Chiiori: Survey and Analysis of Structural Problems Facing a Traditional Japanese Farmhouse

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Background

Chiiori is the name of a Japanese farmhouse (*minka*), located in Iya Valley, a remote mountainous area in the center of Japan's southern Shikoku island. Iya is probably best known as the refuge for survivors of the Heike clan, after their defeat at the end of the 12th century in a struggle for control of Japan. The remoteness and isolation of Iya made it an ideal location for these medieval political refugees, but has kept the area underdeveloped until recent times. After World Wall II, the population of Iya dropped rapidly as people emigrated to urban centers. The remaining residents turned to tourism as their main source of income after the traditional industries of agriculture and forestry collapsed due to a shortage of labor.

Chiiori has been dated to around 320 years old, but not much is known about the house before 1958, when it was abandoned by its original owners. Compared to the surrounding houses, Chiiori was most likely built by a high ranking villager around the time when Tsurui, the hamlet where the house is located, was originally settled. Due to the particulars of Iya's geology, about halfway up the sides of the valley walls there is a porous layer of rock where freshwater springs tend to emerge from the ground. Chiiori is located at this elevation, along with most of the older houses in Iya. These houses also tend to be larger than the surrounding houses, as is Chiiori, a sign of both the status of their owners and the early time period in which they were built.

Chiiori had been left completely abandoned for 17 years before it was purchased in 1973 by an American student, Alex Kerr, who has since gone on to become a famous author on modern Japanese culture. The interior was renovated at the time of purchase and the house was partially occupied for the following five years, with Kerr returning frequently between school terms. In 1978, Kerr moved to Kyoto and Chiiori was more or less abandoned again. It was used by friends traveling through the region and infrequently by Kerr himself, but not regularly maintained. The condition of the roof worsened to the point where it had to be rethatched in 1988, but the house itself was not reoccupied until 1999. That year, Kerr and a photojournalist friend, Mason Florence, started the Chiiori Project, which established a permanent caretaker position at the house on a volunteer basis.

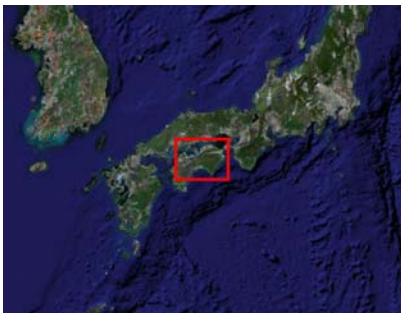


Figure 1. Island of Shikoku


Figure 2. Iya Valley


Figure 3. Hamlet of Tsurui

Present Conditions

The condition of the house seems to have worsened, in spite of near constant occupation and renovation efforts since staff positions were filled in 2000. Typically, a well thatched roof should last between 50-60 years when properly maintained. However, because the house was left unoccupied during the roof's first decade, leaks have developed within a third of its expected lifespan. A portion of the roof was covered with metal sheeting after damage caused by heavy snowfall during the 2005 winter. In 1999, a carpenter was brought in to replace water damaged timbers and buttress the sagging floor structure. However, these repairs seem to have made the entire building even more unstable, due to the removal of key structural elements. The erratic occupation and unknown history of the house has made it impossible to gauge for certain, but the consensus between Kerr, Florence, and the neighboring villagers is that the overall lean of the house has become noticeably worse in recent years.

Part of the Chiiori Project's mission is to promote traditional lifestyles as a sustainable form of eco-tourism for Iya Valley. To this end, the house has been opened up to provide lodging for overnight visitors and farmlands around the house are being cultivated to provide a sustainable source of food for the Project. As a result, several volunteers are needed to handle daily chores. I became involved with the Chiiori Project in the summer of 2006, when I emailed to volunteer for a temporary position on their staff. When I found out about the structural problems of the house, I asked to be allowed to work on an architectural survey of Chiiori in between harvesting potatoes and chopping wood. I ended up spending six weeks there during that summer, dividing my time between volunteer duties and taking photos, making measurement and drawing the structure. This report is a compilation of these efforts.

