論文 / 著書情報
Article / Book Information

題目(和文)	SC杭の曲げおよびせん断性能
Title(English)	Flexural and Shear Performance of Steel-encased Precast Spun Concrete Piles
著者(和文)	Thusoo Shreya
Author(English)	Shreya Thusoo
出典(和文)	学位:博士(学術), 学位授与機関:東京工業大学, 報告番号:甲第11662号, 授与年月日:2020年9月25日, 学位の種別:課程博士, 審査員:WIJEYEWICKREMA ANIL,河野 進,岩波 光保,竹村 次朗,佐々木 栄一
Citation(English)	Degree:Doctor (Academic), Conferring organization: Tokyo Institute of Technology, Report number:甲第11662号, Conferred date:2020/9/25, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Tokyo Institute of Technology

Flexural and Shear Performance of Steel-encased Precast Spun Concrete Piles

by

Shreya Thusoo

Doctoral Committee:

Prof. Susumu Kono
Assoc. Prof. Anil C. Wijeyewickrema
Assoc. Prof. Jiro Takemura
Assoc. Prof. Eiichi Sasaki
Prof. Mitsuyasu Iwanami

A dissertation submitted in partial fulfillment of the requirements for the Doctor of Philosophy Degree

August 2020

ABSTRACT

The thesis presents a comprehensive study on the flexural and shear performance of steel-encased precast spun concrete (SC) piles using large-scale experimental data and analytical modeling. The research mainly focuses on the assimilation of experimental data, improvement of currently available flexural and shear design guidelines, and development of numerical models to simulate the flexural behavior of SC piles. The results from this study are valuable and useful for engineers designing foundations in areas with high seismicity.

The study first focuses on analyzing the test data from previous experiments on 11 SC pile specimens to investigate the bending moment capacity, damage process, and failure criteria for flexural failure. The main parameters include the axial load ratio (0–0.35), steel casing thickness (4.5–6.0 mm), concrete layer thickness (50–68 mm), and filling material (hollow, cement paste, concrete). The test results show that concrete crushing and local buckling of steel are the major factors influencing the bending capacity of SC piles, given that global buckling is not permitted. The damage at failure state is characterized by local buckling of steel between 0–100 mm, concrete crushing at the outer layer of concrete between 0–120 mm, and spalling at the inner layer of concrete between 0–240 mm, all from the base. High curvature demands are seen to be concentrated between 0–125 mm from the base for drift ratios less than 1.5%. Further, it is observed that governing factor changes from concrete crushing to steel local buckling with an increase in axial load or reduction in steel to concrete strength ratio. It is found that filling the core with a low-cost, low-strength material prevents the spalling of the inner line of concrete and, consequently, increases the drift and ductility performance.

The applicability of stress distribution-based methods given in available guidelines by AIJ (2008), Eurocode 4 (2004), and ANSI/AISC 360-16 (2016) for bending capacity of columns/composite members under axial-flexural loads is investigated. The applicability of strain compatibility-based method in the draft guidelines for SC piles by the AIJ (2020) committee is also examined. For this purpose, a database of 79 bending tests on SC piles, including tests from literature and pile manufacturers in Japan, is organized. The scope of the dataset is defined by characteristic parameters, axial load ratio (-0.4–0.5), section slenderness ratio (36–133), member slenderness ratio (6.0–18.8), concrete compressive strength (81–123 MPa) and steel tensile strength (301–521 MPa). Modifications are proposed to the drafted guidelines for SC piles to give conservative predictions with an error of less than 20% for all tests in the database.

The development of a fiber-based finite element model of SC piles is carried out to simulate the moment-drift behavior under axial-flexural loads up to and beyond the peak response. The model is characterized by a single beam-column element in the damage zone at the base. The stress-strain relationship of fiber elements of steel in the damage zone follows a pipe buckling model. For this, a hysteretic model for steel is developed with a linear falling branch and a constant stress branch after initiation of buckling. The fiber elements of steel in the low damage zone do not undergo buckling. The enhancement of concrete strength due to confinement by steel casing is considered by using a confined concrete model such that the reduction in confinement due to the hollow core is also taken onto account. The sectional behavior is validated by comparison with the moment-curvature responses from five simply supported bending tests covering axial load ratios of -0.4 to 0.5 times the section capacity. Whereas the member behavior is validated by comparison with the moment-drift responses from thirteen tests covering simply supported and cantilevered bending tests, hollow and filled-core specimens, and axial load ratios of -0.4 to 0.5 times the section capacity. It is found that the model can simulate the flexural behavior of SC piles for axial load ratios of 0 to 0.5 with good accuracy.

