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Protection of Important Traditional Wooden Structures in Japan under Disaster Conditions: A Case Study of Ine

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Abstract: With the improvement of the protection system for important traditional building clusters in Japan, a large number of traditional buildings have been preserved and restored, providing valuable references for the study of traditional architecture in our country. As Japan faces increasing social issues such as an aging population and low population density, as well as frequent large-scale natural disasters, the conventional research methods for traditional districts, which focus on uncovering historical and cultural values, are no longer sufficient to provide a solid basis for formulating protection strategies. Instead, the physical condition and environmental risk assessment of traditional building clusters offer a useful supplement to the study of traditional districts. This paper takes the research on traditional building clusters in Ine, Kyoto Prefecture, Japan, as an example. It combines conventional methods based on sociological and regional studies with the latest methods for evaluating wooden structures to introduce the process of understanding the regional structural performance of traditional building clusters.

Keywords: *Important Traditional Building Clusters, Disaster Prevention, Regional Structural Research.*

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I. INTRODUCTION

The preservation of traditional wooden architecture represents one of the most significant challenges in cultural heritage management, particularly in disaster-prone regions. Japan, with its rich tradition of wooden construction and frequent exposure to natural disasters including earthquakes, typhoons, and tsunamis, has developed sophisticated approaches to protecting its architectural heritage. This study examines the case of Ine, a traditional fishing village in Kyoto Prefecture, which exemplifies both the challenges and innovative solutions in protecting important traditional wooden structures under disaster conditions.

Ine Town, located in Yosa District, northern Kyoto Prefecture, represents a unique case study in traditional wooden architecture preservation. As of February 2022, the town had an estimated population of 1,984 residents in 899 households, with a population density of 32 persons per square kilometre across its 61.95 square kilometer area. The town's significance extends beyond its demographic profile to encompass its distinctive architectural heritage and its designation as one of Japan's Important Traditional Building Clusters Preservation Districts.

The research presented in this paper addresses the critical intersection of traditional architecture preservation and disaster resilience, offering insights that extend beyond Japanese context to inform global practices in heritage conservation. By combining conventional sociological and regional research methods with advanced structural evaluation techniques, this study provides a comprehensive framework for understanding and protecting traditional wooden structures in high-risk environments.

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II. OVERVIEW OF INE

A. Geographical and Historical Context

Ine Port, situated at the northwest end of Wakasa Bay in northern Kyoto Prefecture, occupies a unique geographical position that has shaped both its architectural development and its vulnerability to natural disasters. The port's location at the southeastern edge of the Sea of Japan, adjacent to Miyazu City to the north and Kyotango City to the east, creates a specific set of environmental conditions that directly impact the preservation of its traditional structures.

The geographical isolation of Ine, with no nearby airport or railway access, has contributed to the preservation of traditional building practices. The two-and-a-half-hour journey by car from major urban centres like Osaka or Kyoto has helped maintain the town's distinctive character, while the limited public transportation options, primarily the Tango Kairiku Koutsu bus service connecting Amanohashidate Bus Station and Miyatsu Railway station, and have reinforced this isolation.

B. Architectural Heritage

The traditional wooden houses of Ine Port, known as "funaya," represent a unique architectural typology that has evolved over centuries to meet the specific needs of a fishing community. These structures consist of two main buildings: the main house on the mountainside and the boat house on the seaside, separated by a coastal road. This arrangement reflects both the functional requirements of the community and the spatial constraints imposed by the steep mountain slope rising sharply behind the main houses.

The funaya were originally constructed to protect boats from rain, insects, and rot, with the ground floor serving as a boat shed and the upper floor used for storing fishing gear and sometimes as living space. Over time, these structures have evolved to serve multiple purposes, adapting to changing transportation methods and economic conditions. The shift from boat-based to car-based transportation has led to the conversion of some funaya into garages, while others have been transformed into guesthouses to accommodate tourism.

III. TRADITIONAL WOODEN HOUSES IN INE PORT

A. Structural Characteristics

The traditional wooden houses in Ine Port demonstrate sophisticated engineering principles that have enabled their survival through numerous natural disasters over the centuries. The main houses feature gable roofs with flat entrances, while the boat houses have gable roofs with entrances on the gable side, designed specifically for boat mooring operations.

The construction materials reflect careful selection based on local availability and environmental resistance. The columns of the main houses are typically made of cypress or Japanese cypress, while the main pillar (daikoku bashira) utilizes oak for its superior strength characteristics. Horizontal members traditionally employed Japanese red pine, though modern renovations often use yellow pine as a substitute. The boat houses utilize evergreen oak for columns, chosen for its resistance to salt air, while horizontal members incorporate Japanese red pine sourced from nearby mountains.

B. Environmental Adaptations

The architectural design of Ine's traditional structures incorporates numerous adaptations to the local environment. The coastal pine and evergreen oak forests function not only as fish-attachment areas but also as natural windbreaks, while Aoshima Island at the bay entrance serves as a natural breakwater, creating calm inner bay conditions that have helped preserve the unique architecture over centuries.

