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STUDY ON MORTAR FINISHING EXTERNAL WALL WITH VENTILATION SPACE FOR SEISMIC RETROFITTING

M. Nakao[1], T. Inoue[2] and K. Inagaki[2]

[1] *Research Associate, Yokohama National University, Japan, mnakao@ynu.ac.jp*
[2] *Japan Building Coating Material Association, Japan*

Abstract

Mortar finishing external wall is one of typical external walls for wooden houses in Japan. It is constructed using sophisticated plasterers' technics, which is able to be given various textures on the surface. The mortar finishing external wall shows good fire resistant performance and shear resistant performance, however, not a few mortar of the external walls fell off under earthquake in the past. The reasons of the falling off of the mortar were use of inadequate materials, decay of timber, corrosion of metal materials, etc. To improve its durability and prevent falling off of the mortar, ventilation method for the mortar finishing external wall has been introduced. With the ventilation space, since moisture is vented out of a wall, it is able to be kept dry.

This research project was conducted to evaluate the seismic performance of a wood frame with the mortar finishing external wall equipped with ventilation space. There were several experimental researches on seismic performance of mortar finishing external walls in the past, but most of the external wall specimens had no ventilation space. The shear resistant performance of the past specimens was as good as conventional shear walls such as bracing or nailed plywood. It is expected that the mortar finishing external wall with ventilation space also shows good performance with proper materials. If the external wall with ventilation space is authorized as a shear wall, rational structural design will be realized. Furthermore, it will be a useful seismic element for seismic rehabilitation.

Focusing on the mortar finishing external wall with ventilation space, basic mechanical characteristics of the wall element were examined through single shear test of staple and tensile test of mortar element specimen. In the experiments, some specimens were corroded by accelerated weathering.

Moreover, incremental FEM analysis of the wood frame with the mortar finishing external wall containing two openings, namely window type opening and door type opening, was conducted using the shear force-displacement relationship of staple and tensile force-displacement relationship from the elemental experiments. From the analysis, it was found the maximum shear strength of the wood frame with the mortar finishing external wall with ventilation space is approximately 10kN/m even with openings and also found that a decrease in the shear force is relatively small even degradation occurs. It is considered that using mortar finishing external wall is applicable for seismic retrofitting.

Keywords: Mortar, External wall, Staple, Metal lath, Retrofitting

1. Introduction

Mortar finishing external wall is one of typical external walls for wooden houses in Japan. It is constructed using sophisticated plasterer's technics, which is able to be given various textures on the surface. The mortar finishing external wall shows good fire resistant performance and seismic performance, however, not a few lath mortars of the external walls fell off under earthquake motions in the past. The reasons for the falling off of the lath mortar were use of inadequate materials, decay of timber, corrosion of metal materials, etc. To improve its durability and prevent falling off of the lath mortar, ventilation method for the mortar finishing external wall as shown in Fig. 1 has been introduced. With the ventilation space, since moisture is vented out of the wall, it is able to be kept dry.

This research project was conducted to evaluate the seismic performance of the mortar finishing external wall with ventilation space. There were several experimental researches on seismic performance of mortar finishing external walls in the past[1, 2]. However, most of the external wall specimens had no ventilation space. The shear resistant performance of the past specimens was as good as conventional shear walls such as bracing or nailed plywood. It is expected that the mortar finishing external wall with ventilation space also shows good performance with proper materials. If the external wall with ventilation space is authorized as a shear wall, rational structural design will be realized. Furthermore, it will be a useful seismic element for seismic rehabilitation.

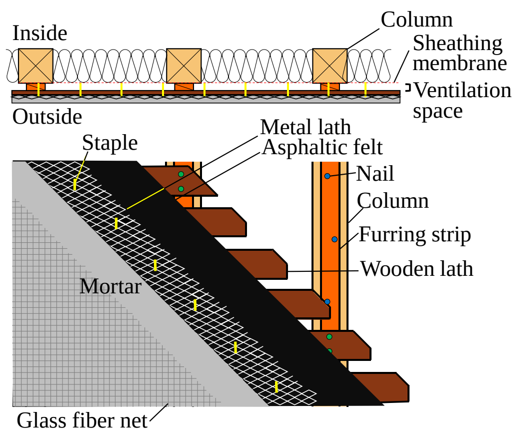


Fig. 1 - Mortar finishing external wall with ventilation space

2. Basic Mechanical Characteristics of the Wall Element

2.1 Single Shear Test of Staple

2.1.1 Specimen and test method

Mortar element specimen whose size is 160mm X 160mm as shown in Fig. 2 was prepared to examine basic mechanical characteristics of the lath mortar. The specimen of 910mmX1820mm was manufactured first and it was cut into 160mmX160mm specimen. Three types of specimen were prepared as shown in Table 1. No.1 consists of W700-06 metal lath and L1019J staple. Metal lath and staple of No.2 are W1050-06 and L0719M. For No.3, metal lath is stainless W700-06 and staple is also stainless L1019JS. Properties of metal lath and staple were shown in Table 2 and Table 3. Mortar used for the specimen is light weight mortar which is conformed to JASS15 M-102(JASS: Japanese Architectural Standard Specification by Architectural Institute of Japan). The thickness of the mortar was approximately 15mm. The material test was performed as shown in Pic. 1, and the strengths are listed in Table 4. The mortar was plastered twice, namely primcoating and finish coating, the strengths are about the same. Glass fiber net was applied on the surface of mortar to avoid shrinkage crack and wall coating was also applied on the top. The properties are listed in Table 5.

