# ELEMENT TESTS AND NUMERICAL ANALYSYS ON THE SHEAR PERFORMANCE OF WOODEN LATH AND PLASTER WALL

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**ABSTRACT**: In this article, we conducted the element test and the numerical simulation of a type of wall which is prevailed in modern Japanese western style architecture, *Kizuri-Shikkui* (wooden lath and plaster finish). From the element tests, the shear performance of the wooden lath and plaster wall were grasped, and the shear resistant mechanism interacting with plaster layer, wooden laths and nails were estimated. Depending on the observation of tests, we proposed a simplified numerical analysis model focusing on the lath-nail joints and the strut-like compressive behavior of plaster.

**Key Words**: Wooden lath, Plaster, Shear element test, Numerical Analysis

## INTRODUCTION

*Kizuri-Shikkui* (wooden lath and plaster finish) is a type of wall constructing method which is prevailed in modern Japanese western style architecture. In order to properly evaluate the structural performance of modern wooden buildings, which are increasingly valued as cultural properties and in need of repair, it is important to understand the structural potential of wooden lath and plaster finish wall that is one of the main load-bearing walls, through experiments and analysis.

We performed compression/shear wall element tests for wooden laths walls (only nailed lath will bear the lateral force. WL series), and wooden laths and plaster finish wall (WL-P series), to clarify the behavior of WL and WL-P series walls, especially the load bearing mechanism and the failure patterns.

Then, we constructed some analytical models to simulate the structural behavior of the WL and WL+P wall, focusing on the bending performance at lath and nail joints, and compressive performance between plaster and wooden frame edges.

**Figure 1.** Construction of the specimen (left: after the 2nd layer coating, right: Plaster with hemp)

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## Shear/Compression Element Tests of Wooden Lath and Plaster Walls

We have shown the specifications of specimens in **Table1**, the construction process of the spe cimen in **Figure 1**, and the apparatus of the tests in **Figure 2**.

Method of the Experiments are as below;

The apparatuses of the tests are shown in **Figure 2.** We tested with universal testing machi ne (Max. load 200tonf), and the cycle of the load was monotonic compression loading with 1mm/min downwards, to 50 mm displacement (between diagonal pin's distance) ,1/8.3 rad.. A Steel frame with pin joints at each corner were attached to the specimen as the deformat ion apparatus. Displacements are measured with two displacement transducers (SDP-200, Tok yo Sokki), and loads are measured with a load cell (TCLP-20B, Tokyo Sokki).

**Table 1.** Specification of specimens

| item | | unit | | | note |
|---|---|---|---|---|---|
| Wooden frame (B*H*L) | | mm | 50*75*630 | | 580mm: between pin |
| | Joint detail | - | Wooden plug ($\phi$ 15) | | 3mm gap for rotation |
| | Center Stud (B*H) | mm | 30*45 | | - |
| | Species | - | Sugi (Japanese Cedar) | | Young Modulus: 7000 MPa |
| Wooden Lath (B*T*L) | | mm | 50*8*530 @58 | | - |
| | Species | - | Sugi (Japanese Cedar) | | Young Modulus: 7000 MPa |
| | Studs for lath (B*H) | mm | 20*25 | | |
| Nail | | mm | N32 *2 [30mm apart] @255 , shell diameter: 1.9 | | |
| Plaster (only on WL+P specimens) | | | t = 16 (planned. The measured value was 20) | | |
| | Mixture ratio | | | | |
| 1st and 2nd layer | Undercoat | mm | t = 2+1 | *Tsuta-awase* (Plaster Slaked lime water with hemp) | |
| 3rd layer | Flatten layer | mm | t = 1 | Same as above | |
| 4th , 5th and 6th layer | Middle layer | mm | t =4+3+3 | Plaster : Sand = 1 : 2 (or more) | |
| 7th layer | Finish coat | mm | t = 2 | Plaster (shell ash) and algae glue | |