The structural design of the boat houses includes several innovative features. The columns are inclined inward in the direction of foundations, with cross-sections shaped like shogi pieces to prevent roof overlap in densely packed areas. The cheek braces, positioned at angles slightly more vertical than 45 degrees, utilize gravity-assisted insertion mechanisms that maintain structural integrity even when settling occurs.

IV. DISASTER RISK ASSESSMENT

A. Seismic Vulnerability

The seismic risk assessment for Ine reveals significant vulnerabilities that require immediate attention. The area faces high probability earthquakes from the Nankai and Tonankai fault systems, with historical precedents including the 1927 Northern Tango Earthquake. While detailed damage records from this event are primarily based on oral traditions, the community's collective memory provides valuable insights into structural performance during major seismic events.

Natural frequency measurements conducted on buildings in Ine reveal important structural characteristics. Main houses demonstrate natural frequencies between 2.4-4.1 Hz in the span direction and 2.8-6.3 Hz in the ridge direction, while boat houses show frequencies between 2.2-7.0 Hz in the span direction and 2.2-3.9 Hz in the ridge direction. These measurements provide crucial data for understanding structural behavior during earthquakes and developing appropriate retrofitting strategies.

B. Environmental and Climate Risks

Climate change presents additional challenges to the preservation of Ine's traditional structures. Recent years have seen reduced snowfall, altering the environmental conditions that these buildings were designed to withstand. Typhoon events, such as the 2004 typhoon that caused water ingress into boat houses, demonstrate the ongoing vulnerability of these structures to extreme weather events.

The geographical subsidence observed in the area compounds these risks. Some houses have experienced ground subsidence of approximately 15 centimeters over the past 60 years, while the sea side of boat houses continues to subside. This gradual ground movement affects structural integrity and increases vulnerability to both seismic events and storm surge flooding.

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V. COMMUNITY DEMOGRAPHICS AND SOCIAL CHALLENGES

A. Population Dynamics

The demographic profile of Ine presents significant challenges for traditional architecture preservation. The declining population trend, combined with an increasing proportion of elderly residents, creates conditions that threaten the continued maintenance of traditional structures. The average number of residents per household is decreasing, with many houses inhabited by elderly couples or single elderly individuals.

Yuasa-Cho, a comparable traditional district facing similar challenges. The elderly population (over 65) in Yuasa exceeds the national average by 5 percent, while the number of households increases even as the population declines. This trend indicates a shift toward smaller household units, which affects both the economic capacity for building maintenance and the availability of labor for traditional construction practices.

B. Economic and Social Factors

The economic sustainability of traditional architecture preservation faces multiple challenges. While tourism provides some economic support through the conversion of funaya into guesthouses, the overall economic base remains limited. The shift from fishing to other economic activities has altered the functional requirements of traditional structures, leading to adaptive reuse that may compromise historical authenticity.

The maintenance of traditional wooden structures requires specialized knowledge and regular attention that becomes increasingly difficult with an aging population. Many houses in Ine are approximately 100 years old and require ongoing maintenance including roof material replacement and kitchen and toilet facility updates. However, comprehensive maintenance programs face challenges including limited availability of skilled craftsmen and the physical demands of traditional maintenance practices.

VI. INVESTIGATION METHODOLOGY

A. Overall Investigation Approach

The research methodology employed in this study combines comprehensive field surveys with advanced structural analysis techniques. The investigation encompassed both detailed examination of individual buildings and broader district-wide assessments to understand the overall condition of the traditional building cluster.

The streetscape survey documented multiple structural characteristics including building type (wooden, steel frame, reinforced concrete), number of stories, building age (modern or traditional), roof type (gable, hip, or other), and building use (residential, commercial, warehouse, or boat house). For residential buildings, the survey recorded floor level relative to road elevation, while boat houses were documented according to facade type facing the sea.

B. Structural Assessment Techniques

The investigation utilized sophisticated measurement techniques to assess structural performance and vulnerability. Ambient vibration measurements were conducted using seismometer GPL-6A3P by Akashi manufacturing, with accelerometers positioned to capture three-dimensional movement data. Each measurement utilized multiple accelerometers synchronized through GPS signals, with sampling frequencies of 100 Hz providing detailed temporal resolution.

The data analysis methodology involved dividing time series data into 40.96-second segments, calculating ensemble means to minimize noise errors, and applying fast Fourier transform (FFT) techniques to identify predominant frequencies. This approach enabled identification of torsional modes and provided comprehensive understanding of structural response characteristics under various conditions.

VII. STRUCTURAL PERFORMANCE ANALYSIS

A. Building Condition Assessment

The investigation revealed significant variations in building condition across the traditional district. Approximately half of the surveyed houses are around 100 years old, with all having undergone some form of renovation including roof material replacement and kitchen and toilet facility updates. However, maintenance practices show concerning gaps, particularly in addressing termite damage and structural decay.

The structural assessment identified several critical issues requiring immediate attention. Termite damage was observed in some surveyed houses, while decay was noted on sea-side columns of boat houses. The moisture content of columns tends to be higher at lower portions, creating conditions conducive to decay and structural degradation.