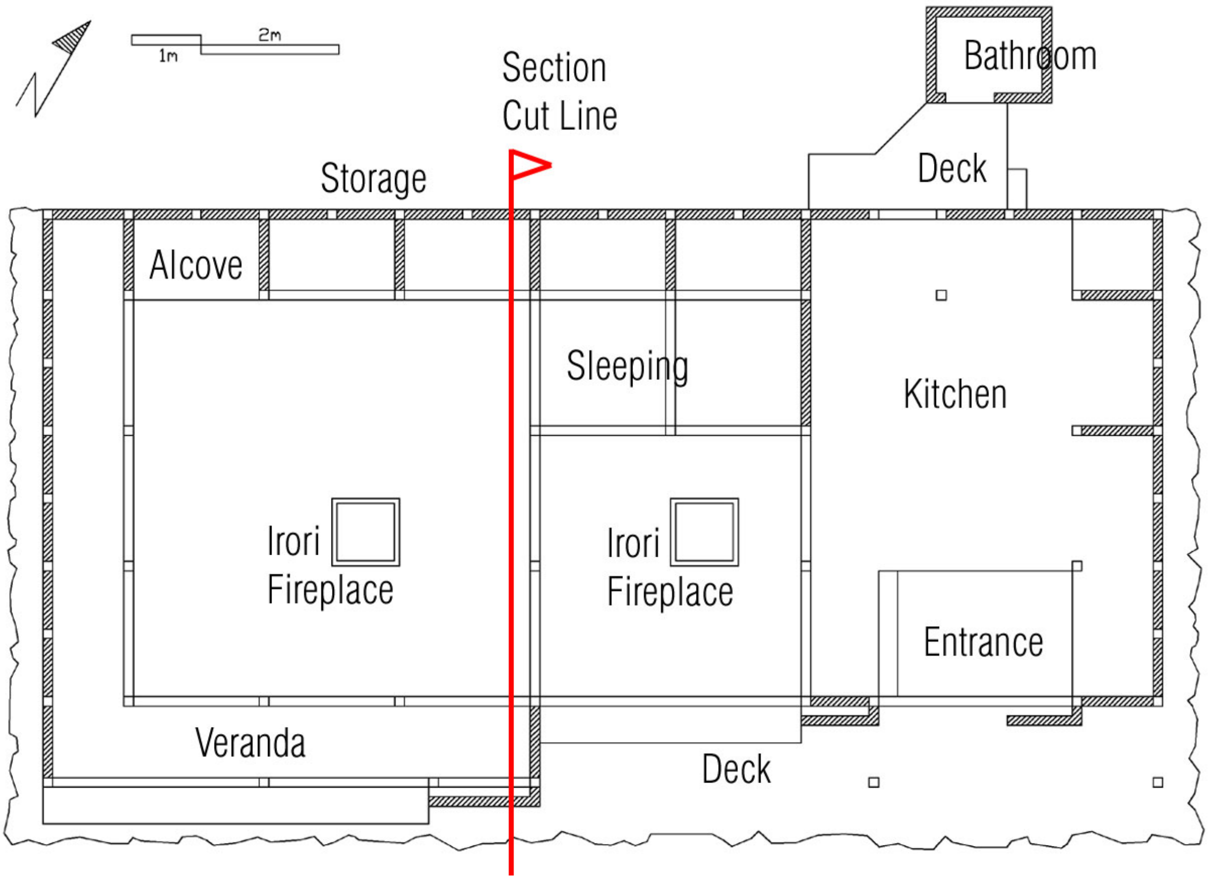


Figure 4. Floor plan of Chiiori

Orientation

While the structure of the house has remained virtually unchanged during its 320 year lifespan, the layout of the interior space has undergone dramatic shifts. The large open rooms we see today had been partitioned into smaller rooms by the original owners, to provide private sleeping quarters for an extended family. Most likely these partitions were a relatively recent addition but it is impossible to know for certain. In 1973 the partitions were removed during an interior renovation. Also at this time, a bathroom was built behind the house to replace the old pit toilet which was originally located over the potato fields. In 2000, a deck was built to connect this new bathroom to the interior of the house.

The schematic model below shows the basic structural components of Chiiori. It is sliced and separated along horizontal planes to give a better view of the roof, column and foundation structure. The large blocks at the foundation level represent the foundation stones of the irori fireplaces. It should be noted that the foundation stones beneath the kitchen, on the east side of the house, are remnants of an old fireplace that was once used for cooking. This fireplace was removed by the original owners at some point before 1958.

