

Analysis on Crack Disease Characteristics and Environmental Causes of Timber Components of Guild Hall-type Historic Opera Stages in Chengdu Area

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Abstract

The "Huguang Filling Sichuan" immigration movement from the late Ming Dynasty to the early Qing Dynasty gave birth to a large number of guild hall buildings in Chengdu. As dual carriers of immigrant culture and traditional timber construction techniques, the attached historic opera stages are of important historical and architectural value. Under the combined effect of subtropical humid monsoon climate and semi-open courtyard space, timber components of this type of opera stage generally suffer from crack diseases, and the disease manifestations are highly correlated with micro-environmental characteristics. Taking typical guild hall opera stages such as Jiangxi Guild Hall, Guangdong Guild Hall and Huguang Guild Hall in Luodai Ancient Town as research samples, this paper summarizes the main types and spatial distribution laws of cracks in timber components of guild hall-type historic opera stages based on on-site disease investigation and spatial environment analysis, and analyzes the environmental causes of crack formation from the perspectives of timber moisture content fluctuation, roof leakage, ground moisture regain, ventilation difference and biological diseases. The research shows that the crack diseases of guild hall-type opera stages in Chengdu have significant position differences: the beams and girders at the stage opening are dominated by surface grain-parallel cracks caused by alternating dry and wet conditions; column bases mostly have cracks accompanied by moisture-induced decay; end cracks are prone to occur at beam-end joints under the superimposed effect of shrinkage and stress; and the backstage side corridors mostly have hidden humid diseases. On this basis, this paper proposes a preventive protection idea centered on environmental improvement, so as to provide reference for the prevention and control of timber component diseases of similar guild hall buildings in Chengdu.

Keywords

Chengdu; Guild Hall-Type Historic Opera Stage; Timber Component Crack; Disease Characteristic; Environmental Cause

1. Introduction

The "Huguang Filling Sichuan" immigration movement from the late Ming to the early Qing Dynasty profoundly changed the social structure and architectural landscape of Sichuan. Immigrants from various provinces built a large number of guild halls based on geographical and kinship ties, which served as public spaces for fellow villagers' sacrifice, discussion, relief and festival activities. As a standard facility of guild halls, the opera stage, with both the functions of ritual performance and crowd gathering, has become an important material carrier of local culture and traditional construction techniques[2-3]. Luodai Ancient Town in Chengdu is the core settlement area of Hakka immigrants in western Sichuan. It preserves many relics of Qing Dynasty guild hall opera stages, including Jiangxi Guild Hall (the 18th year of Qianlong Reign, 1735), Huguang Guild Hall (the 11th year of Qianlong Reign, 1746) and Guangdong Guild Hall. Their timber structure systems are relatively well preserved, and their disease characteristics have strong regional representativeness.

Located in the western part of Sichuan Basin, Chengdu belongs to a typical subtropical humid monsoon climate zone, with high annual air humidity, frequent rainy days and obvious seasonal temperature and humidity fluctuations, which poses a severe challenge to the durability of timber structure buildings[2]. Compared with relatively enclosed spaces such as the main hall of guild halls, opera stage buildings are characterized by open stage openings, semi-outdoor service and significant environmental differences between front and rear spaces. Timber components have long been in a complex environment with alternating dry and wet conditions, local humidity and leakage risks, resulting in frequent diseases such as cracks, decay and insect infestation. Among them, cracks, as the most intuitive disease manifestation, are not only the external embodiment of natural aging of wood, but also may be a signal of abnormal structural stress, environmental erosion and biological diseases, and are the key focus of daily inspection and protection of cultural relic buildings[9-10].

Existing studies on traditional opera stages in Sichuan mostly focus on architectural form, spatial pattern and historical and cultural value[2,4]. Special research on timber component diseases is still relatively insufficient, especially the analysis of crack causes combined with regional climate and guild hall spatial characteristics needs to be deepened. Based on this, taking typical guild hall opera stages in Luodai Ancient Town of Chengdu as samples, this paper sorts out the structural and spatial characteristics of guild hall-type historic opera stages, summarizes the types and distribution laws of timber component crack diseases, and focuses on analyzing the action mechanism of environmental factors on the formation and development of cracks, so as to provide a basis for the protection and restoration of similar cultural relic buildings in Chengdu.

