की भविष्यवाणी करने में सक्षम है।

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