B. Seismic Performance Characteristics

The natural frequency measurements provide crucial insights into seismic performance characteristics. The relatively narrow frequency ranges observed in both main houses and boat houses suggest consistent construction practices and material properties across the district. However, the overlap in frequency ranges between different building types indicates potential for resonance effects during seismic events.

The comparison with Yuasa district reveals interesting differences in structural characteristics. While Ine shows relatively consistent frequency distributions between main houses and boat houses, Yuasa demonstrates larger frequency variations in the ridge direction, suggesting different structural responses to seismic forces.

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VIII. DISASTER PREPAREDNESS AND COMMUNITY RESPONSE

A. Historical Disaster Experience

The community's historical experience with disasters has shaped both architectural practices and emergency response procedures. The 2004 typhoon and the 1927 Northern Tango Earthquake represent significant events in the community's collective memory, influencing current disaster preparedness approaches.

Traditional disaster response mechanisms included evacuation by boat when road access was blocked by collapsed buildings or debris. This historical practice reflects both the community's adaptation to its environment and the limitations imposed by narrow roadways and dense building arrangements. The average ridge spacing of only 98 centimeters between main houses and boat houses creates significant evacuation challenges during emergencies.

B. Modern Disaster Preparedness

Contemporary disaster preparedness efforts face multiple challenges including aging infrastructure, changing demographics, and evolving risk profiles. The community has implemented various protection measures including coastal protection works utilizing cement solidification and stone placement techniques. However, the effectiveness of these measures requires ongoing evaluation and adaptation to changing environmental conditions.

The integration of modern technology with traditional knowledge represents a critical opportunity for enhancing disaster resilience. Seismic alert systems, improved communication networks, and advanced structural monitoring techniques can supplement traditional community-based disaster response mechanisms.

IX. PRESERVATION CHALLENGES AND OPPORTUNITIES

A. Regulatory Framework

The designation of Ine as an Important Traditional Building Clusters Preservation District has created both opportunities and challenges for building maintenance and renovation. While the designation provides legal protection and potential funding support, it also imposes strict regulations that may complicate necessary maintenance and retrofitting activities.

The balance between historical preservation requirements and modern safety standards requires careful consideration. Few houses have implemented seismic retrofitting, with residents citing concerns about ground conditions, historical earthquake performance, and uncertainty about future occupancy by younger generations.

B. Maintenance and Retrofitting Needs

The maintenance requirements for traditional wooden structures in Ine extend beyond routine repairs to include comprehensive structural upgrades addressing seismic vulnerability and environmental degradation. Current maintenance practices focus on ventilation, weeding, and annual thorough cleaning, but lack systematic approaches to termite damage mitigation and structural decay prevention.

The availability of skilled craftsmen represents a critical constraint in implementing comprehensive maintenance programs. While many houses have established relationships with cooperating carpenters, the overall capacity for traditional construction and maintenance work remains limited.

X. FUTURE DIRECTIONS AND RECOMMENDATIONS

A. Integrated Preservation Strategy

The protection of traditional wooden structures in Ine requires an integrated approach that combines historical preservation principles with modern disaster resilience strategies. This approach should encompass comprehensive structural assessment, targeted retrofitting programs, and community-based maintenance systems.

The development of preservation strategies must consider the evolving social and economic context of the community. The integration of tourism development with preservation efforts can provide economic sustainability while maintaining cultural authenticity. However, this integration requires careful planning to avoid commercialization that could compromise the traditional character of the district.

B. Technology Integration

The application of modern technology offers significant opportunities for enhancing both preservation effectiveness and disaster resilience. Advanced monitoring systems can provide early warning of structural degradation, while modern materials and construction techniques can improve structural performance without compromising historical authenticity.

The development of comprehensive documentation systems utilizing digital technologies can preserve traditional knowledge while facilitating modern maintenance and repair activities. Three-dimensional scanning, building information modeling, and digital archiving can create valuable resources for both research and practical preservation activities.

XI. CONCLUSION

The case study of Ine Port in Ine Town, Kyoto Prefecture, provides valuable insights into the protection of important traditional wooden structures under disaster conditions. The research demonstrates that successful preservation requires a balanced approach combining historical preservation principles with modern disaster preparedness strategies.

The traditional wooden structures of Ine have demonstrated remarkable resilience over centuries, adapting to both environmental conditions and changing social needs. However, current challenges including aging demographics, climate change, and evolving economic conditions require proactive intervention to ensure continued preservation.

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The integration of community involvement, technological advancement, and regular maintenance represents the most promising approach for sustainable preservation. The lessons learned from Ine's experience offer valuable guidance for similar traditional communities worldwide facing comparable challenges in balancing heritage preservation with contemporary safety requirements.

The protection of traditional wooden structures in Ine requires ongoing commitment from multiple stakeholders including government agencies, academic institutions, community organizations, and individual property owners. The success of preservation efforts will depend on the ability to maintain this collaborative approach while adapting to evolving challenges and opportunities.

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