DEVELOPMENT OF NUMERICAL ANALYSIS FOR JAPANESE MUD WALL

Koji Yamada[1]

[1] *Associate Professor, Toyota National College of Technology, Toyota. Japan*
Email:kyamada@toyota-ct.ac.jp

ABSTRACT :

In this paper, I propose the numerical analysis method to calculate the restoring characteristic of Japanese mud plaster wall and its variants. The numerical model of mud plaster wall is composed of frame member for both post and beam, the end springs for the connector of frames, rectangular solid model for mud plaster and contact analysis model between mud plaster and frame. The restoring characteristics of end springs are set using examples from element tests. The smeared crack approach is used for mud plaster solid model as reference. The restoring characteristics of mud plaster solid model are set using examples from both the compression test and the splitting test of mud plaster cylinders. The contact element is composed of 2 springs, which transfers only compression. Three models are employed for the comparison between actual tests and analysis. One is the standard mud plaster wall whose length is 910mm, and height is 2730mm with 3 battens. Another model is the wooden frame with hanging wall. And the other model is a mud plaster wall whose length is 1820mm. The comparison between actual tests and analysis shows that the maximum strength, the skeleton curve and the curve in unloading of mud plaster wall are calculated approximately.

KEYWORDS: Japanese mud plaster wall, Numerical analysis, Smeared crack approach, Restoring force characteristic

1. INTRODUCTION

Mud plaster walls are often used in Japanese traditional wooden houses. Mud plaster walls are constructed with grouted clay in wooden frame. The construction process is shown in Fig. 1. A Japanese mud plaster wall has 3 different coat: scratch coat, second coat, and finishing coat. The restoring force characteristic of mud plaster wall is tested by actual loading experiments. An actual experiment spacemen is about 1300 dollars, and it is taken for 3 months to make a specimen. To shorten the development period and to eliminate the material characteristic distribution of mud plaster, a calculation method for mud plaster walls is needed. I report the finite element method for a mud plaster wall. This method requires the material characteristic of both a wooden frame and mud plaster.
This report is composed of 3 parts: assumptions, material tests and mud plaster wall test, and their analysis.

(a) Wooden frame (b) Bamboo lath (c) Scratch coat (d) Painting second coat by plasterer
Figure 1 Construction process

2. ASSUMPTION

2.1. Assumption of Analytical Model

The proposed analytical model is composed of the crack analysis model for mud plaster, contact model, a non-linear spring, and a frame member.

2.2. Model of Mud Plaster Wall

The resistant system of mud plaster wall must express a crush of mud plaster, inroad of wooden frame (especially batten), the rotation resistance at wooden frame connection, and the contact between mud plaster and a wooden frame. Therefore the modeling policy of mud plaster wall is defined as follows:

1) A wooden frame is linear material except the bending fracture
2) Inroad of wooden frame to mud plaster is represented a crush of mud plaster
3) The rotation resistance at wooden frame connection is represents a non-linear spring.

2.3. Frame and Member End Spring

Wooden frames are supposed to be linear materials. A bending fracture and the drop out at a joint are simulated by member end springs. Member end springs are adopted on an axial force, a shear force, and a bending moment respectively. The restoring force characteristics on an axial force and a bending moment are shown in Fig. 2. The restoring force characteristic on a shear force is supposed as linear system.

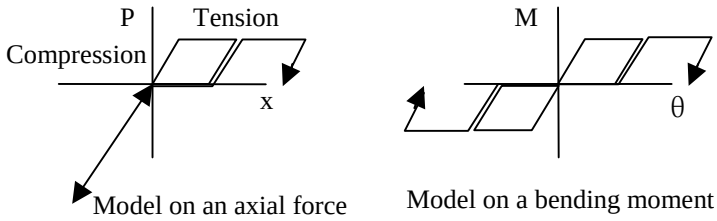


Figure 2 Restoring force characteristics on an axial force and bending moment

2.4. Mud Plaster Element

A finite element for mud plaster is a rectangular element that is a smeared crack model. The smeared crack model has 12 evaluation axes. The restoring force in Fig. 3 is calculated in each evaluation axis respectively. The representative axis for an element is the closest axis to the principal strain.