It is important to evaluate the effect of rusting of metal lath and staple because mortar finishing external wall suffer external degradation force such as storm, solar radiation, etc. In this research, focusing on corrosion of steel material such as metal lath, staple, accelerated degradation of the mortar element specimen was done and single shear test of staple was conducted. Decay of wooden member was not induced.

For the accelerated degradation, the mortar element specimen was placed in a container where water was at the bottom and the container was put into an oven where the thermostat was set to 60 ºC. The temperature and humidity in the container were approximately 60ºC and 100% respectively. The period of the accelerated degradation was one, two and three weeks in addition to no degradation one. Six specimens were prepared for each case. After the accelerated degradation, there was rust on the tip of the staple as shown in Pic. 2. As the degradation period increases, the amount of the rust increases.

For the single shear test of staple, the element specimen was fastened to the test apparatus as shown in Fig. 3, and cyclic shear displacement was applied to wooden lath. The number of repeated displacement on one displacement stage was three. The direction of the shear force was parallel to the grain. Water content of wooden lath of the element specimen was around 15% and age of light weight mortar was over 60 days when the test was conducted.

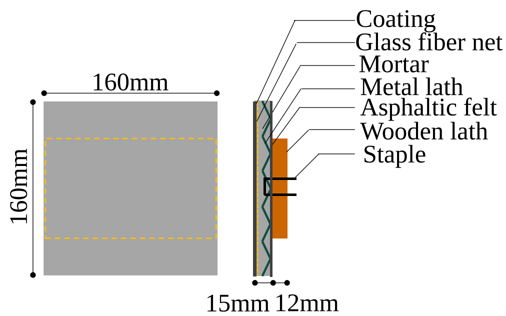


Fig. 2 - Mortar element specimen

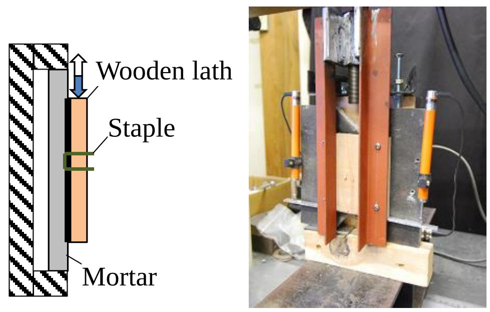
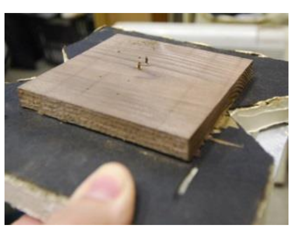


Fig. 3 - Single shear test of staple

Pic. 1 - Material testing of mortar



Pic. 2 - Staple after accelerated degradation

Table 1 - List of mortar element specimen

	Metal lath		Staple
No.1	Wavy lath W700-06	(Galvanizing)	L1019J
No.2	Wavy lath W1050-06	(Galvanizing)	L0719M
No.3	Wavy lath W700-06	(Stainless)	L1019JS

Table 2 - Properties of metal lath

Metal lath	Weight (g/m^2)	Mesh (mm)	Height of wave (mm)
W700-06	700	32×16	6
W1050-06	1050	32×15	6
W700-06 (Stainless)	700	27×14	6

Table 3 - Properties of staple

	Width (mm)	Length (mm)	Shank diameter (mm)
L1019J	11.22	19.08	0.62×1.15
L0719M	8.55	18.90	0.92×1.27
L1019JS	11.22	19.07	0.58×1.15

Table 4 - Material strength of mortar

	Primcoating	Finish coating
Compressive strength (N/mm^2)	11.03	9.87
Tensile strength (N/mm^2)	1.08	1.04

Table 5 - Glass fiber net and wall coating

Glass fiber net	5mmX5mm mesh	150g/m^2
Wall coating	Thin coating for external facing type E	JIS A 6909

JIS: Japanese Industrial Standards

2.1.2 Test result

Typical relationships between shear force and displacement were shown in Fig. 4. Due to the repeated displacement, it is found that stiffness declined and cut-off or pull-out of the staple occurred. The failure mode of No.1 and No.3 is cut-off of staple while the one of No.2 is pull-out of a staple when there is no degradation. After degradation, the failure mode of No.2 transfers to cut-off of metal lath and cut-off of staple because the pull-out strength of staple increased due to appearance of rust on staple. Pic. 3 shows these failure modes. Fig. 5 shows the number of specimens corresponding to each failure mode.