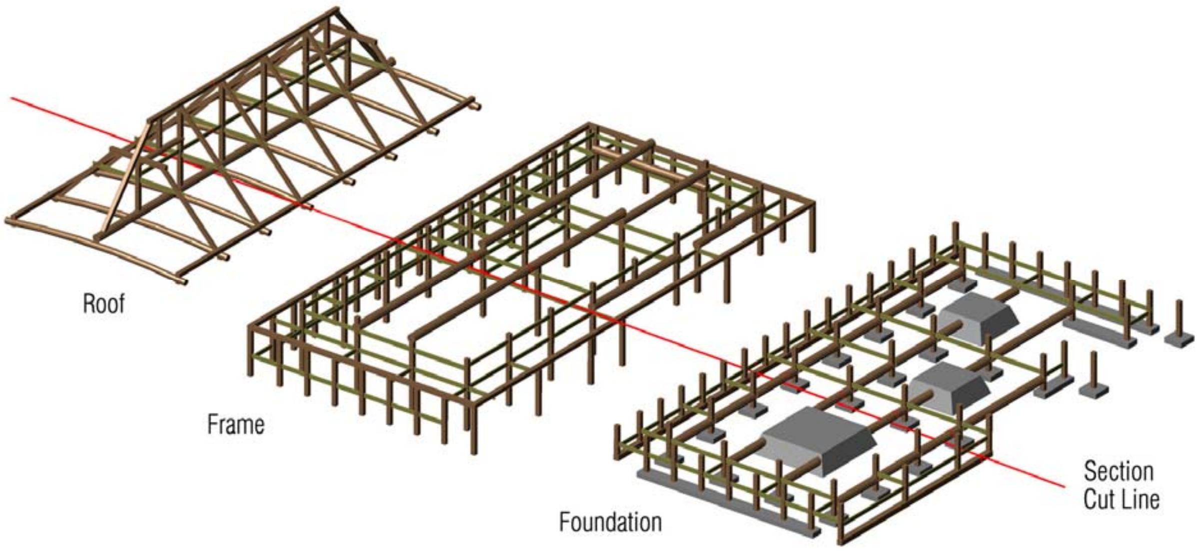


Figure 5. Overview of structural problems

Soil

The house is build on the side of a mountain, where nearly all useable flat land has been reclaimed using traditional cut and fill methods. The house rests for the most part on fill ground held in place by a dry-masonry stone retaining wall to the south. While the age of the house is relatively certain, it is unknown when the ground it is sitting on was reclaimed, or if it had been previously used for terrace farming. On the north side of the site, the cut hillside reveals bedrock close to the surface. Boulders and thick vegetation act as natural retaining walls, augmented by man-made dry-masonry stone walls in some areas. The land on the slope above the house is used for agriculture, but the portion immediately behind Chiiori is a chestnut orchard, which causes only minimal disruption to the soil and uses no irrigation.
Predominantly, there are two types of rock found in the surrounding area, slate and phyllite. Both are low-grade metamorphic rock formed by compression of ancient sea

bed. Phyllite, the stronger of the two, is used for the house's foundation stones, and is strong in compression perpendicular to foliated layers but prone to shearing along grains of mineral foliation. These phyllite foundation stones are fairly porous and tend to wick ground water upwards towards the house's wooden supports. In times of heavy rain, they can become so saturated that droplets of water squeeze out from between layers of mineral foliation. While intended to protect the wooden structure from water intrusion, the stones can in fact draw water towards the support posts during the rainy season.

The soil on the site is mostly clay, with a surface layer of semi-decomposed organic material. This organic material is heaviest on the north side, where surface runoff deposits it in a shallow depression behind the house. However, it does not appear that this material continues to move beneath the house, since the organic matter of the soil there seems to have a different composition. Most likely, the material beneath the house originated from decaying straw mats left to rot inside of the house during its period of abandonment. Beneath the house, the soil on the east side is dense and stable. On the west side, where there is heavy water intrusion, the soil is loose and sinks easily under any weight. The surface of the ground here is marked with depressions which appear to be caused by erosion.


Figure 6. North slope


Figure 7. Saturated rock


Figure 8. Clay soils test

Water

Rainwater enters the site from the north, flowing down the slope of the mountain and onto the relatively flat terrace on which the house sits. On the north-west side of this terrace, a shallow depression traps water behind the house where it is forced to percolates through the soil, creating a subsurface flow of water. During the rainy season, even if the surface soil is relatively dry, the foundation stones in the north-west corner are often saturated with water. This appears to confirm the presence of a subsurface flow of water which can persist even days after a rainstorm. It also means that the bases of wooden columns are almost continually damp during these summer months.

While the foundation stones on the north-west side of the house have the most contact with water, paradoxically their surrounding area shows few signs of erosion. In contrast, the stones beneath the south-west side of the house are relatively dry, yet the ground around them is heavily eroded. Most likely this is because water intrusion on the south side only tends to happen during heavy rains, loosening the ground through cycles of shrinking and swelling and then washing it away with sudden bursts of water. It is difficult to gauge whether the ground here is either sinking or being washed away by a horizontal flow, and where any lost material is being deposited.

Immediately after a rainstorm, puddles of water can be observed lying along a north-south axis beneath the west side of the house. No apparent surface flow of water can be seen between them. It appears that percolating water connects this series of puddles beneath the surface, making them appear almost stagnant. These puddles can be persistent during the rainy season, causing a stagnant atmosphere that allows a white mold to grow, covering any organic material on the ground. The original hardwood columns do not seem to be effected by this mold, however the newly added, cheaper softwood supports do show some signs of fungal growth.

Even during torrential rains, there is no evidence of water flow beneath the east side of the house. On the east side there is a vegetable storage pit, sunk approximately one meter beneath ground level, which did not show any signs of water intrusion even when puddles had formed two meters to the west. This can be partially explained by the slight downward slope of the ground behind the house on the north-east side, which drains water away from the house before it can penetrate the foundation. In contrast, the ground in front of the house on the south-west side often remains saturated for hours after a rainstorm, seeping out slowly through the stones of the retaining wall below. The subsurface flow of water on this west side, combined with water retaining clay soils, gives this area particularly poor drainage.


