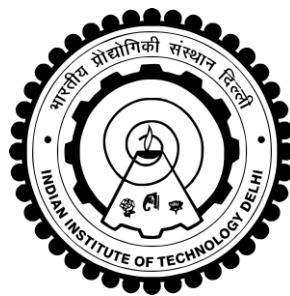


**STUDIES ON USE OF SHREDDED TYRE CHIPS AS
AGGREGATES IN ORDINARY AND ENCASED STONE
COLUMNS**

TANWEE MAZUMDER



**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
JULY 2019**

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by

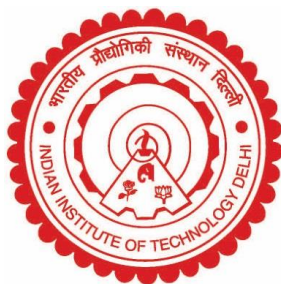
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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2019

CERTIFICATE

This is to certify that the thesis entitled, “**STUDIES ON USE OF SHREDDED TYRE CHIPS AS AGGREGATES IN ORDINARY AND ENCASED STONE COLUMNS**” submitted by **Ms. Tanwee Mazumder** to the Indian Institute of Technology Delhi, is a record of bonafide research work carried out by her under my 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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ACKNOWLEDGEMENTS

Firstly, as I complete my research work, I would like to convey my heartfelt regards and gratitude and sincere thanks to my supervisor, Dr. R. Ayothiraman for his invaluable guidance, constant support and co-operation, endless encouragement and motivation throughout the entire course of my work. Every discussion with him and all his suggestions have been very helpful in shaping my vague ideas into proper validation. I extend my deepest gratitude to my guide for all the painstaking efforts in correcting the thesis and manuscripts, which added more value, enriching my learning.

I am thankful to Ashok Kumar Rolaniya and Nishant Neeraj (former M.Tech students) for all their help and co-operation while performing the model tests.

I express my sincere thanks to Student Research Committee members Prof. Rakesh Khosa, Prof. J. T. Shahu and Prof. B. P. Patel for all their valuable suggestions and support during the entire period of my research work. Their inputs have added more clarity and value to my study.

I extend my sincere gratitude to all faculty of the Department of Civil Engineering, IIT Delhi, who have enriched my knowledge in some way or the other. My heartfelt thanks to Prof. Manoj Datta, Dr. Bappaditya Manna, Dr. Tanusree Chakraborty, for the many ideas gained and lessons learnt during my course-work. I am deeply thankful to Prof. Emeritus K. G. Sharma, Prof. G. V. Ramana, Prof. R. R. Kalaga and Dr. Prashanth Vangla for their support and motivation.

I extend my gratefulness to the staff of Geotechnical Engineering Laboratory, Rock Mechanics Laboratory and Geology Laboratory especially Mr. Manoj Kumar Neelam, Mr. D. Biswas, Mr Alok, Mr. D. S. Gusain, Mr Dinesh, Mr Gopi for all their help and assistance throughout the duration of my experimental work.

I am also deeply indebted and extend my sincere regards to Prof. Ashoke Kumar Sarkar, Senior Professor & Director, BITS Pilani, Pilani Campus; Prof. Bishwajeet Bhattacharjee, Dept. of Civil Engineering, IIT Delhi; Prof. Ashim Kanti Dey, Dept. of Civil Engineering, NIT Silchar; Dr. Partha Pratim Sarkar, Assistant Professor, NIT Agartala and Dr. Pritam Saha, Assistant Professor, IEST Shibpur for their bountiful affection, support and inspiration.

I feel immensely happy to acknowledge and appreciate all the support and camaraderie extended by my seniors and friends especially Dr. Renu Bhaskar, Nivya Basheer, Dr. Romanbabu Oinam, Mamata Mohanty and Dr. Raghavendra Sahu. I would like to specially thank Mr Sumeet Mahajan (Ph.D student) for having spared his valuable time and immensely helping me with *Plaxis 3D software*. I am also very thankful to my juniors Vinay Kumar Singh and Ashwinth Raj (Ph.D students), who have been a good company, for all their help and co-operation. I acknowledge my greatest regards to all those who have contributed directly or indirectly in the course of my research work.

Lastly, I am filled with profound indebtedness and regards for my parents and my sister for their constant love, care, encouragement, support, motivation, inspiration and countless other efforts in making me a more grounded and a better person and helping me aspire to dream and achieve greater heights. I won't be able thank them enough for all the trials and pain they have taken to pull me through the thick and thin, highs and lows of life and help me look at the brighter side, for being my best friends and confidante and ensuring I keep moving ahead in the journey of life.