Fig. 6 shows skeleton curves of all specimens. It is found that degradation decreases ultimate displacement on No.1 and increases the maximum shear force on No.2 while no change was detected on No.3. From the result of No.3 specimens, it was confirmed that there is no degradation on stainless even under high temperature and high humidity atmosphere. Moreover, it was also confirmed that even once wood absorbs water under high humidity atmosphere, the mechanical characteristic recovers after drying.

Fig. 7 shows secant shear stiffness which was derived from the shear force at 5mm, maximum shear strength and ultimate displacement which is defined as the displacement where the shear force declined to 80% of maximum shear force. These values are averages of six specimens in the same case. The figure also shows shear stiffness and maximum shear strength increases after the accelerated degradation on No.2 due to appearance of rust on the staple. As for No.1, the ultimate displacement decreases as the period of degradation increases. It is considered that the reason is decreasing in shank diameter of staple.

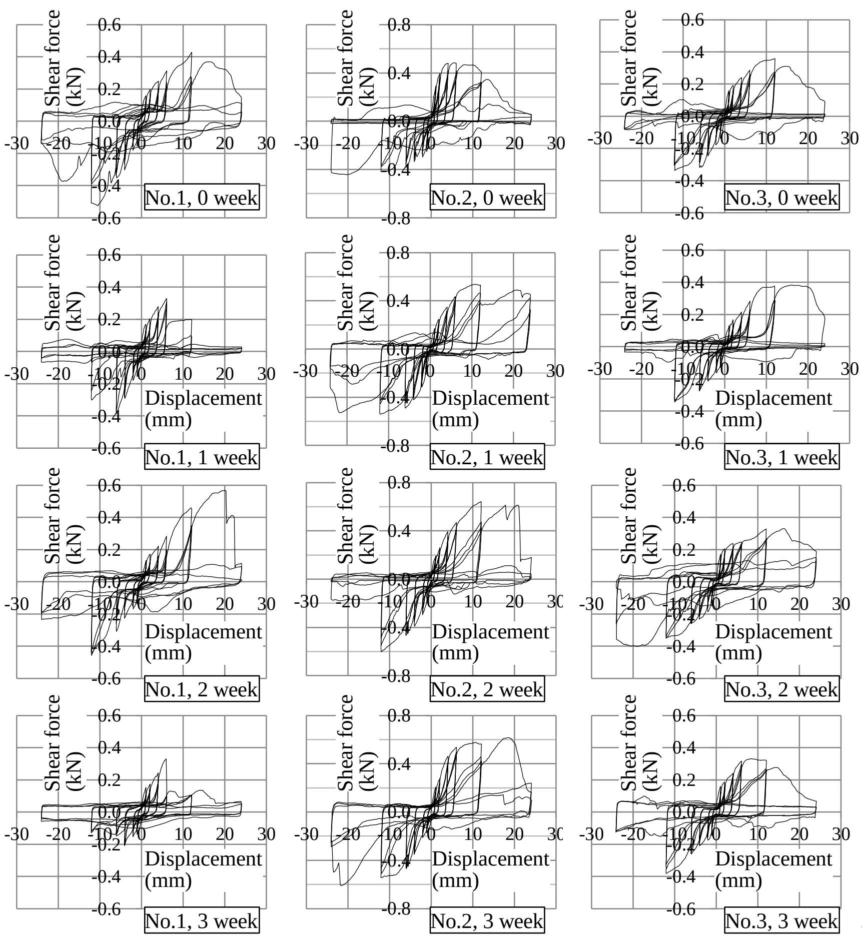


Fig. 4 - Typical shear force-displacement relationships

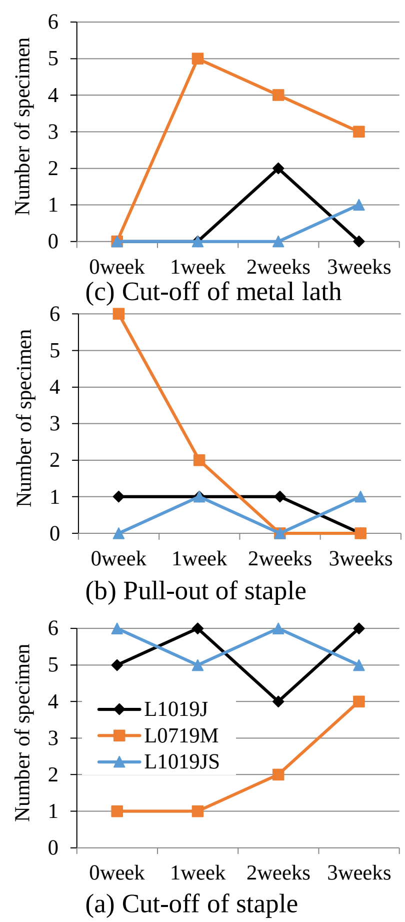


Fig. 5 - Number of specimen corresponding to each failure mode

(a) Cut-off of staple

(b) Pull-out of staple

