Computational design and fabrication of shape optimized concrete slabs in India

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Abstract

In India, material costs can constitute 60 to 80% of the total cost of residential construction [1]. Nonetheless, Indian construction mimics the material inefficient prismatic elements of developed countries, designed to reduce labor over material costs. The mounting use of steel-reinforced concrete structures in Indian cities has also garnered concern for the environmental costs of construction; construction accounts for 24% of India's carbon emissions [2]. At the building scale, cement and steel are responsible for nearly 90% of a multistory concrete frame building's total embodied energy [3], and at least 50% of the embodied energy and mass is in the horizontal spanning elements alone [4]. Structural optimization and digital fabrication provide a pathway to reducing the economic and environmental costs of construction in India.

Utilizing computational structural design, this paper explores the material optimization of concrete floor slabs. Designed for the material and fabrication constraints of India, structural elements undergo constrained shape optimization to reduce the volume of concrete and steel while resisting the loads of an equivalent solid rectangular prismatic beam or slab. Optimization is carried out using the COBYLA algorithm in Design Space Exploration, a plug-in for Grasshopper 3D developed by Digital Structures at MIT. Variable coordinates define the geometry of a free-form slab. Then the slab is compared against the constraints of ductility, flexural capacity, and shear capacity. For this study, the optimization objective is the environmental cost of the slab, defined as the volume of steel and concrete multiplied by their respective embodied energy coefficients. The result of this methodology is a material efficient ribbed slab with a potential 65% reduction in embodied energy, and a similar reduction in material and mass, when compared to a flat slab 1m wide and 5m long.

A full-scale prototype slab will be fabricated in India to provide insight into the construction limitations, material availability, monetary costs, and necessary skill-level to realize the optimized concrete element. The prototype will be built by the local partner organization, Technology and Action for Rural Advancement (TARA), and will be load-tested at the India Institute of Technology in New Delhi (IIT Delhi). This paper will present the computational design methodology, reflect on the fabrication of the prototype slab in India, and discuss the results of the prototype's flexural load test.

References

[1] CIDC, "Planning Commission: 11th Five Year Plan," 2012. [Online]. Available: http://www.cidc.in/new/activities7.html. [Accessed: 16-Oct-2017].
[2] B. V. Venkatarama Reddy and K. S. Jagadish, "Embodied energy of common and alternative building materials and technologies," *Energy Build.*, vol. 35, no. 2, pp. 129–137, Feb. 2003.
[3] S. Bardhan, "Embodied energy analysis of multi-storied residential buildings in urban India," in *WIT Transactions on Ecology and the Environment*, 2011, vol. 143, pp. 411–421.
[4] P. Foraboschi, M. Mercanzin, and D. Trabucco, "Sustainable structural design of tall buildings based on embodied energy," *Energy Build.*, vol. 68, no. Part A, pp. 254–269, Jan. 2014.