

Forum on Hakka Tulous: Lessons to Be Learned, Past, Present and Future
June 24, 2009, Xiamen University, Xiamen, China

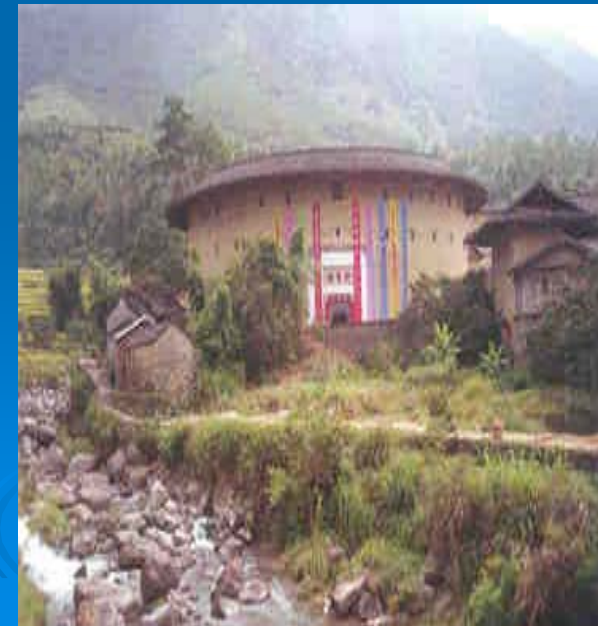
Hakka Tulou and Science: A NSF Project Prospectus

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Rammed Earth Buildings – Hakka Tulous



Our Common Heritage - Hakka Tulous

(inscribed as a cultural property into World Heritage on July 6, 2008)

Tulou building has been built and dwelled by Hakka for hundreds of years and are a type of multi-family housing of unique style and structure in the world.

It represents

- **marvelous artistic achievement and creative masterpiece.**
- **exceptional testimony to Hakka cultural tradition and great example of harmonious living.**
- **outstanding example of a type of architecture which illustrates a significant stage for Hakkas in human history.**
- **outstanding example of a traditional human settlement which is representative of Hakka culture.**

However, its engineering and scientific values are highly underestimated and least understood.

Why do we need to study Hakka Tulou from science and engineering points of view?

Hurricane Katrina's Extensive Damage (August 29, 2005)

<http://www.katrinadestruction.com/images/v/>



Sichuan Earthquake's Devastation (May 12, 2008)



Hurricane Resistant Houses

Withstanding Nature

<http://www.deltechomes.com>

Round houses seem to be hurricane proof. In 2005, when Hurricane Katrina struck the Gulf Coast, none of the Deltec homes in her path suffered any structural damage from Katrina's category 5 hurricane force winds. Two Deltec homes hit by 20-30 foot tidal surges and winds of over 145 mph, incurred no structural damage.



Round Houses Built by Deltec Homes



Why Round?

- **Less exposed surface area.** For a 1600 sq ft round house, the total surface area in contact with the outside environment is almost 650 sq ft less than a square house.
 - Improved durability
 - superior energy efficiency
- **Improved aerodynamics.** There is not enough surface area on any part of the house for pressure to build up.
 - High wind resistance
- **Radial engineering concept that disperses load exerted on the outside wall thru the entire structure**
 - Better structural integrity



Design with nature, not against it
<http://www.deltechomes.com>

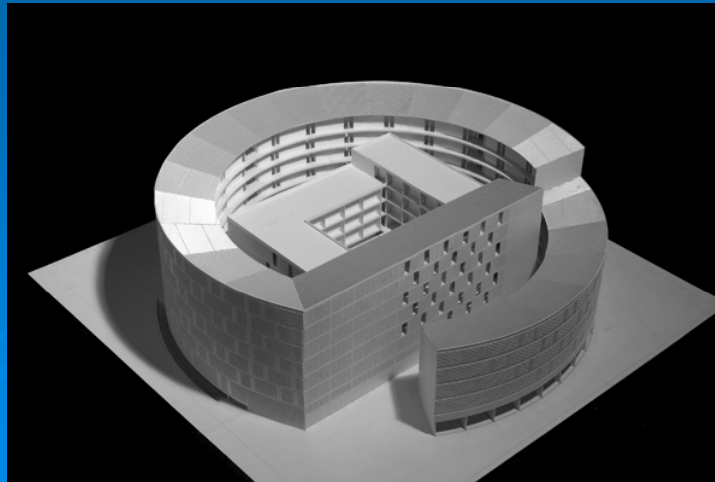
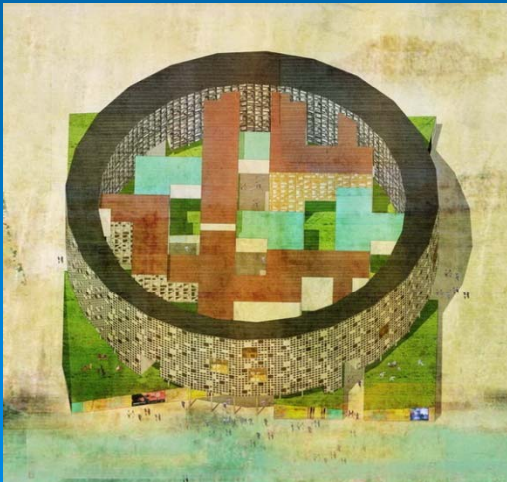
Tulou: Affordable Housing for China