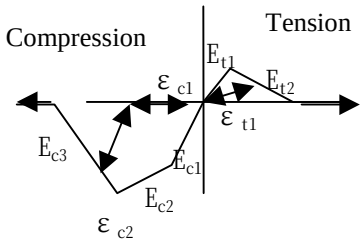


Figure 3 Restoring force characteristics for smeared crack model

2.5. Contact Element

A contact element is the rectangular element including 2 springs in Fig. 4. This element transfers axial forces and frictional forces. The compression stiffness is the product of the 1st Young's ratio of mud plaster (Ec1), the half-length of a frame member, and the thickness of mud plaster element. A friction factor is 0.4.

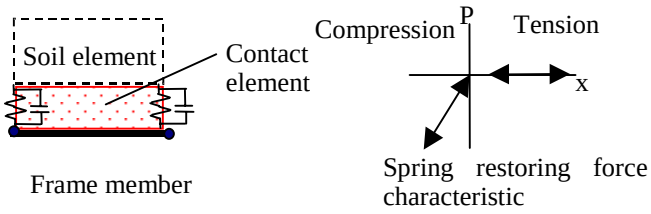


Figure 4 Contact element

3. MATERIAL TEST, FULL-SCALE WALL TEST AND NUMERICAL ANALYSIS

3.1. Material Test on Mud Plaster

Material tests on mud plaster are a compression test and splitting test in Fig. 5. A specimen is the cylinder whose diameter is 5cm and height is 10cm. In this test, I make 2 kinds of mud plaster: scratch coat mud plaster and second coat mud plaster. Scratch coat mud plaster is composed of 10kN clay and 0.1 kN straw. Second coat mud plaster is composed of sand, clay, and straw in bulk proportion of 6:2:1.

The results of test are shown in Fig. 6 and Fig. 7. There is distribution of maximum compression strength in both mud plasters. At the same time, the maximum tension strength is almost the same value 0.15 N/mm2. We use the average of compression strength in Fig.6 and Fig. 7 for numerical analysis. As a result, the parameters for this numerical analysis are adopted in Table 1.