Figure 9. North side depression


Figure 10. Foundation erosion


Figure 11. West Vs. East sides

Foundation

The perimeter columns of the house are made of a poorer quality wood than that used in the columns on the interior of the structure. According to a village resident, the perimeter columns were made from the softwood of Cryptomeria, while those on the interior were made from more durable hardwoods of either Chestnut or Zelkova. Nearly all of the softwood perimeter columns have lost some portion of their structural capacity due to moisture damage, while all of the interior hardwood columns except one are in excellent condition. Being both partially exposed to the elements and made from a lesser quality timber, the perimeter columns are inherently more susceptible to rot. It appears that the original builders chose to save on material here because these columns do not join into the main structural frame and only carry the weight of the eaves.

On the north side of the house, the bases of all of the perimeter columns have been removed and replaced with new support posts in response to moisture damage. However, the original columns are not sufficiently restrained to their new column bases in the north-south direction, making them susceptible to rotation in this direction. Also, during repair work, almost all of the horizontal bracing connecting the north perimeter columns with the rest of the structure was severed. Presumably, the members had been weakened by moisture damage and were simply removed, but it is perplexing why this bracing was not replaced. The result is that the rigid structural frame is disconnected at this point, leaving the lower half of all north perimeter columns floating separately from the rest of the house.

Clustered beneath the west side of the house, simple unrestrained buttresses were installed by repair workers to provide additional support for the floor structure. Some look precariously balanced, but are stable to the touch. If there is any vertical movement in the house structure, these new members have the potential to damage the frame by applying an upwards force in undesirable places. The buttresses were installed to compensate for a loss of structural capacity in the main floor beams caused by moisture damage. Predominantly on the west side of the house, the wood of these beams is flaky and crumbles to the touch in places, consistent with symptoms of dry rot.

Despite the additional support, there is still a noticeable deflection when walking across the floor of the house.

Column bases rest directly on foundation stones with no horizontal restraint. Many of these columns exhibit some signs of movement at the base, either lateral or rotational. The lateral movement is evident in places where the column base was precisely cut to match the surface of its foundation stone, but has now shifted to reveal a small gap between the two. More common is rotational movement, usually only evident from a slight gap between the foundation stone and one side of the column base. In a few places where the column is resting on an irregularity in the foundation stone, the shear force at this point causes a small piece of the column to splinter along the grain.


Figure 12. Exterior column base


Figure 13. Unrestrained member


Figure 14. Column movement

Frame

The most noticeable structural defect of the house is the lean of almost all major structural columns by an average of two degrees towards the south. Some columns lean but remain straight while others bend while leaning. Those that bend tend to exhibit a convex curvature in the direction of the lean, with greater bending at the base of the column and less towards the top. Most also lean slightly in an east-west direction, generally leaning in toward the center of the house. The floors of the house generally follow this lean towards the south, but in a less uniform way than the columns. Some sections of the floor centered along the east west axis of the house are perfectly level, while the lean of others varies to more than twice the angle of the columns without any discernable pattern.

In many of the large, north to south running beams which form the lower chords of the roof trusses, fresh stress cracks can bee seen developing under much older cracks. While there are no new individual cracks, the old and new layers of the same crack can be seen by the clear division between the original crack blackened with soot, and the newly exposed fresh wood. Fresh stress cracks can also be seen where these same large, north to south running beams are joined to vertical columns, indicating extra stresses at these joints. While new cracking in the transverse beams is concentrated on the west side of the house, it does occur to some extent on nearly all of these beams. New cracking at the joints however, can only be seen on the west side of the house.

The thin wood members that provide horizontal bracing in the roof trusses have nearly all been either warped badly or replaced entirely. While this indicates movement of structural members, it is unclear if and how much the effects of this movement have been exaggerated by warping caused by moisture intrusion from leaks in the roof thatch. Also, the original mud and plaster walls which covered the north side of the house have been destroyed by years of water intrusion, and replaced with wood siding. The result of this moisture damage is that most of the horizontal braces tying this north wall into the main structural frame have rotten away and lost their structural capacity, much in the same way as the horizontal braces at the foundation level.


Figure 15. Column lean


Figure 16. Stress cracks


Figure 17. Warped braces

Roof

The bulk of the damage to the thatch roof occurs on the north side, where a lack of sunlight creates damp conditions during the rainy season and a buildup of snow during winter months. Villagers report that snow levels can be two times as deep on the north as on the south side of the roof. During the winter of 2005, the peak levels of snow coverage were approximately one and a half meters on the north side and three quarters of a meter on the south side. The thatch is only eighteen years old, but shows damage more consistent with a roof three times its age. Primarily, this damage is the result of the house's abandonment since rethatching. A crucial part of maintaining a thatch roof is keeping wood fires constantly lit, as the heat helps to dry out the thatch and the smoke destroys any potential plant or fungal growth.