NYTimes.com, October 12, 2008



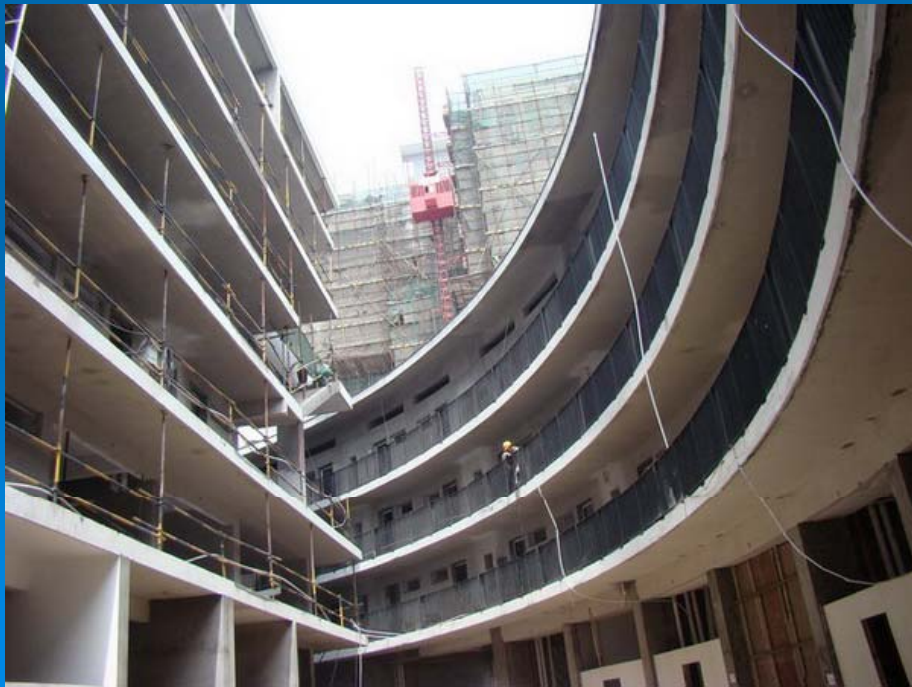
Modern “Tulou”: A Experimental Project

- A design group -Urbanus in Shenzhen is experimenting Hakka Tulou concept nearby Guangzhou, China by building a prototype of affordable housing.
- The Tulou project, developed by the China Vanke Co. Ltd. incorporates 278 apartment units, a dormitory, a small hotel, shops, a gymnasium, a library, and various public spaces.
- The art of work "Tulou: Affordable Housing for China" was on exhibit at the Cooper- Hewitt National Design Museum in New York City October 3, 2008–April 5, 2009.



Modern “Tulou” under Construction in Guangzhou, China

12,000 m², Shenzhen Vanke Real Estate Co., Ltd. 2008. Design: Urbanus



Leadership in Energy and Environmental Design (LEED)

- **A leading-edge system for designing, constructing, and certifying the world's greenest buildings**
 - Developed and administered by US Green Building Council (USGBC)

- **What is “Green” Building?**

A building that significantly reduces or eliminates the negative impact of buildings on the environment and occupants in five broad areas:

- Sustainable site planning
 - Safeguarding water and water efficiency
 - Energy efficiency and renewable energy
 - Conservation of materials and resources
 - Indoor environmental quality
- **LEED establishes measurable benchmarks to measure success in meeting sustainable goals**
 - **LEED-New Construction Certification Levels**
 - Certified Level 26 - 32 points
 - Silver Level 33 - 38 points
 - Gold Level 39 - 51 points
 - Platinum Level 52 - 69 points



LEED
LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

Green Building Movement in USA

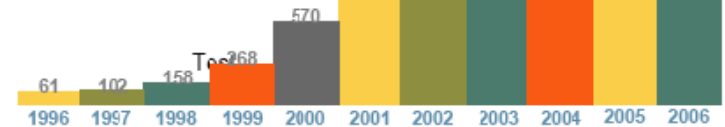
USGBC membership growth reflects the expansion of green buildings in the market

LEED for new construction buildings as of 07/06

Distribution by geography



steady growth in the first 5 years



huge growth in the last 5 years

TOTAL MEMBERS

Building Green
Bell, James D, 2007

Science in Energy and Environmental Design (SEED): Engineering Sustainable Buildings

- US NSF Funding Opportunity

- NSF Emerging Frontiers in Research and Innovation (EFRI) Program has recently announced the above topic for FY2010 competition

- Why SEED?

In any community, buildings are basic infrastructure. In the US, buildings are responsible for:

- 38% of carbon dioxide emissions
- 71% of electricity consumption
- 39% of energy use
- 12% of water consumption
- 40% of non-industrial waste

We spend 90% of our time indoors and the indoor environment affects our physical and mental health and our productivity

- Ecological Footprint data (2006)
 - 9.6 global hectares per person for US (versus 0.63 gha per person for Hakka community as per Ostrowski, 2008)
- Sustainability (Green) concepts have to be integrated into design and construction of next generation buildings in industrial nations

Rammed Earth Construction

Rammed earth is a sustainable construction material due to many benefits for the environment including:

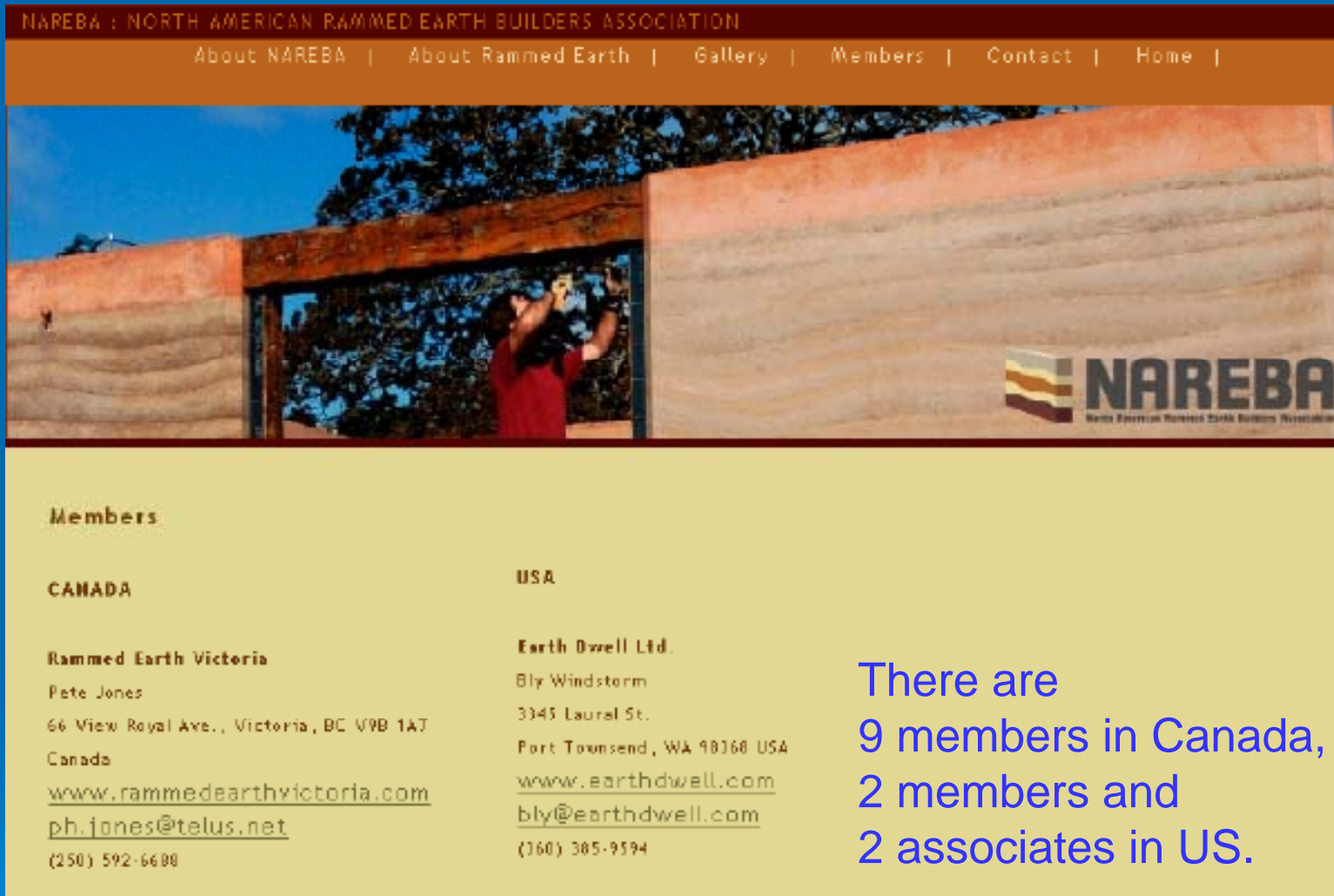
- Natural (non processed) material
- Universal availability
- Durability
- Recyclability
- Low embodied energy
- Low CO2 emissions
- High thermal mass
- Traditional construction method
- Low cost for material, construction, transportation



North American Rammed Earth Builders Association
(NAREBA, <http://www.nareba.org/>)


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NAREBA : NORTH AMERICAN RAMMED EARTH BUILDERS ASSOCIATION

[About NAREBA](#) | [About Rammed Earth](#) | [Gallery](#) | [Members](#) | [Contact](#) | [Home](#) |





Members

CANADA	USA
Rammed Earth Victoria Pete Jones 66 View Royal Ave., Victoria, BC V9B 1A7 Canada www.rammedearthvictoria.com ph.jones@telus.net (250) 592-6688	Earth Dwell Ltd. Bly Windstorm 3345 Laurel St. Port Townsend, WA 98168 USA www.earthdwell.com bly@earthdwell.com (360) 385-9594

There are
9 members in Canada,
2 members and
2 associates in US.