2. Spatial and Timber Structural Characteristics of Guild Hall-type Historic Opera Stages in Chengdu

2.1. Formation Background and Spatial Organization

During the immigration tide in the early Qing Dynasty, after immigrants from other provinces entered Sichuan, they established guild hall organizations one after another to maintain fellow villagers' feelings and protect group interests. Market towns around Chengdu became concentrated distribution areas of guild hall buildings due to prosperous commerce and immigrant settlements[3]. With its node position in the Hakka immigration route, Luodai Ancient Town preserves a large number of well-patterned guild hall building complexes, and their attached opera stages are typical representatives of guild hall-type opera stages in Chengdu.

From the perspective of spatial organization, guild hall opera stages generally adopt a courtyard layout of "gateway — opera stage — courtyard — main hall". The opera stage is located at the entrance end of the courtyard, with its opening facing the main hall, forming a ritual spatial order of "performance in the front and sacrifice in the rear"[2]. Audiences gather in the courtyard and under the corridors on both sides to watch performances. The backstage is connected with the wing rooms on both sides, serving as spaces for waiting, makeup and prop storage. This courtyard layout places the timber components of the opera stage in a semi-enclosed micro-environment: the stage opening and front eaves face the open courtyard, directly affected by sunlight, wind, rain and temperature and humidity changes; the backstage and side corridors are relatively closed with poor air mobility, which is prone to local moisture accumulation; column bases are close to the courtyard ground, significantly affected by drainage conditions and ground moisture regain. The environmental differences in different spatial parts directly lead to the distribution differentiation of crack diseases.



Figure 1. Survey Area Location Map

2.2. Characteristics of Timber Structure System

All guild hall opera stages in Chengdu adopt a traditional timber frame system combining column-and-tie construction and beam-post construction, mainly composed of columns, beams, girders, purlins, rafters and decorative components. The joints are mainly mortise-and-tenon connections, with few metal components[2]. To ensure transparent viewing sightlines, the stage opening usually adopts long-span beams and girders and reduces front-row columns, so that the

stage opening forms a complete open performance interface. The front eaves extend far to shield the stage opening area. Decorative components such as sparrow braces, hanging lattice and bracket sets are arranged under the eaves, which have both structural support and decorative functions. Stone column plinths are set under column bases, originally designed to isolate ground moisture. However, affected by factors such as later ground elevation, poor drainage and rain splash, column bases are still often in a high-humidity environment.

Compared with ordinary residential timber structures, timber components of guild hall opera stages have two remarkable characteristics: first, the beams and girders at the stage opening have large spans and high exposure, and are more directly affected by environmental changes; second, there are rich component types, ranging from load-bearing columns and beams to decorative joinery, with diverse disease manifestations. These structural characteristics determine that the crack diseases of guild hall opera stages are not evenly distributed, but show obvious spatial position differences.

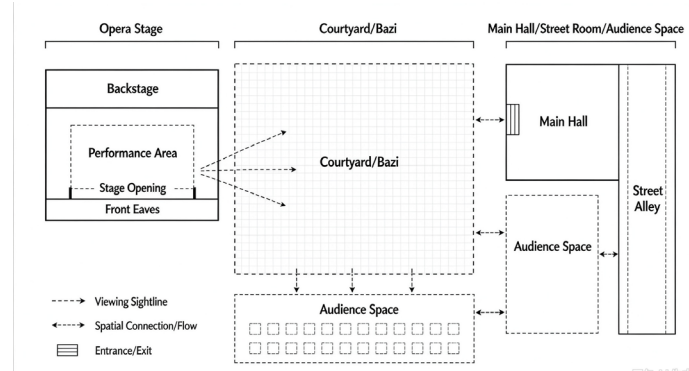


Figure 2. Example of a Stage Viewing Space

3. Types and Distribution Characteristics of Crack Diseases in Timber Components of Guild Hall-type Historic Opera Stages

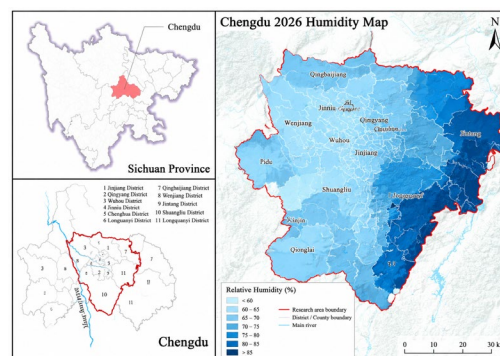


Figure 3. Humidity map of the Chengdu area

3.1. Main Types of Crack Diseases

According to on-site investigation, the timber component cracks of guild hall-type

historic opera stages in Chengdu can be classified by direction, depth and accompanying diseases, and the causes and risks of different types of cracks vary significantly.