(c) Cut off of metal lath

Pic. 3 - Failure mode of staple

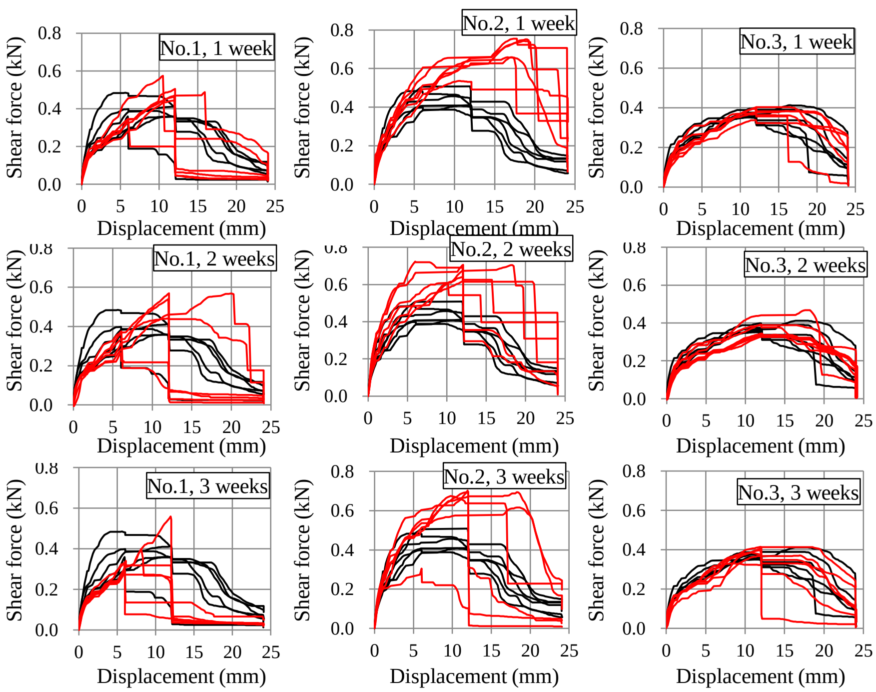


Fig. 6 - Shear force-displacement relationship of staple
(Red line: After degradation, black line: Before degradation)

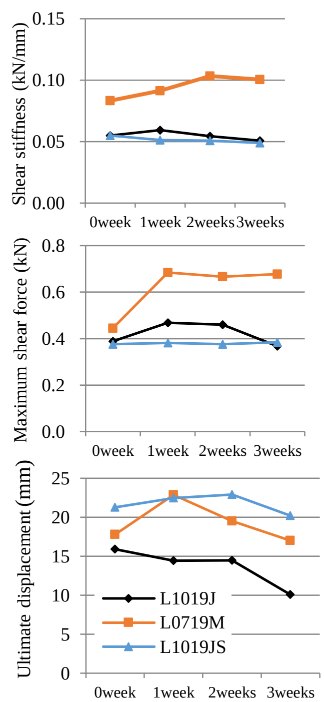


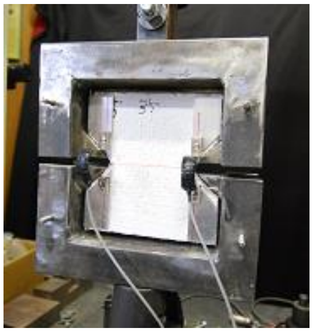
Fig. 7 - Mechanical characteristics on single shear test of staple

2.2 Tension Test of Mortar Element Specimen

2.2.1 Specimen and test method

Using the mortar element specimens which are same as the specimen in a single shear test of staple, in-plane tension test was conducted to examine the relationship between the tensile force and the displacement of lath mortar.

To apply a tensile force to the specimen, two notches were provided in the middle of the specimen. Using the loading apparatus which has edges, tensile force was applied to the specimen as shown in Pic. 4. Because screws were not able to use on the surface of lath mortar, Ω-shaped transducers were attached to the pieces of plates which were glued to the surface. The displacement measured by the transducers was relative displacement between upper and lower portions of the specimen when the tensile load was applied. There were two types of loading according to the direction of mesh of metal lath, namely vertical direction and lateral direction as shown in Fig. 8.