Furthermore, to investigate the performance of SC piles under shear loads, shear tests on 400 diameter SC piles were conducted with the axial load ratio as the main parameter. The objective of these tests is to gather experimental data on the shear behavior of SC piles to investigate the shear capacity, damage process, and failure criteria for shear failure. For the case of SC pile with high compression axial load ratio of 0.5 and shear span to diameter ratio of 0.5, a brittle shear force vs. drift response and shear failure is reported, accompanied by the sudden loss of axial capacity to half of the initial value. From the extent of shear yielding along the cross-section, 1/2 of the area of steel is found to be effective in resisting shear at the failure. Additionally, it is confirmed that the design of SC piles is governed by the bending capacity rather than the shear capacity in most design situations.

ACKNOWLEDGEMENT

I would like to express my sincere appreciation and deep gratitude to my supervisors Prof. Susumu Kono and Assoc. Prof. Anil C. Wijeyewickrema for their continuous advice supporting my research and invaluable guidance during my study at Tokyo Institute of Technology.

I would like to express my deep appreciation to the examiners of my dissertation, Assoc. Prof. Jiro Takemura, Assoc. Prof. Eiichi Sasaki, and Prof. Mitsuyasu Iwanami for taking time from their busy schedule to read and give constructive feedback to my thesis. Their helpful comments and suggestions significantly contributed to improving the work and my understanding of the subject.

I would like to thank to the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan for the scholarship and support. I would also like to thank "Seismic Performance of Concrete Pile Work Group” in Architectural Institute of Japan (AIJ) and “Deformation Performance Evaluation of Pile Work Group” in COPITA for their valuable opinions, and the SOFTech Consortium, Japan, and the Tokyo Institute of Technology, Japan for their support in carrying out this research.

My special thanks to Prof. Rajesh Kumar from IIT (BHU), who always encouraged and supported me and also introduce me to the research world. I also would like to thank Prof. David Mukai of University of Wyoming, Dr. Junji Hamada of Takenaka Corporation, Dr. Yoichi Asai and Mr. Kiyoshi Miyahara of Concrete Pile Installation Technology Association (COPITA), Dr. Katsumi Kobayashi of Fujita Corporation, and Dr. Hidekazu Watanabe of Building Research Institute (BRI) for their discussions and invaluable suggestions which have significantly helped me in advancing the research.

Thanks to Dr. Taku Obara, Ms. Chanipa Netrattana, Mrs. Yuki Hayakawa, fellow students and friends at Kono Laboratory who helped me and supported me during my research work. I greatly appreciate what all these people have done for me.

Finally, my sincerest gratitude goes out to my family that always supported and encouraged me to pursue my dream.

List of Publications

Journal papers

- **Thusoo S.**, Obara T., Kono S., Miyahara K. **(2020)**; Design models for steel-encased high-strength precast concrete piles under axial-flexural loads. *Engineering Structures*. (Under review, Submitted on 21 May, 2020)
- **Thusoo S.**, Kono S., Hamada J., Asai Y. **(2020)**; Performance of precast hollow steel-encased high-strength concrete piles. *Engineering structures*, Vol: 204, 109995.
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- Obara T., **Thusoo S.**, Kono S., **(2020)**; Chapter 7 SC piles: Moment capacity of steel encased concrete piles. in *Report for the precast concrete pile committee of AIJ*. (Draft)

Conference papers

- **Thusoo S.**, Kono S., Hamada J., Asai Y., Mukai D., **(2020)**; Experimental investigation of hollow precast steel-encased concrete piles. *17th World Conference on Earthquake Engineering (17WCEE)*, scheduled for 13-18 Sept, Sendai, Japan, paper no. C000666.
- **Thusoo S.**, Tanaka H., Otaki T., Kono S., Watanabe H., Hayakawa T., Hirade T., Mukai D., Mukai T. **(2018)**; Analysis of bending behavior of hollow and precast steel encased concrete piles using fiber based models. *11th US National Conference on Earthquake Engineering (11NCEE)*, 25-29 June, Los Angeles, California, ID 394.
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- Kasumi F., Kono S., Obara T., Miyahara K., **Thusoo S.**, Mukai D. (**2020**); Axial compression test on SC piles. *Architectural Institute of Japan Annual Convention*, scheduled for 8-10 Sept., Chiba, Japan.
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