On the north side, damage to the thatch is so severe that the bamboo cross pieces used to hold layers of thatch together have been exposed. Normally, these should be no less than five centimeters below the surface of the roof. Most likely, because fires were not constantly lit during previous winters, ice formed as snow melted and refroze, binding to the thatch and gradually stripping it from the surface of the roof. Damage to the north side of the roof has been so extensive that leaks have formed under this side of the house. In early 2006, metal sheeting was installed over the most heavily damaged areas. The edges of the sheets were first wedged under a portion of the thatch, then hammered upwards, to get as deeply beneath the thatch as possible. They were then covered with a protective coating of tar and the edges sealed with an epoxy foam.


Figure 18. North Vs. West sides


Figure 19. Exposed bamboo


Figure 20. Thatch loss

Measured section

This section was drawn from exact measurements taken on site at Chiiori. The original drawing was made in pencil at 1:10 scale and then drafted in hard line off site. Due to the difficulty in measuring parts of the structure, some areas of the drawing are more accurate than others. The bottom half of the drawing is accurate to a half centimeter, while the roof truss is accurate to two centimeters. Being unable to measure the surface of the roof and the roof ridge, these areas are not accurate, and represent an approximation.

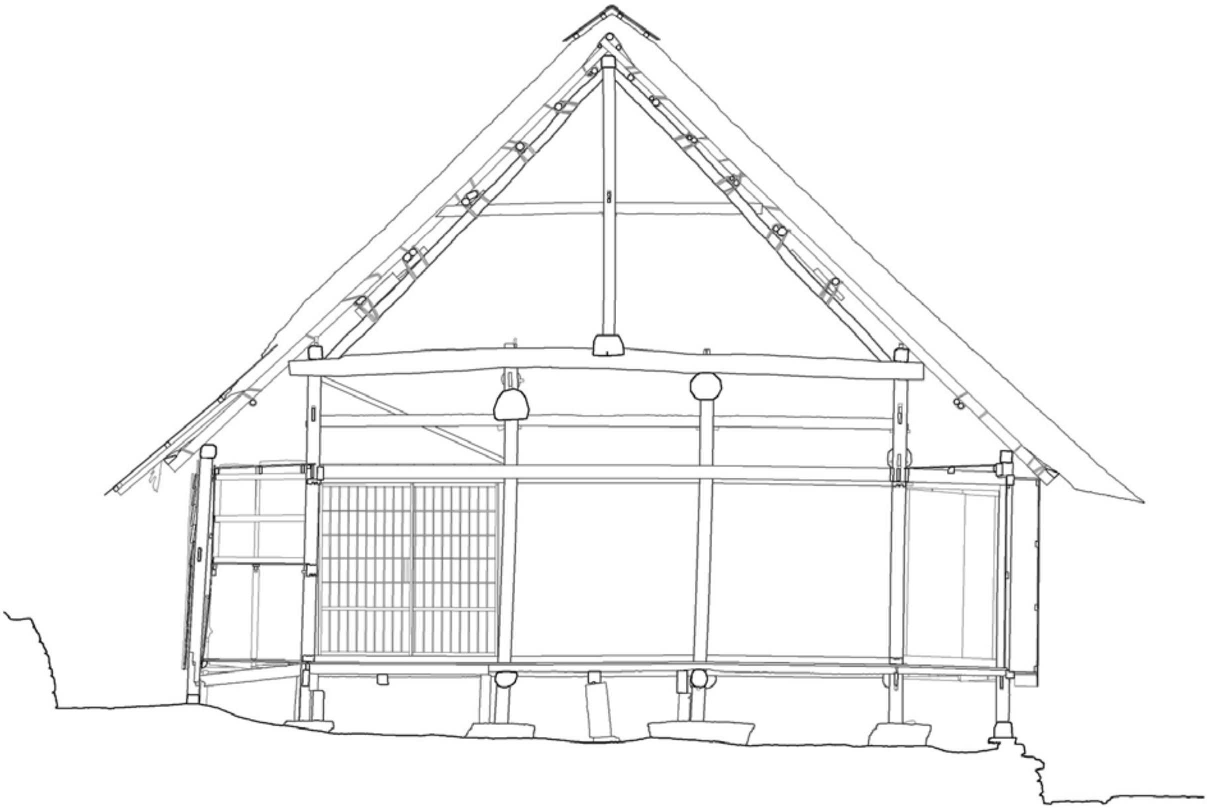
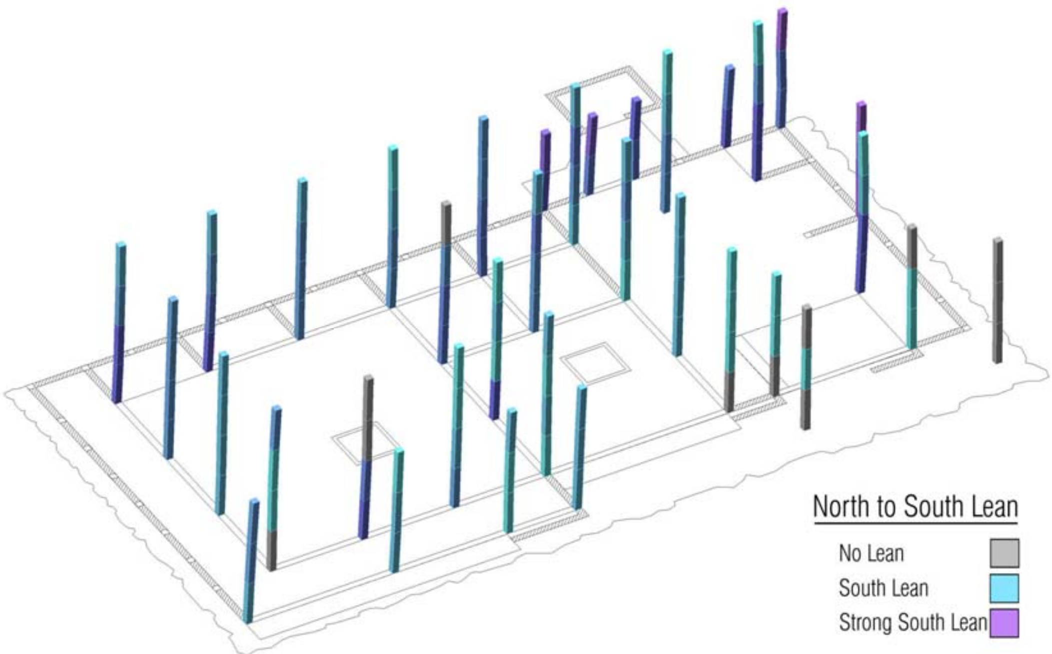
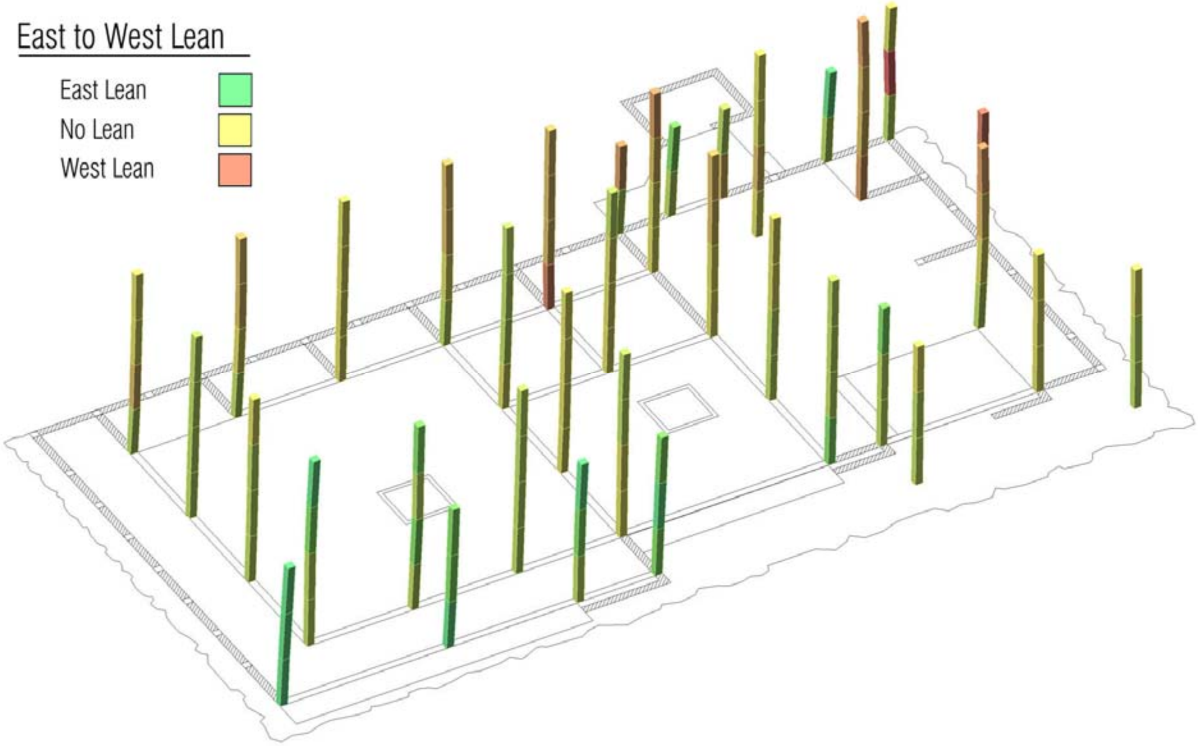


Figure 21. Column lean measurements

The following two images are visual representations of measurements taken on site at Chiiori. All of the major structural columns accessible on at least two sides were measured in four places, at the foundation level, at foot and head heights in the house, and at the ceiling. The measurements were converted into colors representing varying angles of lean.