Pic. 4 - Tension test of mortar element specimen

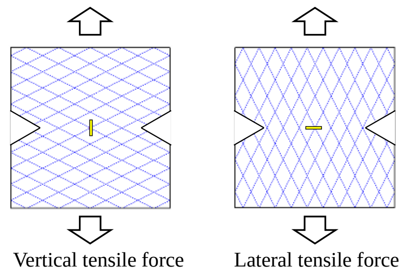
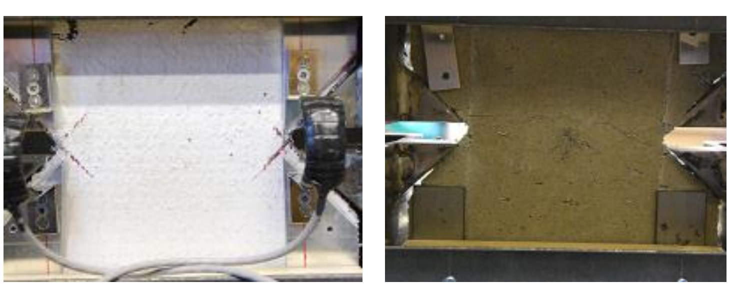


Fig. 8 - Direction of tensile force

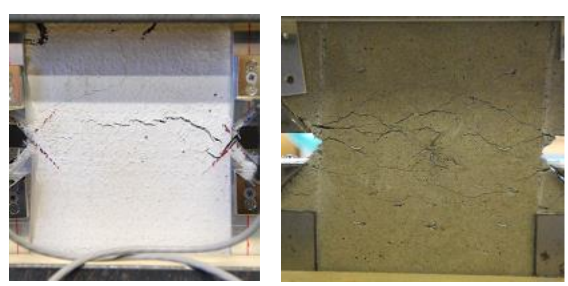
2.2.2 Test result

When the tensile load was applied on the vertical direction, lateral crack appeared on the front and back surfaces at 0.2mm as shown in Pic. 5. When the displacement was less than 1mm, the displacement was restored to approximately zero after unloading. Residual deformation remained over 1mm as shown in Pic. 6. The reason is considered that the glass fiber net yields around at 1mm. Pic. 7 shows tension test of glass fiber net only. Fig. 9 shows relationship between the tensile force and displacement of the glass fiber net. It is found that the tensile force declined over around 1mm. Finally, width of the crack was expanded as shown in Pic. 8. Tensile force-displacement relationship is shown in Fig. 10. Effect of glass fiber net on tensile force was relatively large. To examine the tensile force carried by glass fiber net, glass fiber net was cut before the test on some specimens. In the case of vertical direction of No.1 specimen, maximum tensile forces were approximately 2.5kN with net. When the net was cut before the test, maximum force was about 1kN. It is found that metal lath carries 1kN and the net carries 1.5kN. There was not any remarkable difference between types of metal lath on maximum force. However, as for No.2, the initial force where the displacement begins to increase is higher than other types of specimen. The reason is considered that the weight of the metal lath used in No.2 specimens is 1.5 times compared to the one of No.1.

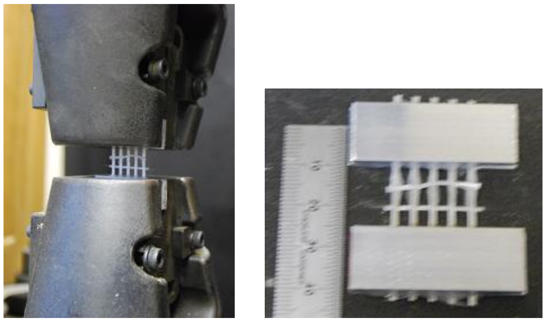
For lateral direction, tests were conducted using the specimen with cut glass fiber net. The failure mode of the specimen with a glass fiber net was shear failure at the notch instead of tensile failure because tensile strength of lateral direction of metal lath was much higher than the one of vertical direction. Fig. 11 shows the tensile force-displacement relationship on lateral direction. It is found that metal lath carries a tensile force approximately three times as much as the one in the case of vertical tensile force.