“The art and engineering of building with rammed earth is lost, in most industrial nations” (McHenry, 1999)

Material and Structural Response of Historic Hakka Rammed Earth Structures

NSF CMMI Grant No. 0908199

PIs: Drs R Liang and G Hota

Program Officer: Dr K Chong

Objective:

To study the material and structural responses of Fujian Tulou buildings that have survived and functioned well under extreme thermal, wind and earthquake-induced loads

“Fujian Tulou & Science” Int. Exploratory Research Team:

Dr Ruifeng Liang, WVU, June 20 – July 10, 2009

Dr Hota Gangarao, WVU, June 20 – 25, 2009

Dr Ying Lei, XMU, June 20 – July 10, 2009

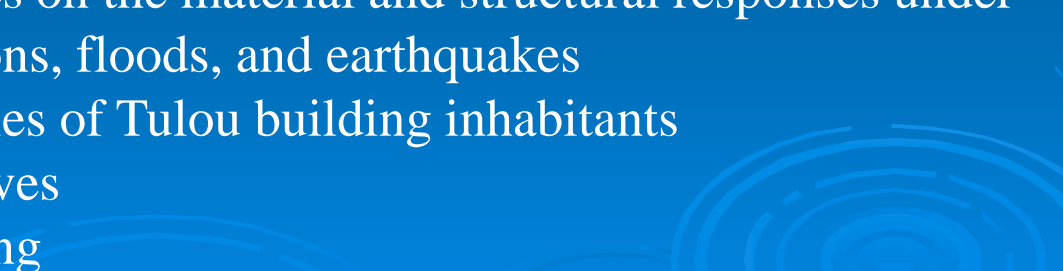
Mr. Jorg Ostrowski, ASH, June 20 – July 10, 2009

Nondestructive Evaluation of Hakka Tulou Buildings Yongding, Fujian, China

Research Areas of Focus:

- Durability of Tulou Buildings
- Role of Wall Ribs as Reinforcements
- Structural Integrity of Hakka Buildings
- Self-healing of Cracks and Earthquake Resistance
- Energy-efficiency and Thermal Comfort

Approaches:

- Field data , rammed earth and wood samples collection
 - Lab testing of rammed earth and wood samples including carbon dating
 - Review of achieve files on the material and structural responses under extreme loads : typhoons, floods, and earthquakes
 - Interview of the families of Tulou building inhabitants for info and clan archives
 - Finite element modeling
- 

The Oldest Square Tulou-Fuxin

Built in 769 (Tang dynasty). Half burned in 1852, the other half still in use by 8 families. In 1986, it took 16 days for residents to create a side door. 20 tulous existing over 600 yrs (built in Yuan ~1308 or Ming~1371).



Durability of Tulou Buildings

Objective:

To investigate rammed earth wall materials in terms of aging, performance, novel load transfer mechanism and binder characteristics

Field Action Items:

- Identify constituent materials of rammed earth with emphasis on binders
- Conduct NDE of rammed earth wall
- Collect core extraction samples for testing
- Identify the reasons for ruined Tulous and failed walls

Subject Tulou Buildings:

- Fuxin Tulou built in 769
- One built in ~1300 TBD on-site after tours
- One built in ~1900 TBD on-site after tours

Equipment:

- Core extraction tool (XMU)
- Rebound Hammer (XMU)
- Tap Hammer if available Sac
- IR Scan

Eroded Rammed Earth Wall



Eroded Rammed Earth Wall of a Tulou exposing wooden chips inside. The wall is made of a mixture of soil, lime, pebbles and wood/bamboo chips held together by soupy glutinous rice and brown sugar

Field Study Plan Review
Ostrowski, J, 2009

Role of Wall Ribs as Reinforcements

Objective:

To investigate the role of wooden/bamboo pieces in the wall including mechanics of force transfer under extreme loads

Field Action Items:

- Quantify rib density (spacing and size) in a typical wall construction
- Identify interfacial bond between rib and earth using NDE on site
- Collect geometric data for FE modeling of interfacial force transfer
- Collect wooden samples for static testing under compression and bending

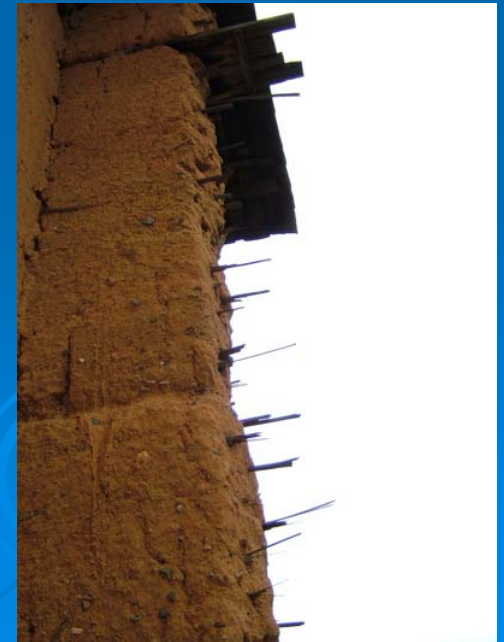
Subject Tulou Buildings:

Tulous with eroded walls

Equipment:

- Infrared Thermography Camera (WVU)
- Core Extraction (XMU)
- Rebound Hammer (XMU)
- Laser measurer (WVU)

Field Study Plan Review
Ostrowski, J, 2009



Inner Wooden Structures

Inside the outer rammed earth wall of a Hakka Tulou are internal wood structures for dividing rooms, ground floor for cooking & dining, 2nd floor for storage, 3rd & 4th floors for living, and 1-3 ring buildings enclosed



Zigzag structure with leaned floors of Yuchanglou, built in 1308, O/D 36 m, 5 storeys, 50 rooms/floor.