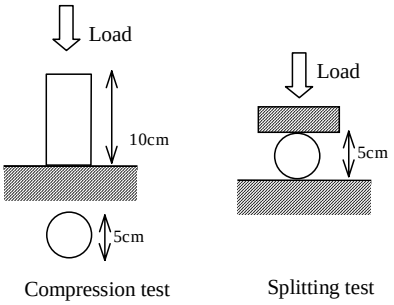
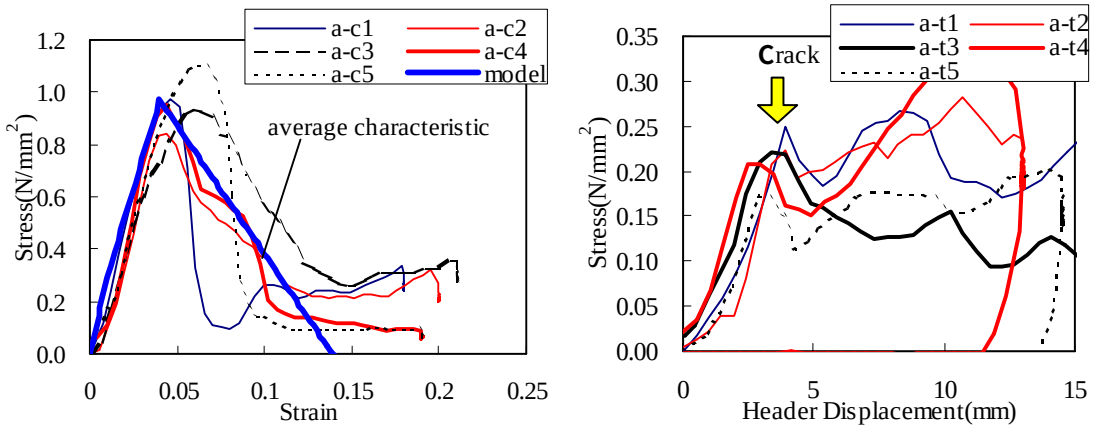
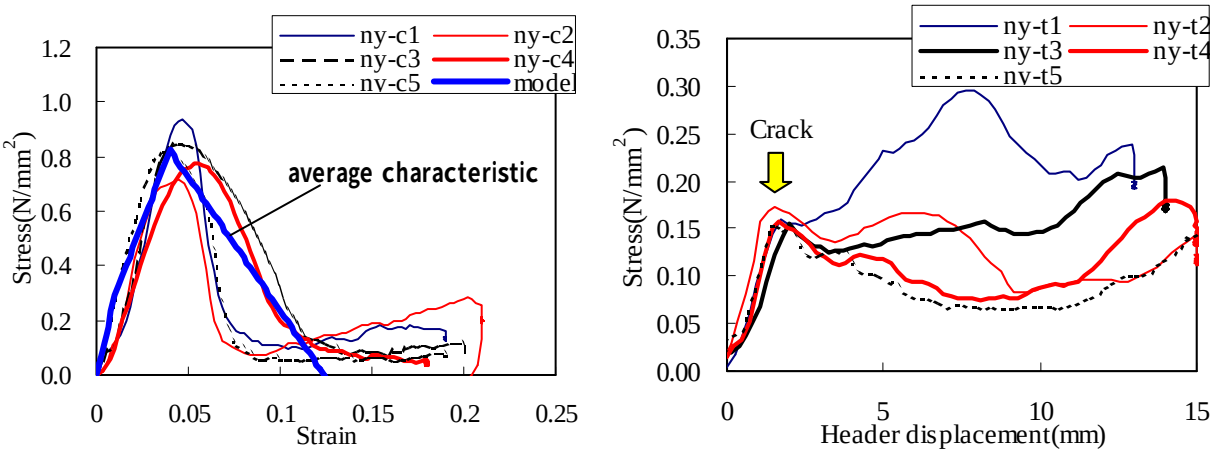


Figure 5 Material test on mud plaster



a) Compression test b) Splitting test

Figure 6 Material test for scratch coat mud plaster



a) Compression test b) Splitting test

Figure 7 Material test for scratch coat mud plaster

Table 1 Parameters for Fig. 6 and Fig.7

		scratch coat mud plaster	second coat mud plaster
compression side	Ec_1	29.4 N/mm^2	29.4 N/mm^2
	Ec_2	22.5 N/mm^2	17.6 N/mm^2
	Ec_3	-9.8 N/mm^2	-9.8 N/mm^2
	εc_1	0.010	0.010
	εc_2	0.040	0.040
tension side	Et_1	29.4 N/mm^2	29.4 N/mm^2
	Et_2	-2.5 N/mm^2	-2.5 N/mm^2
	εt_1	0.0075	0.0054

3.2. Full-scale Wall Test and Numerical Analysis of Standard Mud Plaster Wall

Three standard mud plaster walls are tested in full-scale wall test. Figure 8 shows the full-scale test and the collapse of mud plaster walls. The height of mud plaster wall is 2730 mm, the length is 910 mm, and the thickness of the mud plaster is 75 mm. There are 3 lateral wooden battens (Nuki) in a mud plaster wall. Dimensions of Nuki are 15 x 120 mm. The material of wooden frame is cobia. Dimensions of wooden frame are 120 x 120 mm. In this test, I make mud plaster walls with scratch coat and second coat.

In the test, cracks are firstly occurred on the Nuki in all specimens. Then the second coat mud plaster on the Nuki falls down from the mud plaster wall. The restoring force characteristic and envelope curves are shown in Fig. 9. Three test specimens have the almost the same restoring force characteristic. The maximum lateral load is about 8 kN.