Pic. 5 - Crack at 0.2mm of displacement



Pic 6 - Crack at 1.5mm of displacement



Pic. 7 - Tension test of glass fiber net

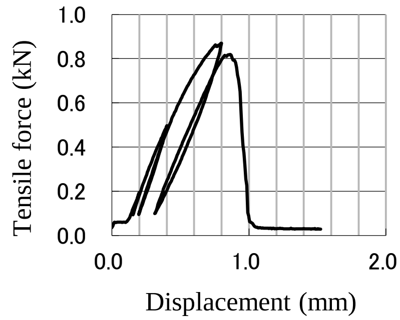


Fig. 9 - Tensile force-displacement relationship of glass fiber net

Pic. 8 - Ultimate state on tension test of mortar element specimen

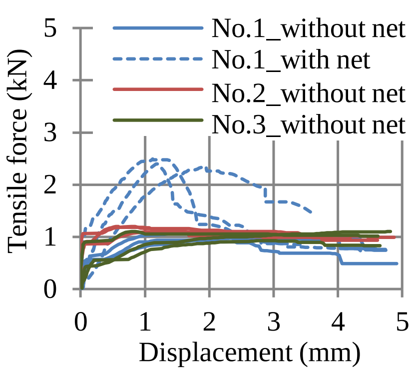


Fig. 10 - Tensile force-displacement relationship on vertical direction

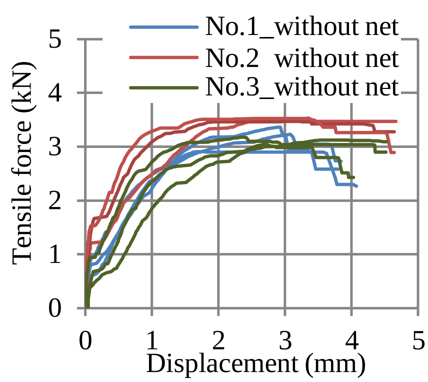


Fig. 11 - Tensile force-displacement relationship on lateral direction

3. Incremental Analysis

3.1 Analysis model

Incremental FEM analysis of typical mortar finishing external wall with two openings as shown in Fig. 12 was conducted using the results of the single shear test of staple and tension test of mortar element specimen. FEM analysis models of the static shear loading test specimens were built using testing data of mortar element specimen, and static non-linear incremental analysis was conducted.

Components of the analysis model are shown in Fig. 13 where it consists of three layers, a wood frame, wooden laths and lath mortar. A layer of wood frame consists of a beam element and column elements which take into account axial stiffness and flexural rigidity. The top ends of column elements are connected to the beam element where the joints are pin. Stud was omitted because its flexural rigidity is too low to affect the result. Sill was also omitted because the bottom ends of column elements were restricted as pin directly. The second layer which represents wooden laths is composed of beam elements. Young's modulus of the beam was 10kN/mm^2 while the one of the column and wooden lath was 7kN/mm^2. Lath mortar layer, the third layer, is modelled as elastic wall elements which take into account axial stiffness, flexural rigidity and shear stiffness. The young's modulus was 5.3kN/mm^2 considering the material testing data of mortar.

The first layer and the second layer, namely a layer of a wood frame and a layer of wooden laths, are connected by non-linear spring elements which represents 65mm long nails. Another spring elements which represent staples connect the second layer and the third layer, namely a layer of wooden laths and a layer of lath mortar. The shear force-displacement relationship model of 65mm long nail is shown in Fig. 14. As for staple, shear force-displacement models of three staple types, namely 1019J, 0719M and 1019JS, were prepared as shown in Fig. 15, 16 and 17 respectively. There are two models before degradation and after three weeks' degradation in each type. For 1019JS(stainless), the models of before and after degradation are the same because no decrease in shear force was detected on a single shear test. Axial stiffness of the non-linear spring model of nail and staple was rigid. Some 65mm long nails were concentrated on one spring element to reduce degrees of freedom of the analysis model. As for staples, one spring element represents some staples as well.

Compressive, tensile and shear failure of lath mortar affects the shear strength of mortar finishing external wall greatly. Therefore, non-linear springs were arranged between wall elements which express compressive, tensile and shear failure of mortar as shown in Fig. 18. Failure of lath mortar was observed around opening in the static shear loading test[3], so spring elements were arranged along the line from the corner of opening to the edge of lath mortar. Length of the spring element was defined as 5mm, compressive stiffness was calculated to be equal to Young's modulus(5.3kN/mm^2) as shown in Fig. 19. On the tension side, based on the tension test result of mortar element specimen, tensile force-displacement relationship model was defined as shown in Fig. 20. As for the model, two models, namely vertical and lateral direction, were prepared while the type of metal lath was not considered. Test results shown in the figure are the ones of No.1 specimen. As for vertical direction, the model was from the test with glass fiber net. The model of lateral direction was defined from the test without glass fiber net first, and the effect of the glass fiber net was added. Compressive strength of the spring element was defined as 10.0N/mm^2 from the material testing result. As for shear strength of the spring element, it was defined as 2.19N/mm^2 from the double shear test of the mortar specimen which contains metal lath and glass fiber net.