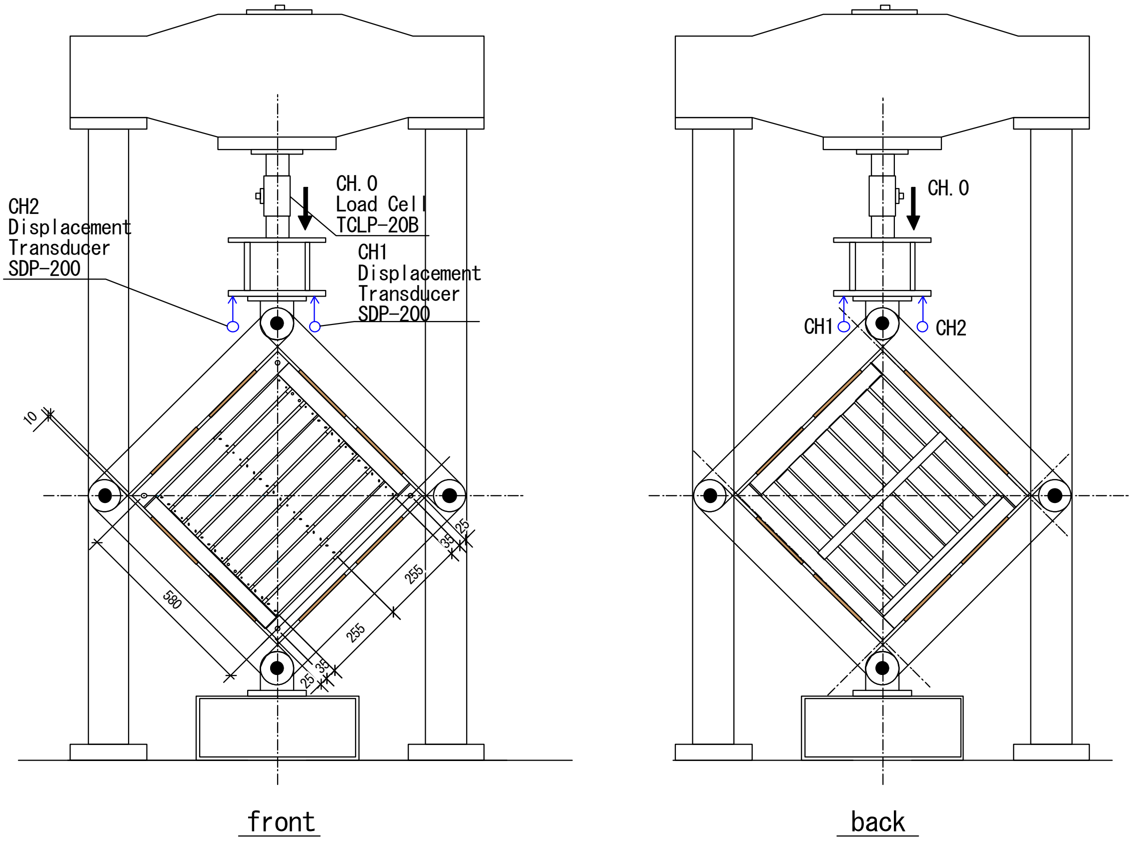


**Figure 2.** Apparatus of shear/compression experiment of wooden lath and plaster wall

## Results of the compression/shear experiments

The summaries of the tests are shown in **Figure 3**, **Table 2** and **Figure 4**.

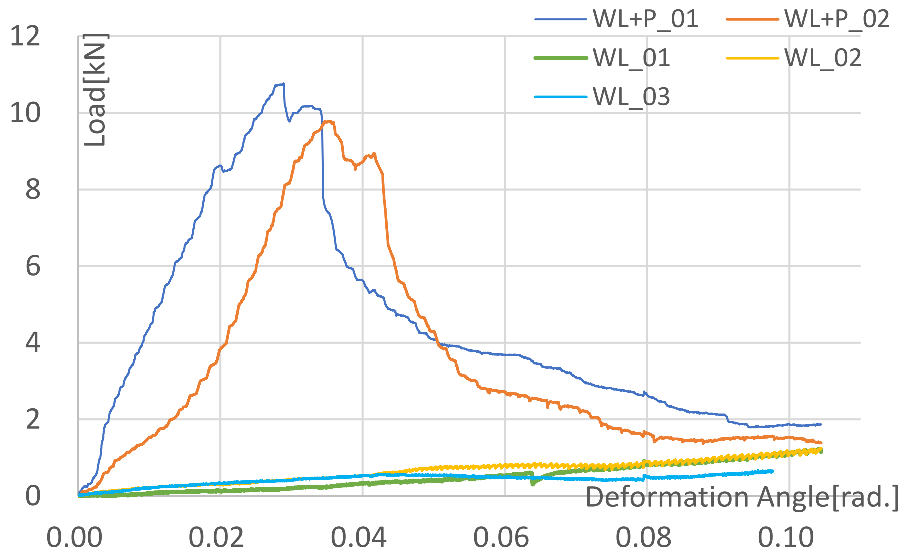


**Figure 3.** Results of the Test: WL+P (Wooden Laths and Plaster) and WL(Wooden Laths)

**Table 2.** Characteristic Value of Compression/Shear Element Test

| Characteristic Value | | Max. Load | Angle at Max. Load |
|---|---|---|---|
| | | kN | rad. |
| Wooden Lath (WL) | 1 | 1.40 | 0.1 |
| | 2 | 1.40 | 0.1 |
| | 3 | 0.60 | 0.1 |
| | ave. | 1.13 | 0.1 |
| Wooden Lath + Plaster (WL+P) | 1 | 10.7 | 0.03 |
| | 2 | 9.7 | 0.036 |
| | ave. | 10.2 | 0.033 |