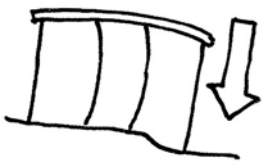
The north to south lean diagram reveals that while all columns are leaning to the south, those on the northern side of the house are leaning more severely than those on the southern side. The east to west lean diagram shows a similar clear pattern of movement, in this case the south-eastern most columns are leaning inwards to the west, and the north-western columns are leaning to the east, indicating that a torsional force is acting on the entire structure. While there are several localized irregularities, a distinct pattern emerges from the diagrams. In both cases, these results show the early stages of global structural failure. The joints holding the structure together have begun to slowly weaken, which will eventually cause the entire building to slowly collapse upon itself.

ANALYSIS

Structural Lean

In order to understand the cause of the structural lean, it is important to make a distinction between columns which lean while remaining straight and those which lean and bend at the same time. There are some exceptions, but generally it is the central columns which show the most bending, while those at the edges of the structure are only leaning.

This behavior implies that additional vertical load is being placed on the central columns, forcing them to bend. Since it is unlikely that the roof structure is causing a load heavy enough to bend the thick columns, it is probably originating from the ground. While an upheaval of the soil could create this pressure, considering the evidence of heavy water infiltration and erosion beneath the house, it is more logical to conclude that the southern portion of the ground is instead sinking. Any sinking would pull down on the roof truss, putting pressure on the central columns from above.



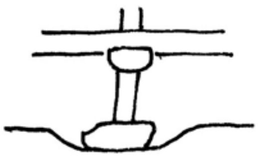
This theoretical sinking of the ground, even if it were to cause bending in the central columns, would not necessarily be responsible for the overall lean of the structure. However, since the structural members are securely jointed together, the entire structure acts like a rigid frame. So if one section sinks, it would tend to pull on the entire frame through its rigid connections, forcing the house to lean in order for the joints to remain square.

There are several indications that the leaning might be caused by forces acting on the north side of the house. Generally, this area is home to most of the house's physical damage, which might suggest some connection with the lean. If that were true, the weakened north exterior wall would cause the structure to lean north due to a loss of support, which is clearly not the case. More plausibly, this is the direction from which heavy winds tend to blow during storms, from which water enters the structure, as well as where shade causes heavier snow loading during winter months. While there is a distinct possibility that these forces are exacerbating the lean, I believe they are not severe enough to be its primary cause.

Close examination of the structure reveals a slight bend in the central support post of the roof trusses. This confirms that sinking ground on the south side of the house is causing the lean of the structure. As explained above, this sinking is causing the horizontal beam of the roof truss to essentially squeeze the central columns against the ground. The ground is stable enough in this central area to resist the pressure, causing the columns to push up on the roof truss, bending its central post.

Sinking Ground

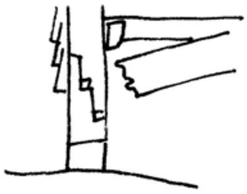
If sinking ground is causing the structural lean, what is causing the sinking ground? Possibly, water intrusion is eroding the soil around individual foundation stones, causing them to sink. In this case the damage would be isolated locally and relatively easy to repair. While signs of erosion beneath the west side of the house would seem to confirm this guess, the complete absence of erosion on the east side makes it very unlikely. Because the entire structure is leaning evenly to the south, the more probable answer is that the terrace itself is sinking.



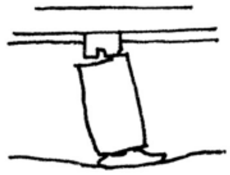
While the terrace on which Chiiori sits is man-made and was originally constructed of loose fill dirt, it is over 300 hundred years old and should no longer be settling naturally. Instead, the water runoff which collects behind the house and drains under it could be increasing pressure on the terrace's stone retaining wall, slowly pushing it down the mountain. The wall itself appears to be stable, and is not in any immediate danger of collapse under normal patterns of usage. However, the structural capacity of the entire terrace could be weakened, and if an unusually heavy load is placed on the site there is a chance the retaining wall could collapse.

Local Damage

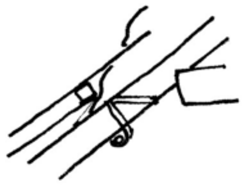
Water intrusion into the structure on the north side of the house hascaused extensive local damage. The moisture has destroyed the bases of all northern exterior columns and most of the horizontal braces connecting them to the interior structure. While the column bases have been replaced, the braces have not, and so the northern wall is essentially floating separately from the structure, connected only at the top through one roof beam. In any other house this could be catastrophic, but since Chiiori is leaning to the south, the damage may provide some benefit by allowing the structure to flex more freely than usual.



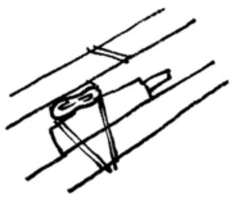
The water intrusion has also elevated the moisture level in the foundation structure, causing dry rot in the beams supporting the floor joists. The humidity is enough to sustain fungal growth in the wood even without any direct contact of water, making the wood flaky to the touch and severely limiting its structural capacity. The damage does not appear to effect the structure on a large scale, but causes noticeable deflection in the floors.