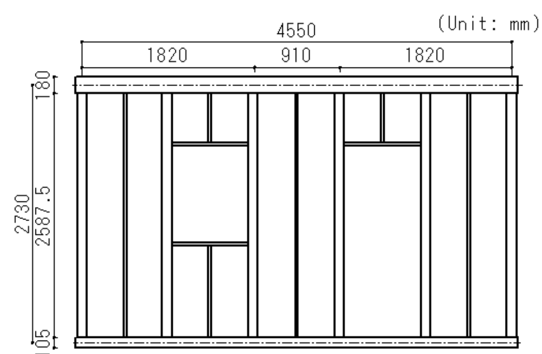


Fig. 12 - Typical wood frame with two openings

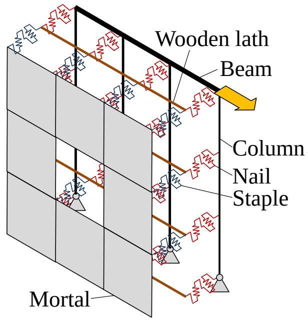


Fig. 13 - Components of FEM model of mortar finishing external wall specimen

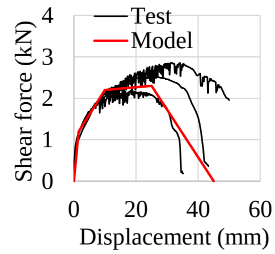
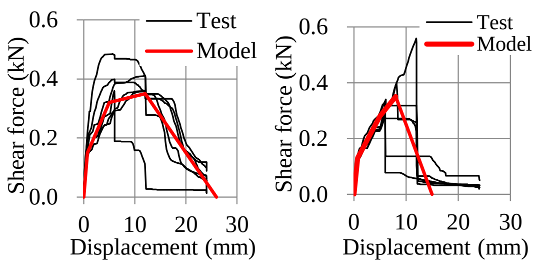
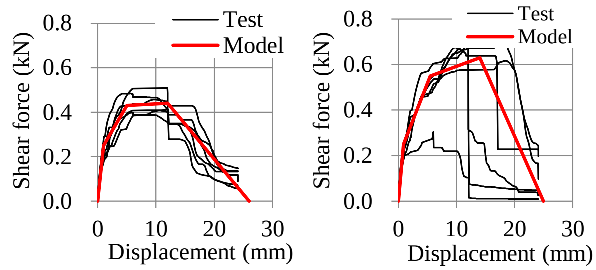


Fig. 14 - Shear force-displacement relationship of N65 nail spring



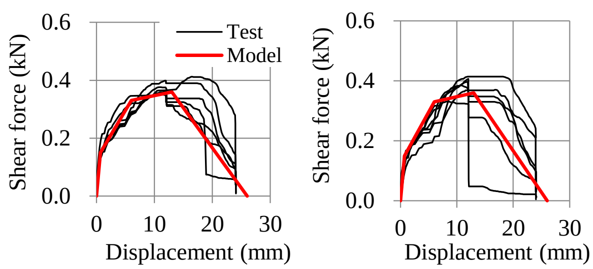
(a) Before degradation (b) After degradation

Fig. 15 - Shear force-displacement relationship of staple(L1019J) spring



(a) Before degradation (b) After degradation

Fig. 16 - Shear force-displacement relationship of staple(L0719M) spring



(a) Before degradation (b) After degradation

Fig. 17- Shear force-displacement relationship of staple(L1019JS) spring

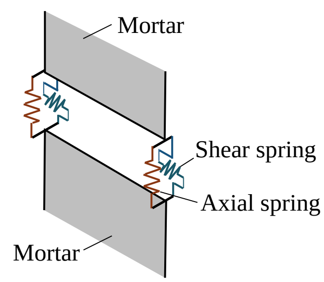


Fig. 18 - Non-linear spring between wall elements

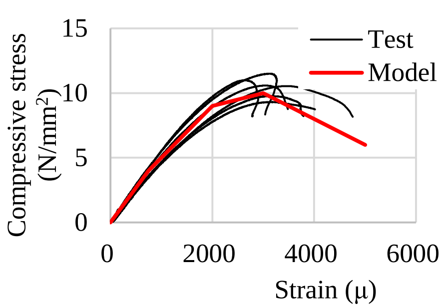
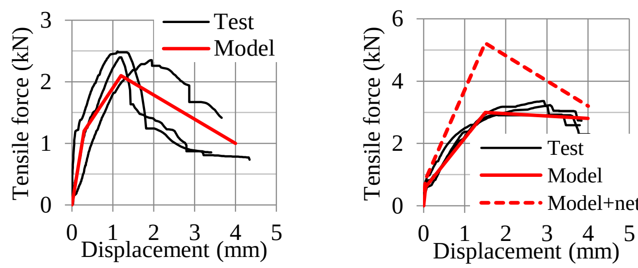


Fig. 19- Axial stress-strain relationship of spring between wall elements



(a) Vertical direction (b) Lateral direction

Fig. 20 - Tensile force-displacement relationship model of spring between wall elements(Test results: No.1 specimen)

3.2 Analysis result

Analysis with three types of staple was conducted and the case of after degradation was also performed. Fig. 21 shows ultimate global deformation of the analysis model. There was no remarkable difference in the deformation mode concerning the type of staple.