Finally, I thank the Almighty from the deepest core of my heart for having bestowed me with a wonderful family, caring teachers, great friends and a privileged life. I pray that he continue to shower his choicest blessings.

Date: 05-07-2019

Tanwee Mazumder

ABSTRACT

With industrialisation taking at a rapid pace, there has been an ever increasing scarcity of the land/ground of appreciable ultimate carrying capacity that can support heavy load of built-up structures, equipment, vehicles, the load of aeroplanes on the runway, the heavy cargo at the ports, embankments, oil storage tanks, etc. Therefore, to enable the execution of such infrastructural activities, more and more soft ground is being utilised. The technique of ground improvement by construction of stone column is a widely accepted method to stabilize soft ground. However, in most cases the stone columns are made of stone aggregates, which being a natural resource, has been depleting due to over-utilisation. Few instances of using construction waste, building debris and spent railway ballast as alternate materials to stone column aggregates are available. In this study the use of an alternate material, i.e. shredded tyre chips, as aggregates in stone columns is explored. The present study therefore emphasizes on the behavior of stone columns made of different mix proportions of stone aggregates and shredded tyre chips. 70 model tests were conducted to measure the load-settlement behavior of ordinary as well as encased columns made of such aggregates under quick and slow loading conditions. The columns are encased with geonet when the quick loading tests are performed. For the slow loading tests, the encasements include geonet, galvanised wire mesh and steel nails. Model tests were performed to analyse the load-settlement behavior of ordinary as well as encased columns in both conditions of loading. To understand the bulging behavior of columns, numerical analysis was performed with *Plaxis 3D* software. Comparative analysis of the behavior of columns for the respective mix proportions are carried out to understand the effect of rate of loading. Finally the efficiency of the ordinary and encased columns is obtained with respect to ordinary conventional columns

i.e. 100S columns both for quick and slow loading. From the efficiency factor, the optimum amount of tyre chips that can replace stone aggregates in stone column without affecting the ultimate load carrying capacity of the composite ground is determined. The results obtained from the model experiments report that under quick loading, the ordinary columns made of greater proportion of stone aggregates exhibit higher load carrying capacity. This is due to the higher stiffness and lower compressibility of stone aggregates over shredded tyre chips. For the geonet encased columns in quick loading tests, the load carrying capacity of the composite ground is further enhanced as compared to that with ordinary columns. Significant enhancement in the load carrying capacity of the columns is observed with the construction of encased columns, a few of such encased columns exhibit similar load carrying capacity. However, the improvement in 100T-QESC is the most significant. Also, comparison of the efficiency with respect to smaller columns helps to infer that smaller diameter columns perform better than larger diameter column. The efficiency plot of the ordinary and encased columns concludes that about 50% - 100% replacement of the stone aggregates with shredded tyre chips by volume is possible with the provision of encasement. From the numerical analysis of ordinary and encased column under quick loading, it is seen that with encasement of the columns, the aggregates exhibit significantly higher modulus of elasticity and hence the stiffness of columns improve. The ordinary columns composed of dominant proportion of stone aggregates bulge predominantly closer to the ground surface while the bulging increases and becomes uniform over the entire depth for columns containing greater quantity of tyre chips (more than about 30% by volume). For the encased columns, the bulging is negligible for columns composed of mix proportions with dominant volume of stone aggregates (upto about 70% by volume), but for the columns composed of more than 30% shredded tyre chips, the bulging behavior is similar to that of ordinary columns composed

primarily of stone aggregates. Thus, encasing the columns helps to reduce bulging/lateral deformation and increases stiffness. Moreover, the encased columns behave similar to that of conventional columns which only leads to the fact that such columns composed primarily of tyre shreds behave similar to conventional columns when provided with suitable encasement. Also, there is a huge decrease in the settlement with the provision of encasement in columns. Thus, with respect to the bulging behavior of columns, partial to complete replacement of tyre chips with stone aggregates by about 70-100% by volume is possible with encasement of desired stiffness.