A numerical analysis using above material parameter (Table 1) is executed for a standard mud plaster wall. Figure 10 is the analytical model of a standard mud plaster wall. The elements of mud plaster are arrayed according to actual specimen in the thickness direction, and the nodes of mud plaster are shared in the thickness direction. The load iteration of a calculation is a one-direction. The comparison between actual tests and analysis is shown in Fig. 9. The maximum lateral load of this analysis is 20% smaller than actual tests. At the same time, the envelope curves are close to the skeleton curve of this analysis. The reason why the calculation decreases the maximum lateral load is as follows: the bending moments by the inroad of Nuki to wooden frame are not considered in this analysis. The material strength of mud plaster may be lower than the material strength of the wall specimen.

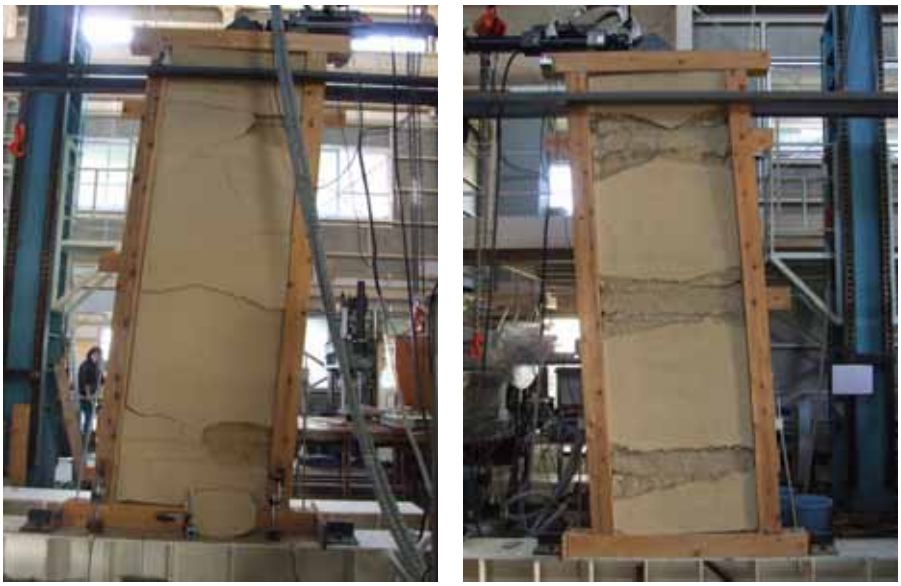
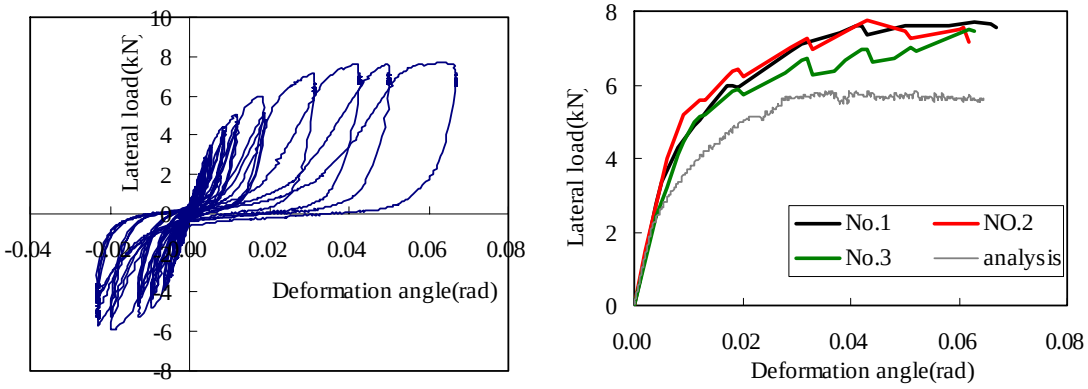
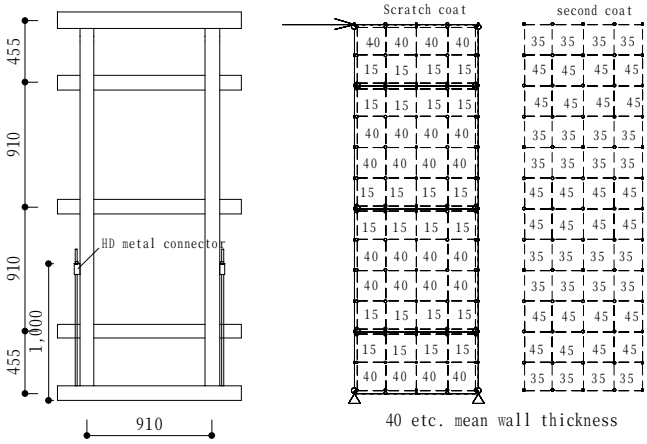