Relationship between shear force and displacement obtained from the analysis with L1019J staple is shown in Fig. 22. From the analysis, it was found the maximum shear strength of the model before degradation is approximately 50kN while the one after degradation is the same level. However, the remarkable decrease in shear force starts around 60mm of story displacement (2.2% of story drift) with the staple after degradation while there is no remarkable shear force deduction in the case with the staple before degradation. When the deformation increases over 60mm, falling off of lath mortar is expected with L1019J staple after degradation.

In the case with L0719M staple, as shown in Fig. 23, there is no remarkable difference in shear force-displacement relationship between the cases before and after degradation of staple. Considering the shear force-displacement relationship of the single shear test result, it was expected that the shear force after degradation increases in comparison with the one before degradation. In this analysis, because degradation of N65 nail was not considered, the effect of degradation of the staple on the shear force is considered to be limited. Maximum shear force is approximately 55kN, which is about 10% higher than the one with L1019J staple.

Fig. 24 shows the analysis result of the case with L1019JS staple. Maximum shear force of this case was approximately 50kN which is almost the same as the one with L1019J. Considering degradation of steel, using stainless staple is effective in securing ductility and prevention of falling off of lath mortar under a large earthquake.

It was found that the maximum shear force of mortar finishing external wall is expected around 10kN/m even with openings and also found that a decrease in the shear force is relatively small even degradation occurs. It is considered that using mortar finishing external wall is applicable for seismic retrofitting.

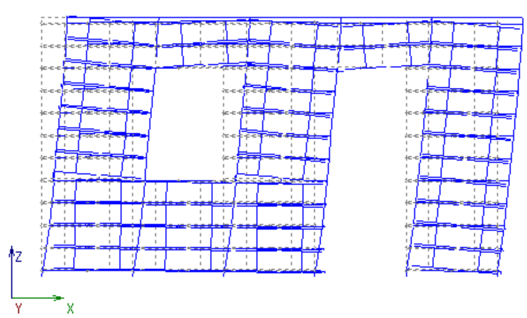


Fig. 21 - Global deformation of incremental analysis model

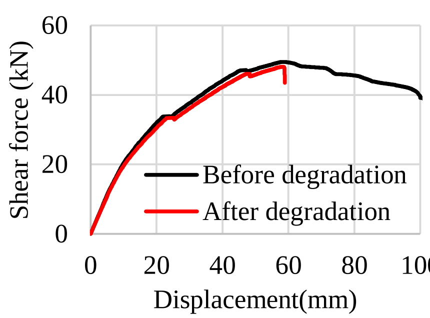


Fig. 22 - Shear force-displacement relationship by incremental analysis with L1019J staple

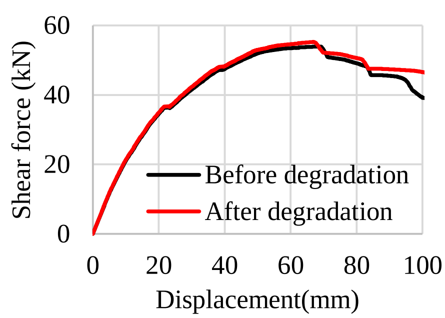


Fig. 23 - Shear force-displacement relationship by incremental analysis with L0719M staple

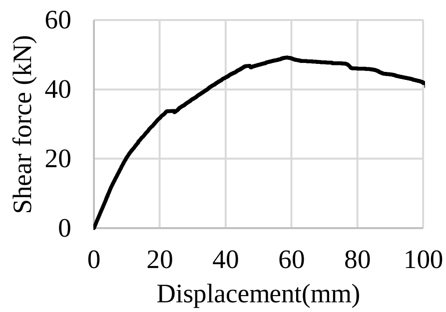


Fig. 24 - Shear force-displacement relationship by incremental analysis with L1019JS staple

4. Conclusions

Focusing on the mortar finishing external wall with ventilation space, basic mechanical characteristics of the wall element were examined through single shear test of staple and tensile test of mortar element specimens.

On single shear test of staple, using mortar element specimens whose size is 160mmX160mm were manufactured and tested. The test was also conducted using the specimen after accelerated degradation. It was found that degradation affects the shear force and the failure mode in the single shear test of staple.

From tension test of mortar element specimen, shear force-displacement relationship of lath mortar with glass fiber net was obtained. There was a remarkable difference concerning the direction of metal lath. The effect of glass fiber net on shear force was also remarkable.

Finally, incremental FEM analysis of typical mortar finishing external wall with two openings using the results of the single shear test of staple and tension test of mortar element specimen was conducted. It was found that the maximum shear force of the mortar finishing external wall was evaluated to be around 10kN/m even with openings and also found that a decrease in the shear force is relatively small even degradation occurs. It is considered that using mortar finishing external wall is applicable for seismic retrofitting.

In this study, degradation was considered only for the staple. Degradation of nail, metal lath and wood members is needed to be considered for further study.

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