Structural Integrity of Hakka Buildings

Objective:

To investigate structural efficiency of a round Tulou thru NDE measurement and FE modeling of force transfer mechanisms

Field Action Items:

- Collect geometric information such as wall thickness, OD/ID, column & beam positions using Laser distancer and plumb if Reflectorless Station is available
- Conduct load tests (no load, with centralized load, with distributed load)
- Document the modes of failures (if any) and their effects on structural integrity e.g. damages due to fire, wind and earthquake,

Subject Tulou Buildings:

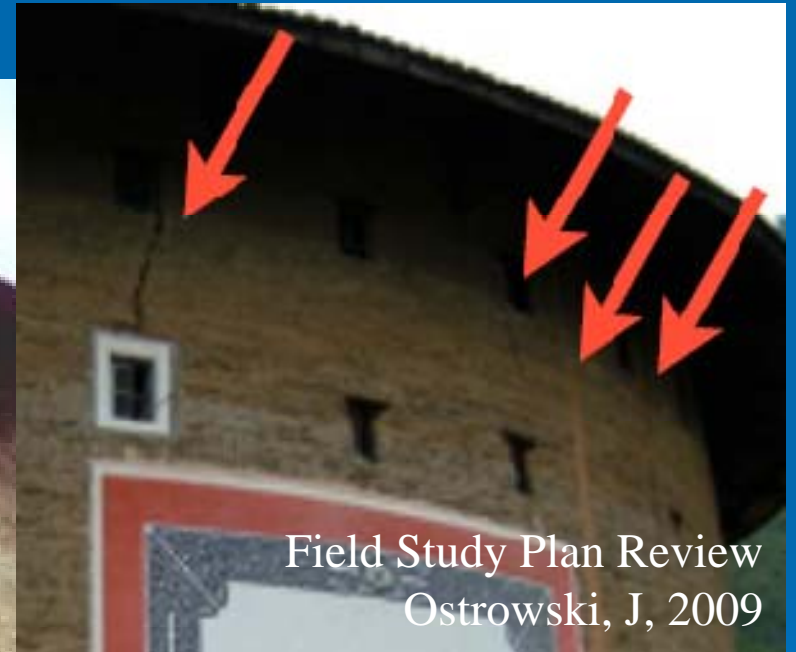
One round Tulou with emphasis on inner wooden structure

Equipment:

- Load cell, strain gages, mechanical gages (XMU)
- Data acquisition system (XMU)
- Laser measurer (WVU)

The Strongest Tulou- Huanji

- Built in 1693, O/D43.2m, 20m high, 4 floors, 2 rings, 152rooms, 21 families, 116 people. There was a crack (20cm x 3m) in the wall from a R.7 earthquake in 1918, but later the gap was sealed up naturally!



Field Study Plan Review
Ostrowski, J, 2009

Self-healing of Cracks and Earthquake Resistance

Objective:

- Study Tulou structural response under earthquake loads thru FE modeling
- Evaluate if the mass of outer wall plus the integrity of inner wooden structure is a contributing factor for their earthquake resistance

Field Action Items:

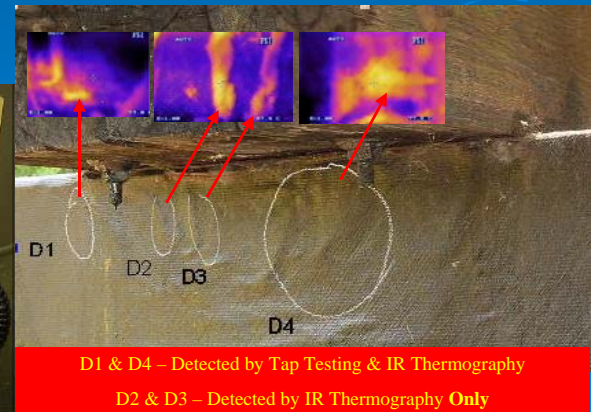
- Collect geometric data of Huanji Tulou and one square Tulou for inputs
- Measure the reported crack (L x W x D) of Huanji due to R7 Earthquake
- Conduct NDE for bond between wall rib and rammed earth to verify any self-healing of cracks-after-quake

Subject Tulou Buildings:

Huanji Tulou built in 1693; one square Tulou TBD on-site after tours

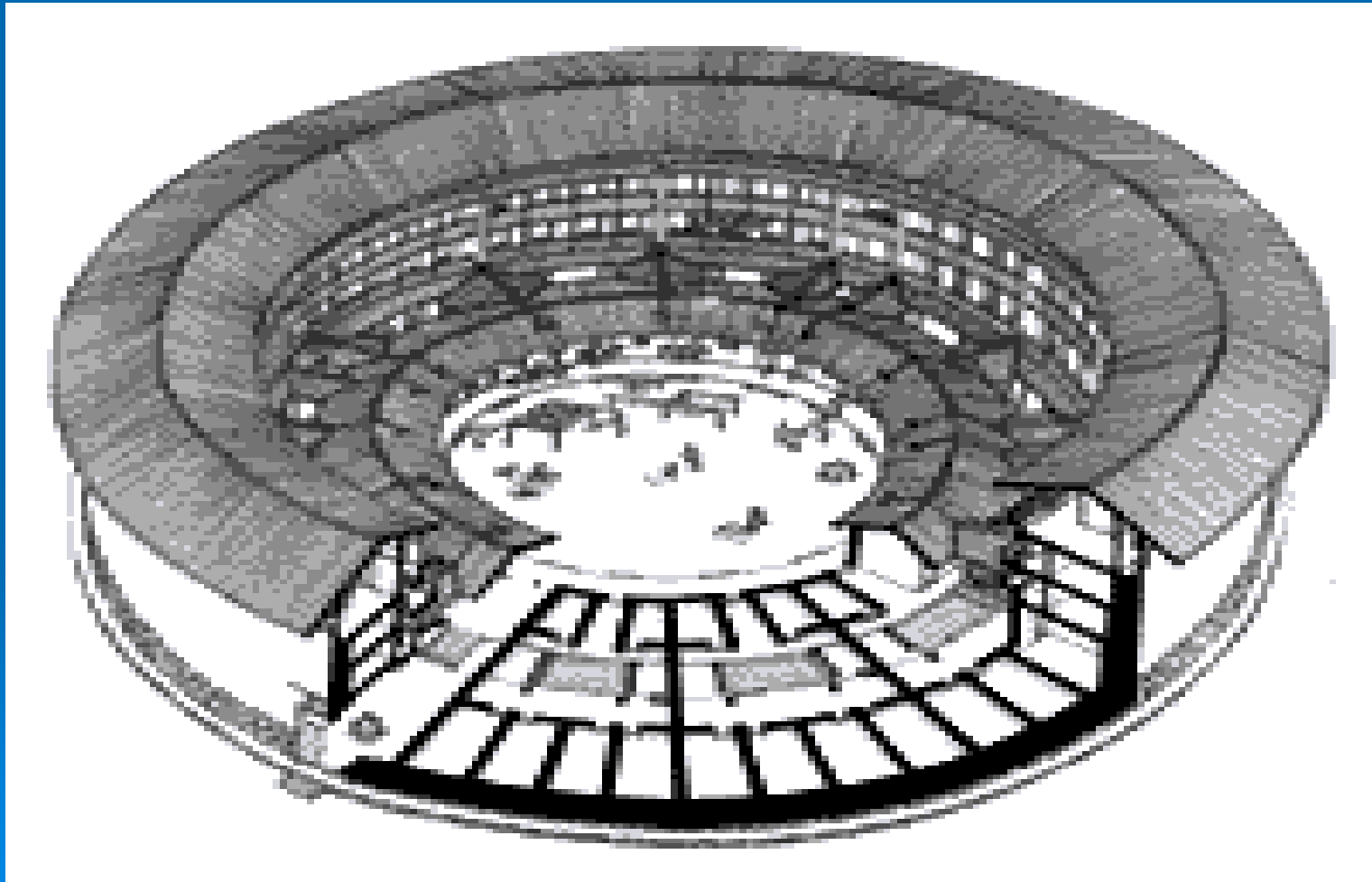
Equipment:

- Infrared Thermography Camera (WVU)
- Core Extraction (XMU)
- Rebound Hammer (XMU)
- Laser measurer (WVU)

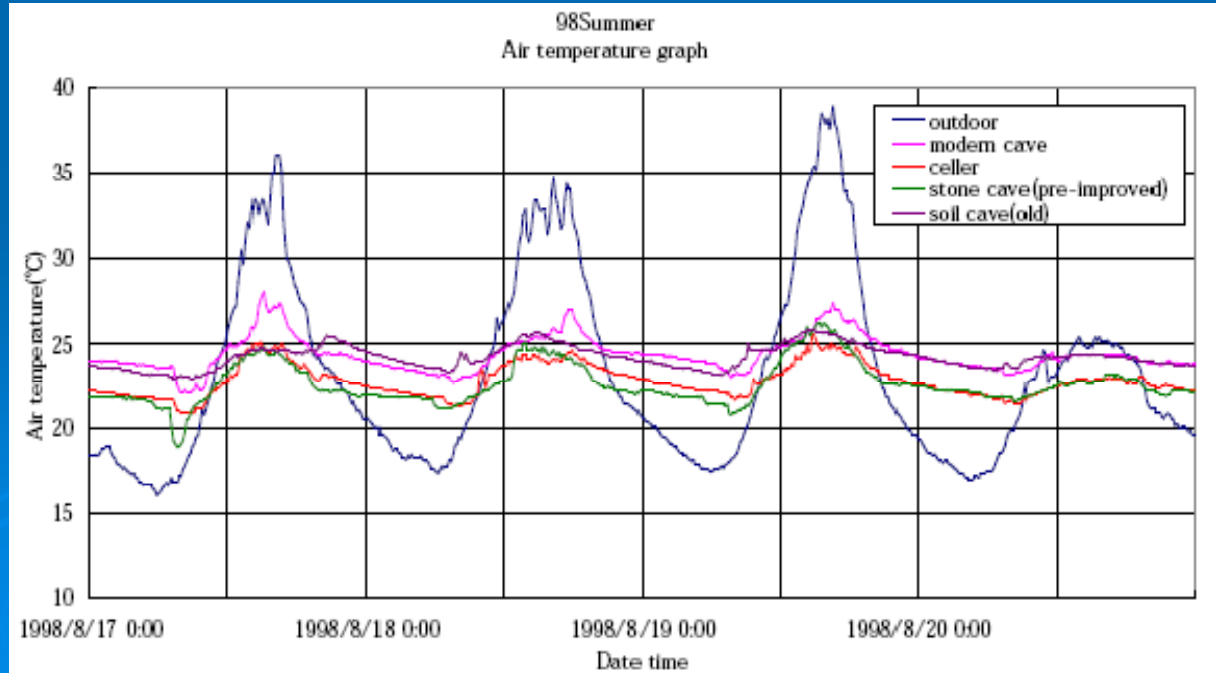
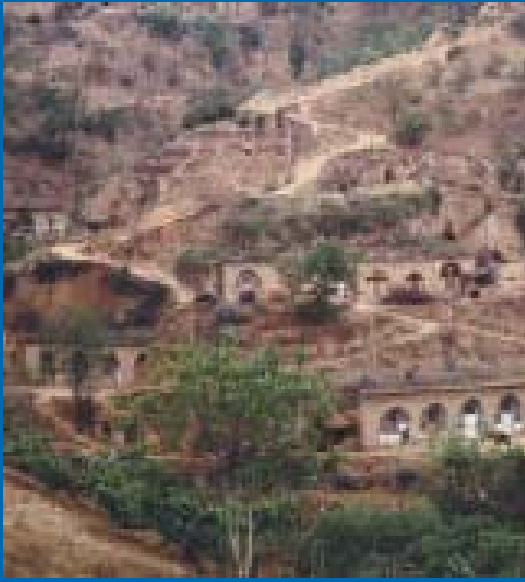