Classified by crack direction, grain-parallel cracks are the most common. They mostly extend along the wood fiber direction, with long length and varying width, mainly distributed on column bodies, beam sides and girder surfaces, and are closely related to wood shrinkage and swelling and long-term aging[15]. Transverse cracks and oblique cracks are relatively few but have higher risks: transverse cracks are perpendicular to the fiber direction, which easily weakens the section continuity of components, and mostly appear in the tension area at the bottom of beams and near beam-end joints; oblique cracks are mostly found at mortise-and-tenon joints, often related to shear stress, joint restraint and uneven shrinkage.

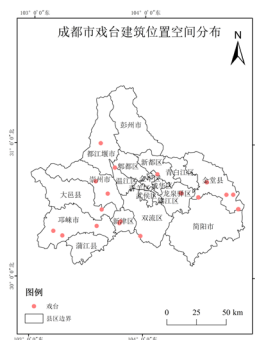


Figure 4. Spatial Distribution of Theater Stage Buildings in Chengdu

Classified by crack depth, they can be divided into three categories: surface cracks, deep cracks and through cracks. Surface cracks are mostly cracks on the wood surface or paint layer with shallow depth. They are common in exposed components at the stage opening and decorative timber components, mainly affecting the architectural style, with low structural risk in the short term. Deep cracks have obvious gaps and have developed into the interior of the wood. If they are located at key parts of load-bearing components, attention should be paid to their weakening effect on the section. Through cracks run through the component section, causing great damage to structural integrity. They occasionally appear at moisture-prone or stress-concentrated parts such as beam ends and column bases, which require key monitoring.

Classified by accompanying diseases, they can be divided into simple shrinkage cracks and composite cracks. Simple shrinkage cracks are only caused by changes in wood moisture content, without accompanying phenomena such as decay and insect infestation, and are mostly in a stable state. Composite cracks are accompanied by decay, insect infestation, water stains or later repair traces. Diseases often promote each other, with higher risk levels, and are the key objects of protection and repair[5].

3.2. Spatial Distribution Law of Crack Diseases

From the investigation of three guild hall opera stages in Luodai Ancient Town, the spatial distribution of crack diseases has obvious regularity, concentrated in four key parts:

(1) Stage opening and front eaves

Beams and girders at the stage opening, purlins and rafters on the front eaves, and decorative components under the eaves are the areas with the most concentrated cracks. Located in the transition zone between indoor and outdoor, this part is long affected by the alternating effects of sunlight exposure, rain splash and seasonal temperature and humidity changes. The wood repeatedly shrinks and swells, and is prone to form a large number of surface grain-parallel cracks and end cracks[16]. At the same time, under the superimposed effect of long-term load and shrinkage stress, the long-span beams and girders at the stage opening are prone to extended cracks on the beam sides and ends. For example, there are multiple grain-parallel cracks along the length direction of the large girder at the stage opening of Jiangxi Guild Hall Opera Stage, with a maximum length of more than 2 meters, accompanied by local paint peeling.

(2) Column bases and platform foundations

Column bases are high-incidence parts of composite diseases. Due to poor courtyard drainage, elevated ground pavement, rain splash and other reasons, the column base area is in a high-humidity state for a long time. The wood moisture content is high, which is easy to induce decay and insect infestation, and then form cracks[7]. Such cracks are often accompanied by wood discoloration, softening, wormholes and other phenomena. The cracks extend upward along the column base, and in severe cases, the section of the column base will be weakened, affecting the vertical load-bearing safety. Obvious cracking and wood decay can be seen at some courtyard-side column bases of Huguang Guild Hall Opera Stage, with moisture regain traces on the surrounding ground.