Superficially, damage to the thatch is caused by water penetration and the abrasion of ice and snow, however, a properly maintained thatch roof should be able to withstand these inevitable forces for half a century. The root cause of the roof's early deterioration is a lack of preservation and maintenance. In addition to cooking food and providing heat, traditionally a fire was kept constantly burning in the irori as a way of prolonging the roof's life. The smoke is essential for curing the thatch, killing off fungal growth, and driving away insects, while the added heat keeps the thatch dry and prevents ice from forming during the winter. After being left essentially abandoned for the first dozen years of the roof's life, the damage has already been done, and there is little that current staff can do to turn the tide.

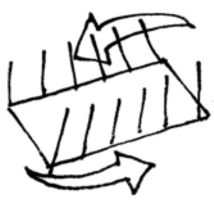


Due to the house's orientation, the north face of the roof remains in perpetual shade during winter months. This causes double the amount of snow to accumulate on the north face of the roof as on the sunny south face. As can be seen in section, the roof timbers supporting the thatch have deformed under the extra weight of the snow, causing crushing of some of the bamboo cross pieces. This is not a major problem, because the members effected are not part of the main structural core and could be easily replaced during the next rethatching of the roof. While there is little realistic danger of structural collapse, a record breaking snowfall could cause the local collapse of a small portion of the roof.

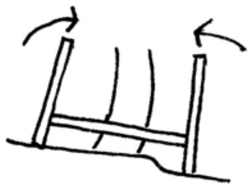


Global Collapse

While the most obvious structural defect is the predominant north to south lean, the detailed column lean measurements indicate an additional counter-clockwise twisting of the structure. The column lean on this east to west axis, averaging at a half degree off the vertical, is less severe than on the north to south axis, which averages at two degrees off the vertical. However, this racking is troubling because it indicates a large scale weakening of the entire structure.



The column lean measurements indicate a heavier southern lean in columns on the north side of the house than those on the south side. However, if the house were viewed at an angle, correcting for its average lean, it would appear that the columns are leaning inwards subtly. Combined with the racking of the structure, this indicates that added stress is not only causing the house to lean, but is weakening its joints. With almost no diagonal bracing, these joints provide crucial stability to the wooden frame. It should be stressed that these effects are very minor at the moment, but if the overall lean of the house is not corrected and stress removed from the structure, there is a danger of gradual collapse.

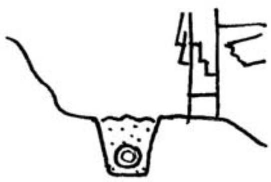


Recommendations

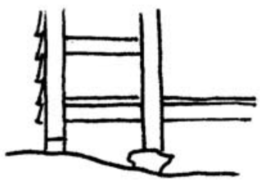
Simple maintenance will alleviate some of the deterioration suffered by the house. Hearth fires should be kept burning as often as possible to maintain the thatch roof, and during winter months snow should be gently cleared from the north side of the roof. It is important not to clear all of the snow, which could result in scraping and damaging the thatch bundles. The goal is simply to level the snow load between north and south sides of the roof.

At this point, damage to the roof is too severe to correct with maintenance alone. The north side of the roof has lost almost a quarter of its original thickness, exposing the internal bamboo cross pieces. The most severely damaged and decomposed areas of thatch were removed after a particularly heavy snowfall during the winter of 2005. Metal sheeting was installed to cover this area and prevent leaks, but this is only a temporary solution and may in fact be encouraging further moisture penetration. Quite simply, the roof must be rethatched soon.

Regardless of whether the sinking ground is being caused by localized erosion or a large scale settling of the terrace, the solution to both problems is to divert the water currently running off the mountain and collecting behind the house. The area directly behind the house should be re-graded to encourage drainage over the surface towards the east. Special attention should be paid to the area beneath the bathroom deck, which could block organic matter and prevent the flow of water. A more reliable solution would be to install a drainage pipe in a trench of gravel fill.



While diverting water runoff will alleviate the rot of floor timbers, the amount of damage already suffered and their reduced structural capacity will require them to be replaced at some point in the future. When this is done, all free-standing braces should be removed and an experienced carpenter should evaluate and more securely brace any unstable sections. Similarly, if the exterior north wall is to be rebuilt, it is important that the horizontal braces connecting this wall to the interior structure be reconstructed.



Due to the potential instability of the terrace itself, correcting the structural lean will have to be minimally invasive without the use of heavy equipment. This will be difficult and expensive, requiring the services of an experienced carpenter with specialized knowledge of traditional wooden construction. It cannot be stressed enough that the use of hydraulic jacks or any other such equipment has the potential of disrupting the retaining wall, causing massive structural collapse.

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