सार

औद्योगिकीकरण तीव्र गति से होने के कारण, भूमि की बढ़ती हुई कमी हुई है। जमीन जो निर्मित संरचनाओं, उपकरणों, वाहनों, रनवे पर हवाई जहाज के भार, बंदरगाहों पर भारी माल, तटबंधों, तेल भंडारण टैंकों, आदि के भारी भार का समर्थन कर सकती है, दुर्लभ हो रही है। इसलिए इस तरह की अवसंरचनात्मक गतिविधियों के निष्पादन को सक्षम करने के लिए, अधिक से अधिक सॉफ्ट ग्राउंड का उपयोग करने की आवश्यकता है। स्टोन कॉलम के निर्माण से जमीनी सुधार की तकनीक इस तरह के सॉफ्ट ग्राउंड को स्थिर करने के लिए एक व्यापक रूप से स्वीकार की गई विधि है। हालाँकि ज्यादातर मामलों में स्टोन कॉलम स्टोन के समुच्चय से बने होते हैं, जो एक प्राकृतिक संसाधन और अधिक उपयोग के कारण घट रहे हैं। स्टोन कॉलम समुच्चय के लिए वैकल्पिक सामग्री के रूप में कन्स्ट्रक्शन और डेमोलिशन वेस्ट और इस्तेमाल किए गए रेलवे बॉलस्ट का उपयोग करने के कुछ उदाहरण उपलब्ध हैं। इस अध्ययन में एक वैकल्पिक सामग्री, अर्थात् कटे हुए टायर के चिप्स का उपयोग किया गया है, जिससे स्टोन कॉलम में समुच्चय का पता लगाया गया है। इसलिए वर्तमान अध्ययन में स्टोन कॉलम के व्यवहार को समझने के लिए स्टोन्स और कटे हुए टायर के चिप्स के अलग-अलग मिक्स अनुपात से बने स्टोन कॉलम के व्यवहार पर जोर दिया गया है। 70 मॉडल परीक्षण किए गए हैं जिसमें इन मिक्स अनुपात का इस्तेमाल करके सामान्य और एनकेस्टड कॉलमों का व्यवहार क्लिक लोडिंग और स्लो लोडिंग पर किया गया है। जब क्लिक लोडिंग परीक्षण किया जाता है तो कॉलम जियोनेट के साथ एनकेस्टड होते हैं। स्लो लोडिंग से लोडिंग परीक्षणों के लिए एंक्रेमेंट में जियोनेट, वाइयर मेश और स्टील नेल्स शामिल हैं। लोडिंग की दोनों स्थितियों में साधारण और साथ ही एनकेस्टड कॉलम के लोड-सेटलमेंट व्यवहार का विश्लेषण करने के लिए मॉडल परीक्षण किए गए थे। कॉलम के बल्लिंग व्यवहार को समझने के लिए, प्लाक्सिस 3डी सॉफ्टवेयर के साथ संख्यात्मक विश्लेषण किया गया था। लोडिंग की दर के प्रभाव को समझने के लिए संबंधित मिश्रण अनुपात के लिए कॉलम के व्यवहार का विश्लेषण किया गया है। अंत में साधारण और एनकेस्टड कॉलमों की दक्षता सामान्य पारंपरिक कॉलमों के संबंध में प्राप्त की जाती है अर्थात् क्लिक और स्लो गति से लोड करने के लिए 100एस कॉलम। दक्षता कारक से, टायर चिप्स की इष्टतम मात्रा जो कि स्टोन कॉलम में स्टोन के समग्र को प्रतिस्थापित कर सकती है, बिना अल्टिमेट लोड के बेरिंग कैपेसिटी को प्रभावित किए हुए निर्धारित किया गया है। मॉडल प्रयोगों से प्राप्त परिणामों की रिपोर्ट है कि क्लिक लोडिंग के तहत, स्टोन समुच्चय के अधिक अनुपात से बने साधारण कॉलम उच्च भार वहन क्षमता प्रदर्शित करते हैं। यह कड़े टायर चिप्स पर पत्थर समुच्चय की उच्च स्टीफनेस और