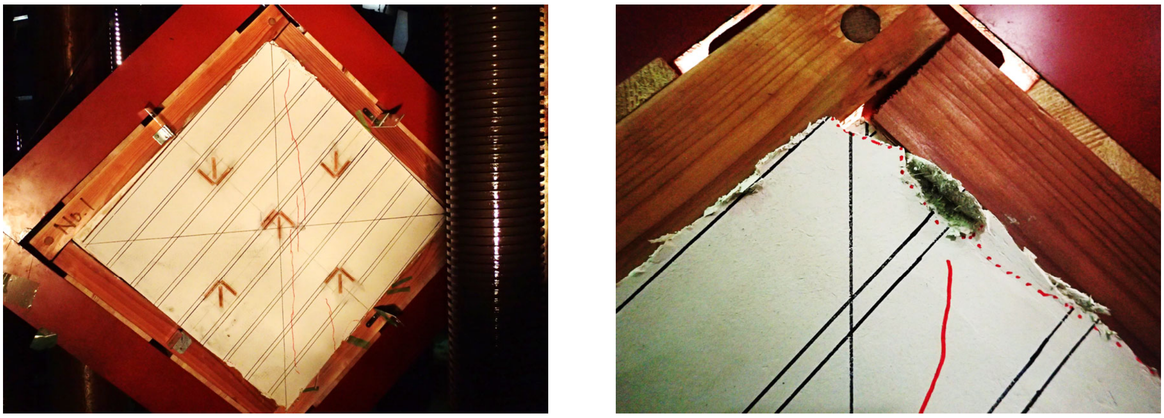

**Figure 4.** Characteristic failure patterns; shear cracks on the plaster and crushing at the edge

WL: Specimen without plaster finish.

As the specimen deformed in shear, rotational shear deformation occurred at the joints of each wooden lath to the supporting wood at the edge by nails and to the studs. The distance between the edge of the wooden lath and the wood frame was about 1 to 1.5 mm, and the contact between the wood frame and the edge of the wooden lath was observed from around 1/15 rad. The contact between the wood frame and the edge of the wood frame was confirmed around 1/15 rad. After that, the nails of the wood frame support were pulled out and embedded in the wood frame (maximum embedded length: about 10 mm) in parallel. Although the load did not decrease, cracking and fracture were observed at the edge of the wooden lath. The maximum loads were 1.4 kN (0.11 rad.), 1.4 kN (0.12 rad.), and 0.6 kN (0.1 rad.).

WL-P: Specimens with plaster finish.

In the test of WL-P1, the plaster layer gradually began to swell and went up on the wooden frame before it reached the maximum load, and eventually the shear failure of plaster at the gap between wooden laths and the crushing of the plaster layer at the top and bottom edges. However, no shear cracks were observed.

On the other hand, in the case of WL-P2, although slip was observed at the beginning, the plaster layer did not protrude but resisted within the wooden frame surface, and the load decreased after the deformation angle of 0.03 rad. Cracks between the top and bottom were observed at a deformation angle of about 1/22 rad. In both specimens, the behavior was similar to each other; compression between the top and bottom edges became remarkable, as the plaster layer did not follow the shear state in the large deformation. The maximum load was 10.7 kN (0.03 rad.) for WL-P1 and 9.7 kN (about 0.036 rad.) for WL-P 2.

## Numerical Analysis of wooden lath wall and Wooden lath and Plaster Wall

In this section, we tried to construct a frame analysis model to simulate the transmission of stress in the *kizuri-shikkui* wall, that is the wooden laths and plaster wall. We hypothesized that the shear resistant force of substrates mainly derives from the shear and compression stress between wooden laths and nails, and the reinforcement of shear stress is accomplished by plastering on the substrates and forms a stiff plaster layer. The modelling and analysis were conducted on midas iGen. **Figure 5 to 7** are the composition of the analytical model.