Tulou Structural and Functional Features

Well lighted, well ventilated, windproof, fireproof, quakeproof, warm in winter/cool in summer, easily defensible with heavy/strong doors and thick walls (2.5m).
Secured, safe, strong, durable, closed, communal.



Thermal Comfort of Cave Dwelling



Watanabe, T. 2003. Research
Committee of Architectural
Institute of Japan

Energy-efficiency and Thermal Comfort

Objective:

To identify if Tulou design and its earth wall mass contribute to thermal comfort thru monitoring temp and humidity and heat transfer analysis

Field Action Items:

- Collect geometric data of the Tulou building e.g. wall thickness (top, bottom), OD/ID etc for analytical inputs and mass estimates
- Collect temp and humidity data thru continuous monitoring inside and outside the building, inner and outer wall surface, and at different depth across the wall in typical hot and mild days

Subject Tulou Buildings:

One square and one round Tulous TBD on-site after tours

Equipment:

- Digital thermometer with thermocouple (4)
- Digital thermometer including humidity (4)
- Surface temp gun
- Laser distancer

Lab Testing of Rammed Earth Wall Samples

Objective:

To characterize thermo-mechanical properties of rammed earth and wooden rib samples thru core extraction

Action Items:

- Conduct compression and bending tests on core extracted samples for strength and stiffness
- Evaluate bond between constituents and wood rib piece/earth thru SEM
- CT scanner test for porosity of rammed earth samples
- Conduct Carbon Dating test on wall-ribs
- Conduct test for thermal conductivity of rammed earth
- Process data and documents collected from field studies
- Pack and ship some of the samples to WVU

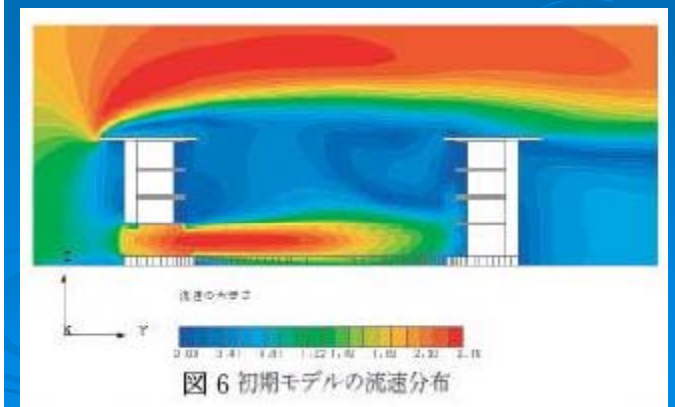
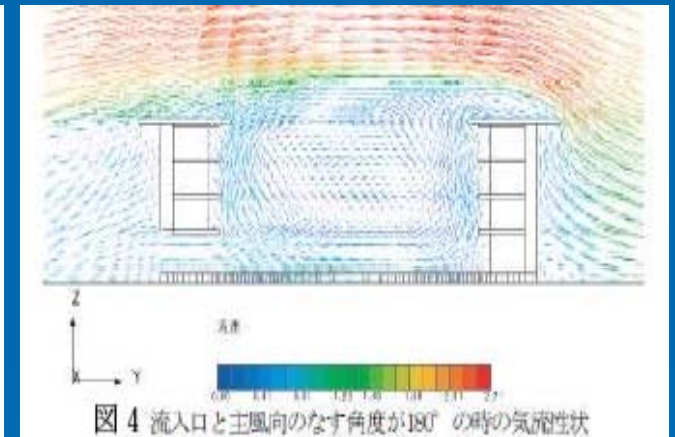
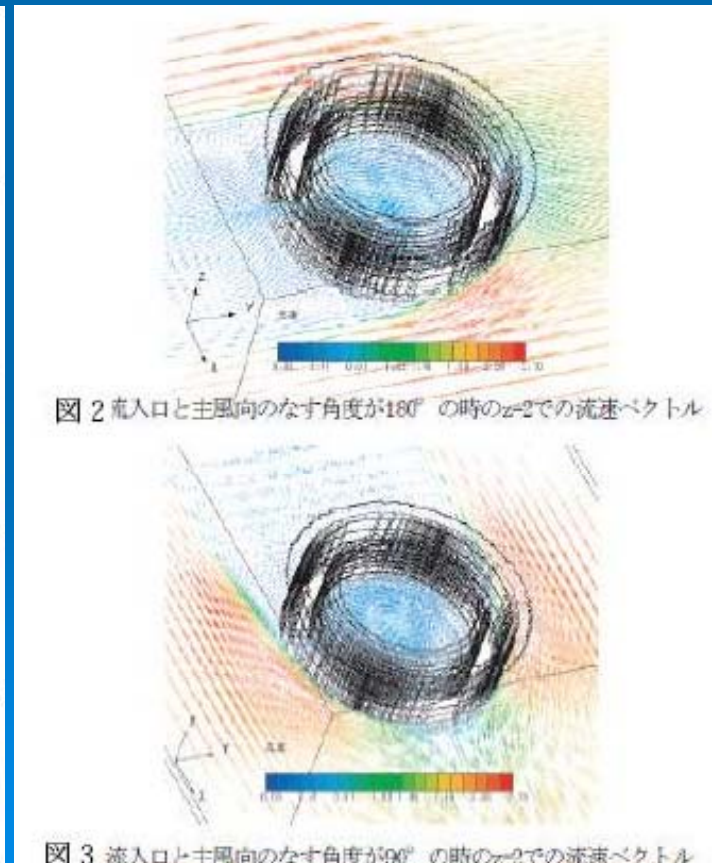
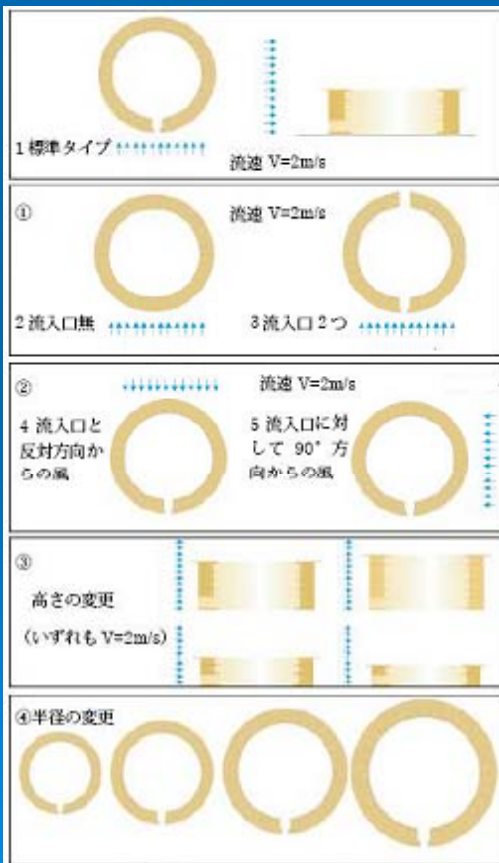