कम कंप्रेज़िबिलिटी के कारण है। क्रिक लोडिंग परीक्षणों में जियोनेट एनकेस्ट कॉलमों के लिए, सामान्य स्तंभों की तुलना में मिश्रित जमीन की लोड सहने की कैपैसिटी को और बढ़ाया जाता है। कॉलम्स की लोड सहने की कैपैसिटी में महत्वपूर्ण वृद्धि को एनकेस्ट कॉलम क निर्माण से पेया जाता है, ऐसे कुछ संलग्न स्तंभ समानलोड सहने की कैपैसिटीको प्रदर्शित करते हैं। हालांकि, 100त-क्रेसक़ में सुधार सबसे महत्वपूर्ण है। साथ ही, छोटे कॉलम के संबंध में दक्षता की तुलना यह अनुमान लगाने में मदद करती है कि छोटे व्यास के कॉलम बड़े व्यास के कॉलम से बेहतर प्रदर्शन करते हैं। साधारण और एनकेस्ट कॉलम्स की दक्षता प्लॉट यह निष्कर्ष निकालती है कि लगभग 50% - 100% मात्रा द्वारा कटे हुए टायर के चिप्स के साथ स्टोन के एग्रीगेट का प्रतिस्थापन एन्सेसमेंट के प्रावधान के साथ संभव है। क्रिक लोडिंग के तहत साधारण और एनकेस्टकॉलम्स की स्टीफनेस में सुधार होता है। पत्थर के प्रमुख अनुपात से बने साधारण कॉलम मुख्य रूप से बल्लज होते हैं, जबकि बल्लिग मात्रा में टायर की चिप्स (लगभग 30% से अधिक मात्रा से अधिक) वाले स्तंभों के लिए पूरी गहराई पर समान रूप से बल्लज होती है। एनकेस्ट कॉलम के लिए बल्लिग, पत्थर एग्रीगेट (वॉल्यूम द्वारा 70% तक) के प्रमुख अनुपात के साथ मिश्रण अनुपात से बने cओलुम्स के लिए नगण्य है, लेकिन 30% से अधिक कटा हुआ टायर चिप्स से बना कॉलम्स के लिए बल्लिग व्यवहार साधारण कॉलम्स के समान है जिसकी रचना मुख्य रूप से स्टोन समुच्चय की है। इस प्रकार, कॉलम को एनकेसिंग करने से बल्लिग/लॅटरल डीफोर्मेशन को कम करने में मदद मिलती है और स्टीफनेस भी बढ़ जाती है। इसके अलावा, एनकेस्ट कॉलम पारंपरिक स्तंभों के समान व्यवहार करते हैं, जो केवल इस तथ्य की ओर जाता है कि मुख्य रूप से टायर के टुकड़े से बने ऐसे कॉलम पारंपरिक कॉलम के समान व्यवहार करते हैं जब उपयुक्त एन्सेसमेंट प्रदान किया जाता है। इसके अलावा, स्तंभों में अतिक्रमण के प्रावधान के साथ निपटान में भारी कमी है। इस प्रकार, स्तंभों के बल्लिग व्यवहार के संबंध में, मात्रा द्वारा लगभग 70-100% तक स्टोन के साथ टायर चिप्स के पूर्ण प्रतिस्थापन के लिए आंशिक रूप से वांछित स्टीफनेस के अलगाव के साथ संभव है।

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LIST OF NOTATIONS

c	shear strength (undrained)
c'	shear strength of kaolinite clay (drained)
c_u	undrained shear strength of kaolinite clay
c_{uf}	undrained shear strength of the clay in field study
c_{ul}	undrained shear strength of the clay in literature
c_{um}	undrained shear strength of the clay in present model study
ϕ	angle of internal friction (undrained)
ϕ'	angle of internal friction (drained)
ϕ_m	angle of friction of the aggregates in present model study
ϕ_f	angle of friction of the aggregates in field study
ϕ_l	angle of friction of the aggregates in literature
μ	Poisson's ratio
τ	shear stress
B	test tank width (reported in literature)
D	test tank diameter (reported in literature)
D_c	diameter of stone column (reported in literature)
d	diameter of the column
d_s	size of aggregates
d_{smax}	maximum size of aggregates
E	Modulus of elasticity
EB	end-bearing
G	group columns

H	test tank height (reported in literature)
l	length of the column
n	prototype stone column diameter/model test column diameter
l/n^3	scale factor for force (for 1g laboratory)
Q	overall safe load on each column and its tributary soil
Q_1	safe load on column alone (against bulging)
W	width of the test tank
z	depth of clay bed (reported in literature)
IS	Indian Standard
100S	100% stone aggregates
70S+30T	70% stone aggregates + 30% shredded tyre chips
50S+50T	50% stone aggregates + 50% shredded tyre chips
30S+70T	30% stone aggregates + 70% shredded tyre chips
100T	100% shredded tyre chips
OSC	ordinary stone columns
ESC	encased stone columns
QOSC	OSC under quick loading
QESC	ESC under quick loading
SOSC	OSC under slow loading
SGESC	geonet-encased columns under slow loading
SWESC	galvanised wire mesh-encased columns under slow loading
SIESC	steel-nails reinforced columns under slow loading