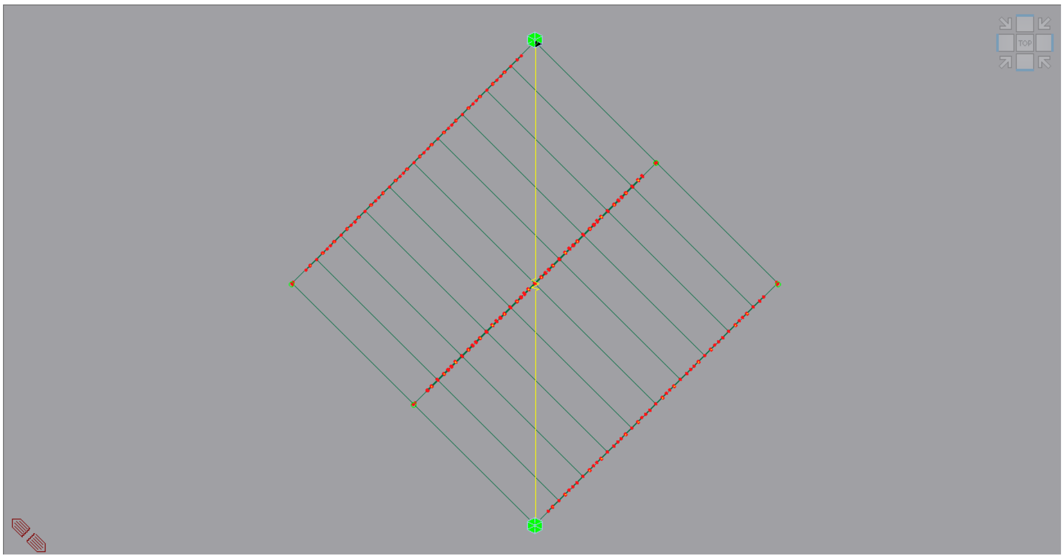

**Figure 5.** Analytical model with beam elements and multi-direction elastoplastic springs

**Figure 6.** Details around the top(left) and the right joint(right) of the analytical model

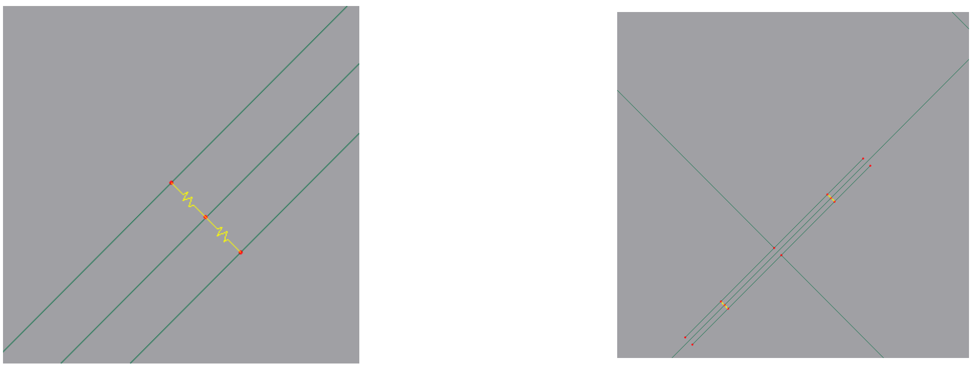

**Figure 7.** Details on the springs (left) and joint between wooden lath and studs (right)

## The Specifications of structural elements on analysis

We show the details of nail-lath joints and the compression test of plaster. We calculated the structural performance of them in accordance with the existing theory and some experiments. The Stiffness and yielding load of nail-lath joints are calculated with the beam theory on elastic floors [**Reference 1**] and the replacement of the wall's compression and shear performance to an equivalent brace. (**Table 3** and **Figure 8**). Abou the stiffness and yielding loads of plaster, we applied the results of compression tests conducted with same material, though the material is for the undercoat one. In this simulation, we hypothesized that the undercoat plaster and the middle layer plaster has the same characteristics. (**Figure 9 and 10**)


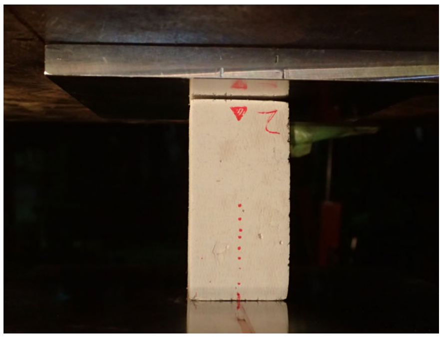

**Figure 8.** Details of the joint between wooden laths and supporting wood
**Figure 9.** Compression test of plaster

**Table 3.** Stiffness and yielding load at lath and nail joint

| Direction of Force | $P_y$ Yielding load (N) | $D_y$ Yielding displacement (mm) | $K_j$ Coefficient of stiffness (N/mm²) |
|---|---|---|---|
| Compression | 241.1 | 1.20 | 201.1 |
| Tension | 241.1 | 1.20 | 201.1 |
| Shear | 241.1 | 1.14 | 211.1 |