(3) Beam ends and mortise-and-tenon joints

The tenon insertion parts of beam ends and column-beam joints are high-incidence areas of cracks. On the one hand, the water loss rate at the end of wood is faster than that in the middle, which is easy to produce end shrinkage cracks, resulting in larger gaps between tenons and mortises; on the other hand, roof load transfer and joint restraint produce additional stress at the ends, aggravating the development of cracks[10]. If there is leakage on the roof, rainwater seeps into the joints along the beam ends, which will also induce decay and loosening, forming a vicious cycle of "leakage — cracking — decay — loosening". Cracks and iron reinforcement traces coexist at some beam-end joints of Guangdong Guild Hall Opera Stage, indicating that joint diseases have been treated later.

(4) Hidden parts of backstage and side corridors

Due to poor ventilation, insufficient lighting and perennial dampness in the

backstage and side corridors, the moisture content of timber components is generally high, which is easy to form hidden cracks and decay-related diseases. Diseases in this part are often not easy to be found, and long-term development can cause decay of purlins and rafters and joint loosening. Compared with the surface cracks at the stage opening, the cracks in the backstage are less obvious in appearance, but have a higher probability of accompanying biological diseases and greater potential threat to the structure.

4. Analysis of Environmental Causes of Crack Diseases in Guild Hall-type Historic Opera Stages

The formation of cracks in timber components is the result of the combined action of wood properties, structural stress and environmental factors. The coupling effect of Chengdu's humid climate and guild hall courtyard space is the core reason for the regional characteristics of crack diseases in guild hall opera stages. Combined with wood science theory and on-site environmental observation, the action mechanism of environmental factors can be analyzed from the following five aspects.

4.1. Moisture Content Fluctuation and Wood Shrinkage-Swelling Effect

Wood is a typical anisotropic hygroscopic material. Its moisture content changes with ambient temperature and humidity, resulting in shrinkage and swelling deformation[15]. The air humidity in Chengdu is at a high level all year round, but seasonal fluctuations and local micro-environment differences will cause repeated changes in wood moisture content. For components at the stage opening and front eaves, the surface temperature rises under sunlight during the day, and the moisture content decreases to produce shrinkage; at night or in rainy weather, the humidity rises and the wood absorbs moisture again and swells. Long-term repeated dry-wet cycles produce uneven internal stress in the wood, and finally form grain-parallel cracks along the weak parts of the fiber[16].

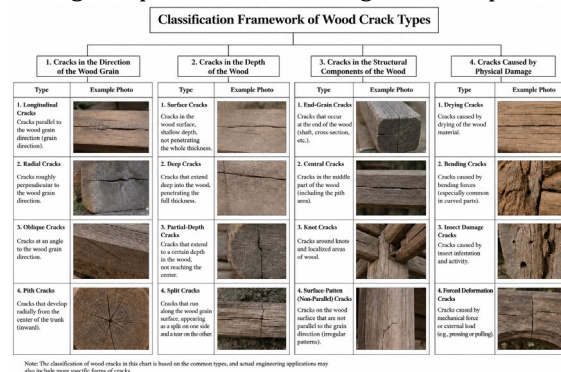


Figure 5. Classification Diagram of Cracks in Wooden Components of Ancient Theaters

At the same time, there are significant differences in the shrinkage rates of wood in radial, tangential and longitudinal directions. The tangential shrinkage rate is about

twice that of the radial direction, and the longitudinal shrinkage rate is extremely small[15]. This anisotropy leads to inconsistent deformation in different directions of the component section, which is more likely to produce internal stress concentration in columns and beams with larger sections, and induce grain-parallel cracking. This is also an important reason for the widespread existence of grain-parallel cracks on column bodies and beam sides.

4.2. Roof Leakage and Moisture of Upper Components

The roof is the first barrier for timber components to resist rain. Once the traditional tile roof has damaged tiles, cracked ridge joints or poor gutter drainage, rainwater will seep into the roof system and transfer downward along rafters, purlins and beams step by step[5]. Chengdu has heavy rainfall and many rainy days, and the risk of roof leakage is significantly higher than that in dry areas of northern China.

