

French Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes one of the PhD subjects proposed by the French Polytech network. The network is composed of engineering schools/universities. The document also provides information about the supervisor.

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Country	France

PhD information	
Title	Mechanical characterization and numerical modeling of Fujian tulou-type buildings under ambient vibration and environmental loading
Main topics regards to CSC list (3 topics at maximum)	IV-7, IV-12, VI-3

Required skills in science and engineering	Civil engineering, structural dynamics, material mechanics
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Subject description (two pages maximum including biblio)

Fujian Tulou (福建土楼) are earthen buildings built between the 12th and 20th centuries. They were inscribed on the UNESCO World Heritage List in 2008 because of its unique architectural tradition. The load-bearing structure is massive, made of thick walls composed of rammed earth. Their design provides durability and natural insulation, remaining relatively cool in summer and warm in winter.

Tulou buildings are fascinating from a structural engineering perspective because they combine mass, ductility, geometry, and local geo-sourced materials and they perform surprisingly well during earthquakes. The exterior rammed-earth walls are extremely thick, often up to several meters at the base, providing stability to vertical loads and resisting to lateral earthquake forces. The walls are constructed by compacting layers of earth mixed with sand, clay, gravel, and reinforcing materials such as bamboo and wooden strips.

Many famous Tulou are circular, or usually highly symmetrical around a central courtyard. Symmetric structures experience less torsional motion during earthquakes, which means fewer damaging stress concentrations. In particular, a circular plan distributes the seismic forces and avoids stress concentrations that typically occur at corners in rectangular buildings. During ground shaking, forces are distributed more uniformly around the perimeter, reducing localized failure.

The floors, roof structures, and internal framing are made of wood. The timber slab and frame are flexible and have good ductility, so they can deform without suddenly breaking, allowing the structure to absorb seismic energy and accommodate movement during an earthquake. The wooden floors and ring beams tie the structure together, helping the walls act as a global system (box behavior). This interaction between the stiff earthen shell and the more flexible timber framework improves the building overall seismic behavior.

Tulou construction enhances the use of local geo-sourced materials. Historical accounts indicate that builders sometimes incorporated materials such as lime, stone, bamboo, and even mixtures containing sticky rice into the rammed-earth walls, improving cohesion, durability, and resistance to cracking.

For these reasons, Fujian Tulou can be studied as centuries-old examples of performance-based seismic design using earthen materials, demonstrating that earth construction can be both sustainable and

earthquake-resistant when geometry, material composition, and structural detailing are carefully considered. Understanding the old construction technique represents a lesson for modern sustainable construction in France and in Europe. In the framework of earth-based construction and seismic design, Tulou illustrate several principles that remain relevant today: regular and symmetric layouts; strong connections between walls, floors, and roofs; use of lightweight ductile elements together with massive earthen walls; thick load-bearing walls with good confinement; integration of local materials with seismic resilience strategies. These principles are closely aligned with modern approaches to improving the seismic performance of rammed earth and compressed earth block (CEB) masonry structures [1], studied in Polytech'Lab (ANR DynaTerre project, European INBUILT project).

A first goal of this PhD thesis is to understand the construction technique of Fujian Tulou, taking advantage of the collaboration between Polytech Nice Sophia and the College of Civil Engineering in Fuzhou University. A first part of the doctoral research project aims to develop the numerical model of a Tulou in a finite element scheme, using the data (geometry, mechanical properties of materials) provided by the University of Fuzhou. A second part of the proposed research consists of calibrating the finite element model by comparison of dynamic properties obtained by numerical and operational modal analysis. Natural frequencies and mode shapes obtained directly (numerical modal analysis) and by inversion of the structural response under ambient vibration are compared, and the model is corrected until the match of modal parameters. A third part of this PhD thesis is related to the Tulou response to environmental loads and disaster risk reduction. Among other aspects, the soil-structure interaction (SSI) model [2], considering the Tulou building on a soil domain, is developed to design a vibration barrier (ViBa) tool. The development of numerical models and their calibration will be carried out in Polytech'Lab of Polytech Nice Sophia (France). The structural response under ambient vibration will be measured in-situ by researchers of Polytech Nice Sophia. The experimental tests related to material characterization, scaled-models in shaking tables and vibration barriers will be developed by Fuzhou University.

References

- [1] Zarzour N., Santisi d'Avila M.P., Mercerat D., Lenti L., Oggero M., 2024. Structural performance assessment of compressed earth block masonry building in seismic zone, *Soil Dyn. Earthq. Eng.*, 187, 108990.
- [2] Fares R., Santisi d'Avila M.P., Deschamps A., 2019. Soil-Structure Interaction analysis using a 1DT-3C wave propagation model, *Soil Dyn. Earthq. Eng.*, 120, 200-213.