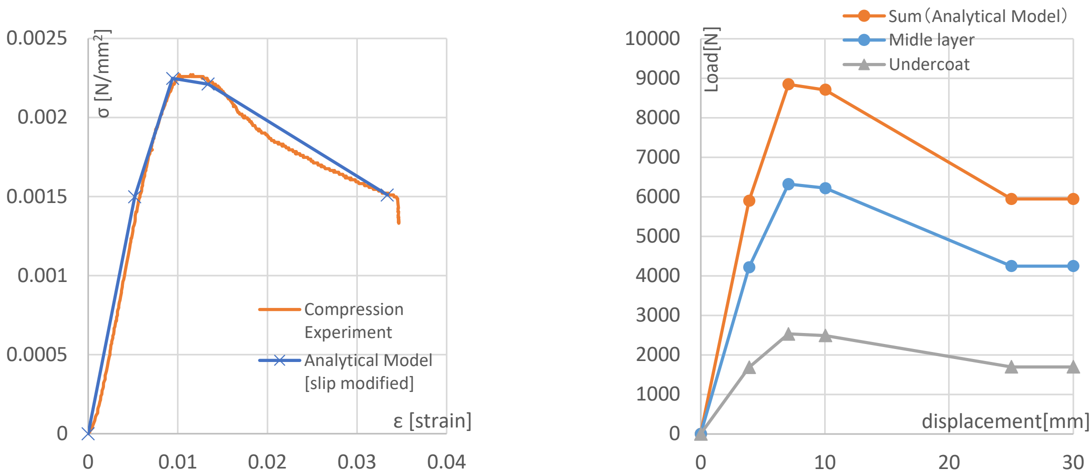


**Figure 10.** The result of the compression test of plaster (left) and the application of the data to analytical model (right)