Figure 8 Full-scale wall test of standard mud plaster wall



a) specimen No.1 b) Envelope curves(No.1 - 3)

Figure 9 Restoring force characteristic from full-scale wall tests



a) Wooden frame b) Element array of mud plaster

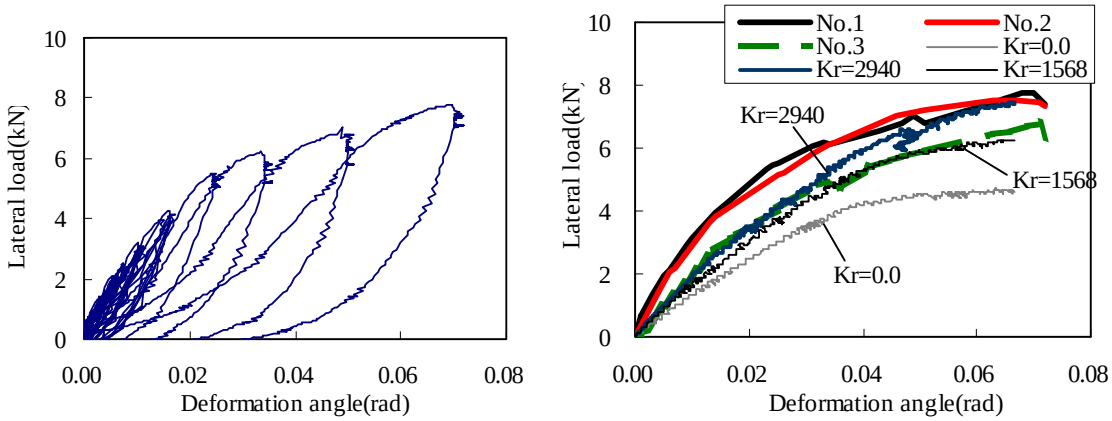
Figure 10 Analytical model of standard mud plaster wall

3.3. Full-scale Wall Test and Numerical Analysis of Wooden Frame with Hanging Wall

Three wooden frames with hanging wall are tested in full-scale wall test. Figure 11 shows the full-scale test and the collapse of mud plaster walls. The height of frame is 2730 mm and the length is 1820 mm. The height of mud plaster wall is 910 mm and the thickness of the mud plaster is 75 mm. In the mud plaster wall, there are a lateral Nuki and a vertical Nuki. Dimensions of Nuki are 15 x 120 mm. The material of wooden frame is cobia. Dimensions of wooden frame are 120 x 120 mm. In this test, we make mud plaster walls with scratch coat and second coat. In the test, cracks are occurred on the Nuki in specimen 1. But there is no crack on the Nuki in specimen No.2 and No.3. The restoring force characteristic and envelope curves are shown in Fig. 12. Two test specimens have the almost the same restoring force characteristic except specimen No.3. The maximum lateral load is about 6 or 8 kN.