Rainwater infiltration will directly increase the local wood moisture content. On the one hand, it aggravates the shrinkage-swelling effect; on the other hand, it provides suitable moisture conditions for the reproduction of decay fungi and borers. At beam ends, purlins and column heads in long-term leakage areas, cracks, water stains, discoloration and decay often coexist, and cracks develop along the rainwater infiltration path. For example, obvious water stains can be seen around the cracks of some under-eave purlins in Huguang Guild Hall Opera Stage, and there are traces of loose tiles at the corresponding roof position, indicating a direct correlation between leakage and cracks.

4.3. Ground Moisture Regain and Column Base Diseases

Column bases are isolated from the ground by plinths. However, in the humid environment of Chengdu, rising ground moisture, courtyard water accumulation and rain splash still keep the column base area in a high-humidity state for a long time[8]. If the courtyard ground pavement is elevated later and the plinths are buried, it will block the air circulation around the column bases and aggravate the erosion of moisture on the column bases.

When the wood at column bases is in a high moisture content environment for a long time, the fiber strength decreases, and biological damages such as decay fungi and termites intensify, leading to wood decay from the surface and then cracking. Such cracks are often not simple shrinkage cracks, but decay-accompanied cracks, characterized by soft wood around the cracks, dark color, accompanied by wormholes or mildew spots. Since column bases bear vertical loads, there are structural safety hazards after section weakening, which is the top priority of disease prevention and control for timber components of guild hall opera stages

4.4. Ventilation Condition Differences and Hidden Diseases

There are significant differences in ventilation conditions between the front and

rear spaces of guild hall opera stages: the stage opening faces the open courtyard with good air circulation; the backstage and side corridors are mostly closed or semi-enclosed spaces with poor air mobility, making it difficult for moisture to discharge, and easy to form a local high-humidity microclimate[5].

Insufficient ventilation will not only increase the average moisture content of wood, but also prevent the wet parts from drying for a long time, accelerating the development of decay and mildew. Timber components in the backstage often have intact surfaces but internal deterioration. Cracks are mostly hidden on the back of components or in joint gaps, which are difficult to find in daily inspections and have strong concealment. Once such diseases are discovered, they have often developed to a relatively serious degree.

4.5. Superimposed Promotion Effect of Biological Diseases

The warm and humid climate in Chengdu is very suitable for the survival and reproduction of decay fungi and borers, and there is an obvious mutual promotion relationship between biological diseases and cracks[7]. On the one hand, cracks provide channels for rainwater, dust and insect eggs to enter the interior of the wood, accelerating the development of decay and insect infestation; on the other hand, decay and insect infestation will destroy the wood fiber structure, reduce component strength, and make cracks further expand and deepen, forming a vicious circle.

On-site investigation found that where there is decay and insect infestation, the cracks are often wider, deeper and irregular in shape; while simple shrinkage cracks have neat edges and stable development. This also shows that the risk of cracks cannot be judged only by width, but should be comprehensively judged combined with accompanying biological diseases and component positions.

5. Conclusion

As important relics of immigrant culture and traditional timber construction techniques, guild hall-type historic opera stages in Chengdu have distinct regional and type characteristics in their crack diseases. Under the combined influence of courtyard-style spatial layout and humid climate, the cracks in timber components show obvious position differentiation rules: the front eaves of the stage opening are dominated by surface grain-parallel cracks caused by alternating dry and wet conditions; column bases are characterized by moisture-induced decay-accompanied cracks; end cracks are prone to occur at beam-end joints under the superimposed effect of shrinkage and stress; and the backstage side corridors mostly have hidden humidity-accompanied diseases.

The formation of cracks is not the result of a single factor, but the product of multiple environmental factors including wood shrinkage and swelling, roof leakage, ground moisture regain, insufficient ventilation and biological diseases. Among them, moisture content fluctuation is the basic cause of crack formation, leakage,

moisture regain and ventilation differences are the main reasons for the differentiation of disease parts, and biological diseases accelerate the development and deterioration of cracks.

For such diseases, protection and repair should not only focus on the filling treatment of cracks themselves, but start with environmental governance, and control the occurrence and development of diseases from the source by improving roof drainage, column base moisture protection, backstage ventilation and other conditions. This preventive protection idea centered on environmental improvement is not only applicable to guild hall opera stages in Chengdu, but also has certain reference significance for the protection of other traditional timber structure buildings in the humid environment of western Sichuan.

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