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

by
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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.

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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.
- **Thusoo S.**, Maithi P.R. and Rai A. (2014); Foam concrete - A better replacement to the traditional heavy concrete. *i-manager's Journal on Civil Engineering*, Vol:4, No:1, 1-5.

Reports

- 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.
- **Thusoo S.**, Tanaka H., Otaki T., Kono S., Watanabe H., Hayakawa T., Hirade T., Mukai D., and Mukai T. **(2017)**; Numerical study on seismic structural performance of steel encased concrete piles. *19th Taiwan-Japan-Korea Joint Seminar on Earthquake Engineering for Building Structures (19SEEBUS)*, 08-09 Sept., Korea, 167p.
- **Thusoo S.**, Modi, K., Kumar, R., Madahar H. (**2015**); Response of Buildings with Soil-Structure Interaction with Varying Soil Types. *XIII International Conference on Structural Engineering, Construction and Management (ICSECM)*, 8-9 April, Dubai, UAE.

Extended abstracts

- **Thusoo S.**, Kono S., Obara T., Mukai D. **(2020)**; Verification of strength of steel-encased high-strength concrete piles under combined axial and flexure forces using different design codes. *Architectural Institute of Japan Annual Convention*, scheduled for 8-10 Sept., Chiba, Japan, ID. 20244.
- 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.
- Obara T., Subedi N., Sayaka A., **Thusoo S.**, Kono S., Hirao K., Imai Y., Mukai D. (**2020**); Experimental study on ultimate shear capacity of steel encased concrete piles (Part 1:

Research background and outline of experiment). *Architectural Institute of Japan Annual Convention*, scheduled for 8-10 Sept., Chiba, Japan.

- **Thusoo S.**, Kono S. **(2020)**; Development of numerical models for the steel-encased high-strength concrete piles. *SOFTech Workshop for Young Researchers*, 13 Feb., Tokyo Institute of Technology, Japan.
- **Thusoo S.**, Kono S., Obara T., Asai Y., Hamada J., Kobayashi K. **(2019)**; Performance evaluation of earthquake-resistant steel-encased concrete piles based on prestressed concrete member design criteria. *Architectural Institute of Japan Annual Convention*, 3-6 Sept., Ishikawa, Japan, p. 213-214.
- Egawa M., **Thusoo S.**, Obara T., Kono S., Hirao K., Kobayashi K., Mukai D. (**2019**); Study on shear capacity of steel encased precast concrete piles (Part 1: Results of specimen SC1). *Architectural Institute of Japan Annual Convention*, 3-6 Sept., Ishikawa, Japan, p. 227-228.
- Oktiovan Y.P., **Thusoo S.**, Kono S., Mukai D. **(2018)**; Analysis of bending behavior of precast concrete piles using fiber based model (Part 1: Description of fiber model), *Architectural Institute of Japan Annual Convention*, 4-6 Sept., Sendai, Japan, p. 609-610.
- **Thusoo S.**, Oktiovan Y.P., Kono S., Mukai D. **(2018)**; Analysis of bending behavior of precast concrete piles using fiber based model (Part 2: Results and Discussion), *Architectural Institute of Japan Annual Convention*, 4-6 Sept., Sendai, Japan, p. 611-612.
- Hayakawa T., Tomoshisa M., Watanabe H., Tosauchi Y., Tanaka M., Mizukami D., Fukuda T., **Thusoo S.**, Kishida S. (**2018**); Study on structural performance evaluation for concrete pile system with post-earthquake functional use (Part 19: Section analysis on cast-in-place steel encased concrete piles subjected to varying axial load), *Architectural Institute of Japan Annual Convention*, 4-6 Sept., Sendai, Japan, p. 583-584.
- **Thusoo S.**, Tanaka H., Watanabe H., Kono S., Hirade T., Mukai D., Mukai T., Mizukami D. **(2017)**; Study on structural performance evaluation for concrete pile system with post-earthquake functional use (Part 7: numerical analysis of SC piles), *Architectural Institute of Japan Annual Convention*, 31-3 Sept., Hiroshima, Japan, p. 587-588.

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