A numerical analysis using above material parameter (Table 1) is executed for a wooden frame with hanging wall. The load iteration of a calculation is a one-direction. The comparison between actual tests and analysis is shown in Fig. 12. Kr in Fig. 12 means the rotation stiffness at plinth. The maximum lateral load and the skeleton curve of this analysis are changed by the rotation stiffness at plinth. In this actual test, the rotation stiffness at plinth is not measured. But this parameter study shows that this proposed analysis method represent the actual tests well.

Figure 11 Full-scale wall test of wooden frame with hanging wall (No.1)



a) specimen No.1 b) Envelope curves(No.1 - 3)

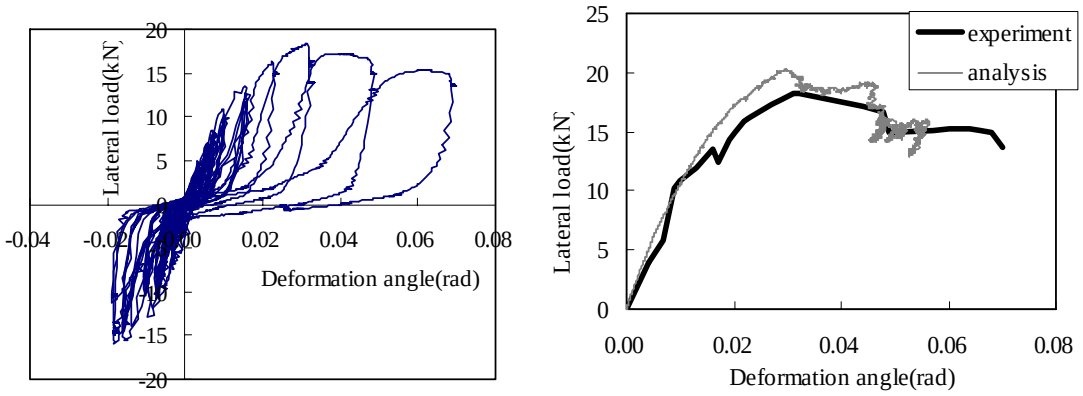
Figure 12 Restoring force characteristic from full-scale

3.4. Full-scale Wall Test and Numerical Analysis of Mud Plaster Wall with 1820 mm Length

A mud plaster wall with 1820mm length is tested in full-scale wall test. Figure 13 shows the full-scale test and the collapse of mud plaster walls. The height of mud plaster wall is 2730 mm, the length is 1820 mm, and the thickness of the mud plaster is 75 mm. There are 3 lateral wooden battens (Nuki) and a vertical Nuki in a mud plaster wall. Dimensions of Nuki are 15 x 120 mm. The material of wooden frame is cobia.

Dimensions of wooden frame are 120 x 120 mm. In this test, we make mud plaster walls with scratch coat and second coat.
In the test, cracks firstly occur on the Nuki in the specimen. Then the crack by shear force occur. The restoring force characteristic is shown in Fig. 14. The maximum lateral load is about 17 kN.
A numerical analysis using above material parameter (Table 1) is executed for a mud plaster wall with 1820 mm length. The load iteration of a calculation is a one-direction. The comparison between actual tests and analysis is shown in Fig. 14. The maximum lateral load of this analysis is a little larger than actual tests. At the same time, the envelope curves are close to the skeleton curve of this analysis.

Figure 13 Full-scale wall test of mud plaster wall with 1820 mm length



a) specimen b) Envelope curve

Figure 14 Restoring force characteristic from full-scale wall tests

4. CONCLUSION

In this report, I propose the numerical analysis method to calculate the restoring characteristic of Japanese mud plaster wall and its variants. To examine this proposed method, both material tests and full-scale wall tests are performed. As a result, this proposed calculation method gives the appropriate envelope curve of Japanese mud plaster wall and its variants.

ACKNOWLEDGEMENTS

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientic Research (C), 18560571, 2006.

REFERENCES

Ministry of Construction, "Checking standard for seismic safety and retrofit method on Japanese wooden structures", 1985.