## Result: Distribution of Stress

Analysis 01: Wooden laths wall: WL series

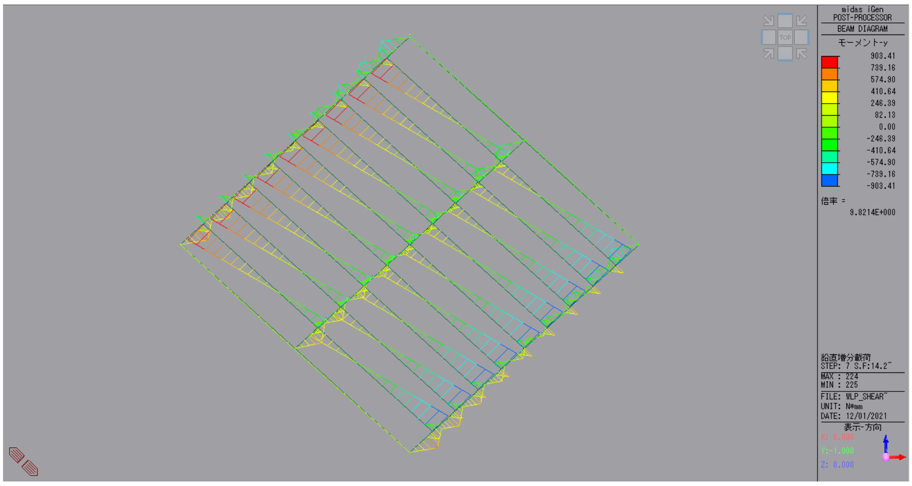


**Figure 11.** Distribution of stress in lath element wall (My: Bending Moment)

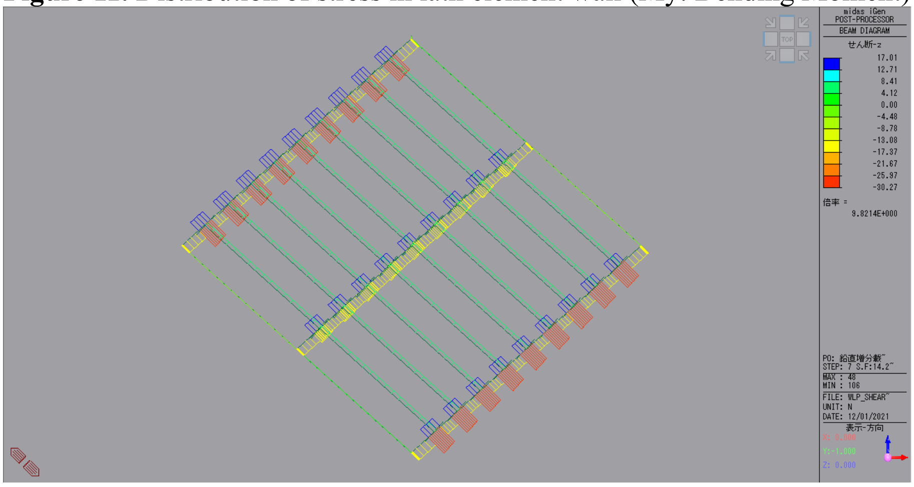


**Figure 12.** Distribution of stress in lath element wall (Fz: Shear Force)

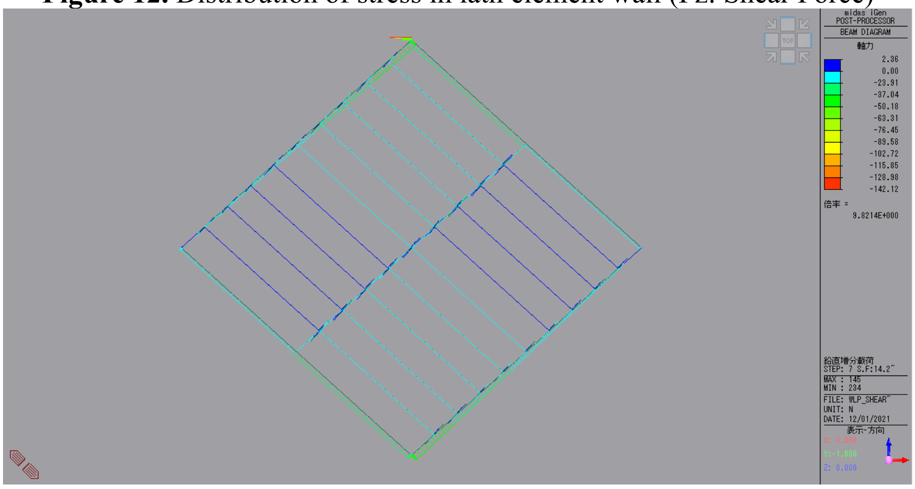


**Figure 13.** Distribution of stress in lath element wall (Fx: Axial Force)

Analysis 02: Wooden laths and Plaster finish wall: WL-P series

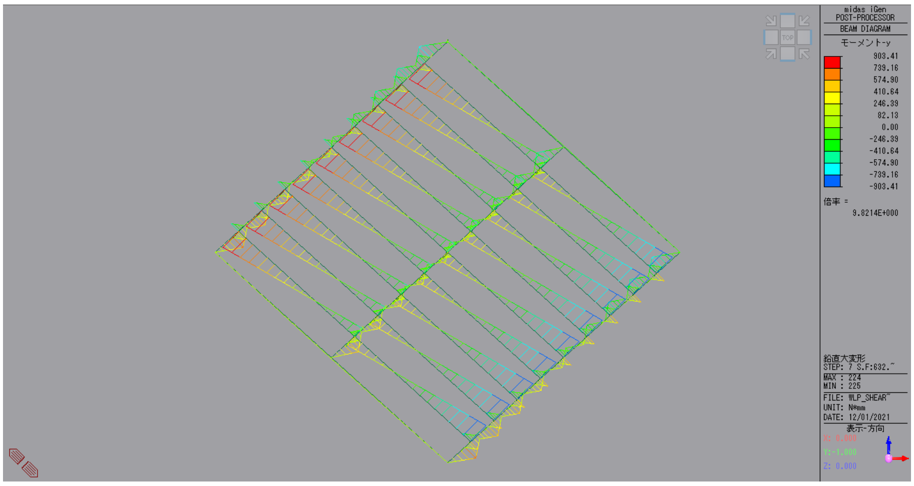


**Figure 14.** Distribution of stress in lath element wall (My: Bending Moment)

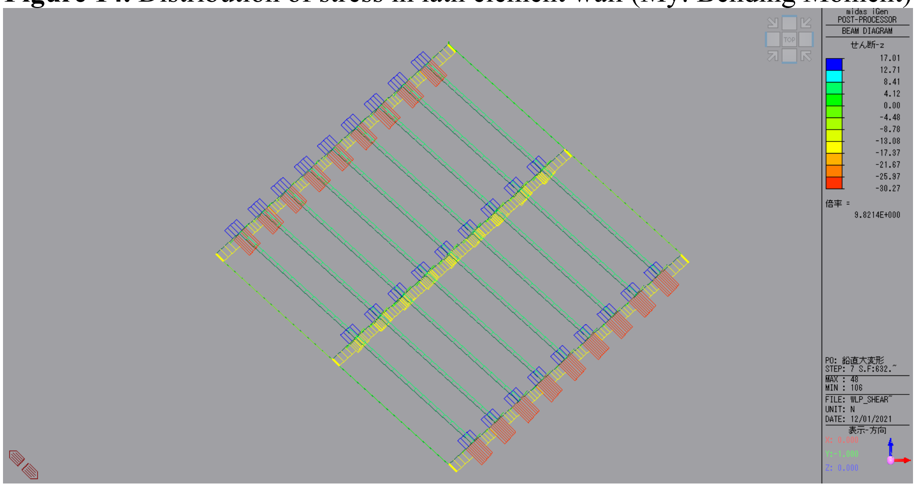


**Figure 15.** Distribution of stress in lath element wall (Fz: Shear Force)

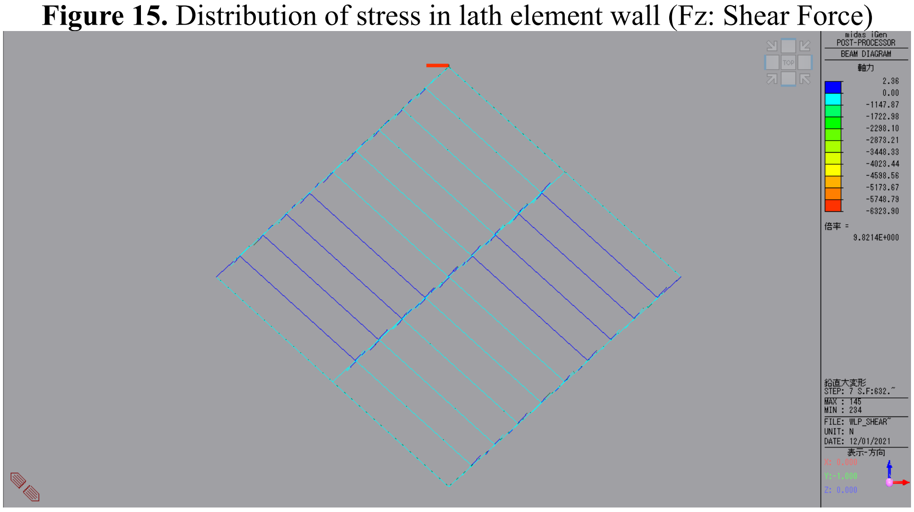


**Figure 16.** Distribution of stress in lath element wall (Fx: Axial Force)

**Results of Analysis: Load-Deformation Angle Relationship**

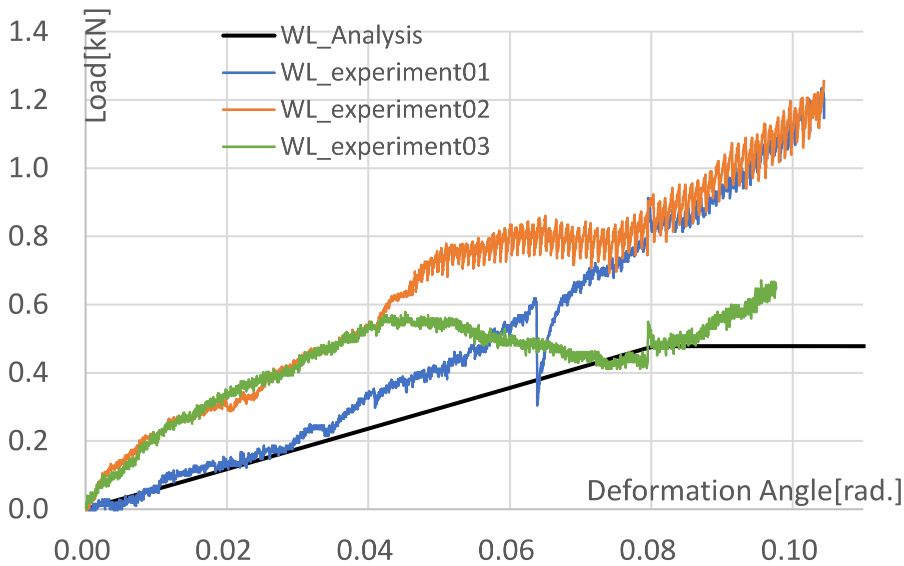


**Figure 17.** Comparison of the results of the tests and analysis: WL series

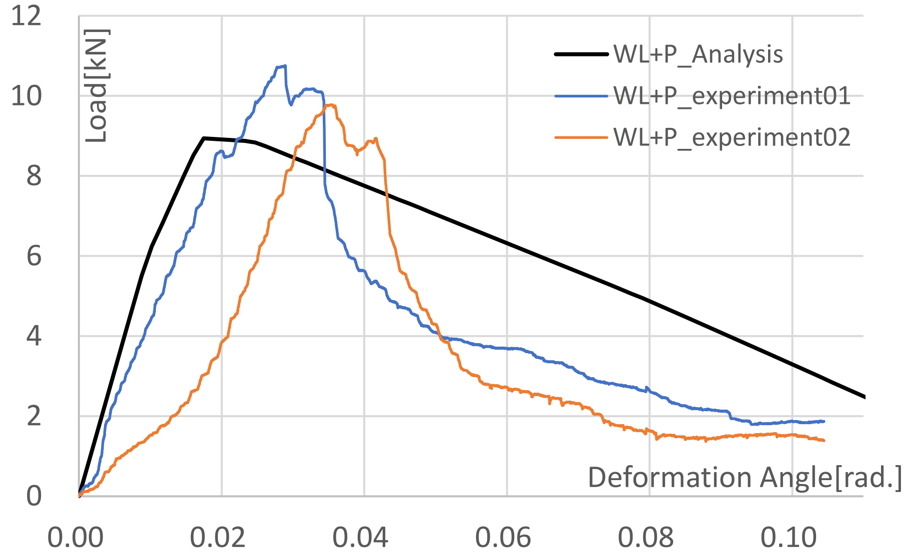


**Figure 18.** Comparison of the results of the tests and analysis: WL-P series

Load-Deformation angle relationships

We show the result of analysis on **Figure 11** to **Figure 18.** From the comparison of the load-deformation angle curve and the result of the experiments, result of the analysis had higher stiffness, though very similar to those of the elastic stiffness of experiments, and 82 % of the maximum load. In addition, after reaching the maximum load, in the experiments, the load reduced abruptly because of the occurring of cracks with lateral tensile force, but in the analysis, we have not been able to simulate those fracture characteristics. One of the reasons by which we are not able to simulate that behavior is that