Finite Element Modeling of Tulou Material and Structural Responses

- Load transfer mechanism of earth/rib wall system
- Load transfer mechanism of inner wooden structure
- Self-healing of crack-after-quake
- Thermal comfort

Yoshino et al, 2005

Modeling of Tulou's response under strong wind



Sustainability and Other Issues of Scientific Interest for Future Studies

Objective:

To develop a follow-on research proposal thru international collaboration on sustainability concepts embedded in Hakka Tulou buildings for future sustainable structures

- Rammed earth materials
- Feng Shui
- Planning, design, construction, **Operation**

Other Issues

- Retrofitting and repair technology
- Rammed earth wall stability analysis
- Any requests from Local Government or Property Owners

Field Action Items:

- Identification of Tulous for in-situ monitoring
- Development of specific research plans

Assisting the History Channel Hakka Tulou Program

Objective:

To assist the US History Channel "History. Made for Tomorrow" crew to film-shoot the Tulou episode, including our scientific research on-site/XMU and Tulou Forum.

Field Action Items:

- Record the Hakka Tulou Forum
- Assist History Channel to film Hakka Tulous on-site, July 3 -7
- Visit Jiaying University Hakka Research Institute, Meizhou, July 8
 - Visit core Hakka Culture County – Meizhou, July 8
 - Meet Prof. Fang Xuejia for potential future collaboration
 - Tour local Yuan Yuan Tulou that was not reinforced with wall ribs
- Visit 3rd core Hakka Culture County –Shanghang on the way of return journey from Meizhou, July 8 Afternoon
- Visit ongoing rammed earth wall construction site if any in the Area
- Visit Longyan Univ Hakka Culture Research Institute, Longyan, July 9
- Film lab testing of rammed earth samples at XMU, July 10

Summary

- The in-service Hakka rammed earth structures, i.e. Fujian Tulou of China, are historic and unique in design, construction and performance. However, people including Hakka had underestimated the engineering value and historical significance of those buildings in terms of energy consumption for comfortable living, sustainability and durability.
- Our NSF project will attempt to better understand their thermo-mechanical and aging responses under thermal, flood, hurricane and earthquake loads. We would also like to develop an extensive research plan to understand the Hakka Tulou construction and its sustainable living in an interdisciplinary manner through international collaboration.
- The eventual objectives are to emulate the Hakka Tulou Technologies for implementation in modern constructions, leading to: 1) durable rammed earth material systems; 2) advanced rammed earth construction technique using reinforcing wall ribs; 3) affordable housing and space-efficient office towers in urban areas; 4) disaster-resistant structural configurations; and 5) energy-efficient and green buildings.

Acknowledgements

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Dr Ken Chong, NSF

Thank YOU for your attention!