the material properties we have applied to the analytical model is only the date of compression test, in which the specimen doesn't break brittlely. Although the above issues remain, with this simplified simulation we were able to estimate the elastic stiffness of the element shear tests and the maximum load with a certain accuracy.

## Discussion

Limit of the model and the issues to be examined in the future are shown as below. The phenomena and mechanisms that we have not considered in this model are as below. Though the precise modelling and the extra experiments to be conducted in the future.

1. The occurrence of cracks: the failure patterns

In this simulation, we have hypothesized that the cracks do not occur, and only the crushing with compressive force at the edge are considered. However, in the experiments, cracks appeared when the deformation progressed, and lateral tensile force applied. To simulate the adequate failure patterns and the reduction of load caused by those failures, we need to make the model which can show the areal distribution of stress.

2. Interaction between plaster and wooden laths

In this article, we hypothesized that the behavior of the plaster layer does not been linked to that of wooden laths, and replaced the plaster layer with an equivalent brace, depending on the hypothesis that the major compression area of this specimen is inside areas enclosed with the secant drawn between the middle points of the edges. Through this interpretation of the system, the interaction behavior between the plaster layer and the wooden laths transmitted by the plaster inside the gaps of laths.

3. Buckling of laths and plaster layer

In this calculation, we did not consider the effect of buckling of laths and plaster, especially the former was apparent in the element experiments. On the other hand, the plaster layer has the effect of preventing the buckling of laths, so it should have improved the structural performance of the wall. Buckling of laths and plaster and the reinforcement of laths with the plaster, all those should be considered to clarify the precise mechanism of this type of wall.

## Conclusion

The purpose of this study is to clarify the structural performance of wooden lath and plaster walls, which are widely used in modern wooden architecture in Japan, especially in the case of Shinkabe walls, through experiments and analysis.

From the elemental experiments, it was found that the initial stiffness and the maximum load were significantly increased by coating with plaster (about 20mm thickness) compared to the case of only wooden lath wall. About the failure patterns, in the case of the wooden lath wall, the failure around the nails progressed slowly, while the stiffness of the wooden lath with plaster decreased relatively rapidly at 1/50 rad. due to crack failure caused by lateral tension and buckling caused by compression at the upper and lower ends.

Then, structural frame analysis was performed to simulate the elemental experiment. The plaster was assumed to be reproducible by the elastic-plastic spring between wooden laths and nails, and the spring of the plaster layer, and the results of the compression test of the plaster material were applied. As a result, the elastic stiffness was relatively close and the maximum load was about 80%. In the future, it will be necessary to verify the areal stress distribution, clarify the bifurcation conditions of the failure modes, and refine the material tests to elucidate more appropriate mechanisms and refine the structural evaluation methods.

## REFERENCES

[1] Design Manual for Engineering Timber Joints, Architectural Institute Japan, 2009