WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

EFFECT OF AXIAL FORCE ON NATURAL FREQUENCIES OF COLUMNS ATTACHED TO TIMBER BUILDINGS

Hiroki Yoshinuma[1], Riku Muramatsu[2], Yuya Takaiwa[3]

ABSTRACT: The effect of axial stress on the natural frequency of columns attached to existing buildings was investigated by evaluating Young's modulus of the columns. First, elemental tests revealed that the natural frequency of the wood increased when axial stress was applied to the wood, and then showed a downward trend when the axial stress was 1.5 kN/mm2. The maximum of the natural frequency of the first-order mode was almost the same as that of the fixed end, and the third-order mode increased to 63 % of the natural frequency of the fixed end. Next, tests on an existing building revealed that the attachment of beams to columns other than at the ends of the columns caused vibration modes similar to harmonics in the column vibration modes. In addition, the natural frequency of the columns increased when the upstairs floor beams were loaded. Although the comparable relationship between axial stress and natural frequency obtained from elemental tests was confirmed, the natural frequency obtained differed due to differences in Young's modulus of the wood.

KEYWORDS: Transverse Vibration Method, Axial Force, Fixedness, Natural Frequency

1 – INTRODUCTION

In Japan, the Law for the Protection of Cultural Properties was enacted in 1950 to promote preserving and utilizing traditional timber buildings. The Law was revised in 1996, and a registration system for cultural properties was introduced, which is less restrictive than that for national treasures and important cultural properties. Wood is one of the main structural members of timber buildings, and it is particularly important to understand the material strength and Young's modulus of columns to understand the resilience characteristics of the building. On the other hand, since it is difficult to nondestructively determine the material properties of columns used in existing timber buildings in the field of seismic diagnosis, the values of ungraded wood with the highest safety factor, as specified in the material standard strength of Notification No. 1452 of the Ministry of Construction, are often quoted. To preserve the cultural value of existing timber buildings, it is desirable to correctly evaluate the material properties of the columns and reduce the amount of seismic reinforcement as much as possible. In this vein, several test methods for nondestructive evaluation of existing building columns have been studied. Velocity-of-propagation [1-5] and transverse vibration [6-11] methods can be used to measure Young's modulus of columns attached to existing buildings. The velocity-of-propagation method estimates Young's modulus from the velocity of vibration propagating through a sensor placed between two points along the length of the column member. Some of the measuring instruments are lightweight and easy to carry, making them highly practical, and they have been applied to actual buildings [5]. On the other hand, it requires a dedicated device with two sensors, making it less versatile. The transverse vibration method is a method for estimating Young's modulus of a column from the free vibration generated by striking the column. The transverse vibration method can be implemented with equipment capable of recording and Fourier transforming the sound of blows and is expected to be implemented with smartphones in the future. On the other hand, it has become clear that the natural frequencies of the transverse vibration method vary depending on the joining conditions of the wood ends [11]. This study focuses on the dead loads acting on the columns of existing buildings to determine the effect of the dead loads acting on the columns on the natural frequencies of the columns using the transverse vibration method. In this study, compressive stress and lateral pressure were applied to the edge of the wood to determine changes in the natural frequencies of the wood. Next, axial forces were applied to columns attached to existing timber buildings to investigate changes in the natural frequencies of the columns.

[1] Hiroki Yoshinuma, Doctoral Student, Course of Architecture and Urban Design, Graduate School of Science and Engineering, Toyo University.

[2] Riku Muramatsu, Master's Student, Course of Architecture, Graduate School of Science and Engineering, Toyo University.

[3] Yuya Takaiwa, Associate Professor, Department of Architecture, Faculty of Science and Engineering, Toyo University, Dr. Eng. takaiwa@toyo.jp 2100 Kujirai, Kawagoe-shi, Saitama, Japan (350-8585)

https://doi.org/10.52202/080513-0700

2 – CHANGE IN NATURAL FREQUENCY DUE TO AXIAL FORCE IN WOOD

In terms of material mechanics, the natural frequency of a member increases when a tensile force acts on it and decreases when a compressive force acts on it. This phenomenon has been used in research to measure the strain acting on railroad rails, and it has become clear that the thermal expansion of fixed rails causes compressive forces that lower the natural frequency of the rails [12]. In this chapter, it is clarified whether the same phenomenon occurs in the fixed condition of wood.

2.1 TEST METHOD

An arbitrary axial force is applied by placing a compression jig at the end of the element specimen to determine the effect of the axial force on the natural frequency of the wood. Fig. 1 shows an overview of the test. The test specimens were made of cedar with a cross-sectional dimension of 120 mm × 45 mm, a length of 1600 mm, a weight of 3.01 kg, and a density of 348 kg/m^3. In the test, a piece of wood is placed between two fixtures, and compression forces are applied to the wood by adjusting the length of the horizontal bolts attached to the fixtures. The compression force acting on the wood is measured by a load cell placed between the jig and the wood. The axial force acting on the wood was determined in 0.5 kN increments, with a maximum value of 10 kN.

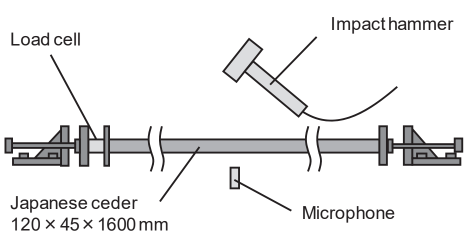

Figure 1. Overview of percussion test with axial force applied

Fig. 2 shows the vibration modes for each mode. The conceptual diagram of the vibration modes shows that for the first- and third-order modes, the center of the span is the belly of the vibration, and for the second-order mode, the center of the span is the node of the vibration. Although striking the center of the span results in a smaller excursion of the second-order mode, the first-order mode is the most dominant mode in each mode, so the change in natural frequencies of the first-order mode was given priority and the center was struck in this test. An impulse hammer with a built-in accelerometer is used to strike the wood to measure the input vibration to the wood. Aluminum was selected as the material for the striking portion of the impulse hammer because of the wide frequency range of the input to the wood. The sound of the wood vibrating, when struck, is measured by placing a directional microphone in the center of the length of the wood. The measured wood vibration sound is an FFT (Fast Fourier Transform) spectrum analyzer. The natural frequency of the wood is determined by the excitations of the transfer function.

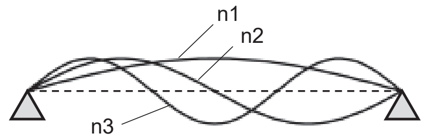

Figure 2. Vibration mode

2.2 TEST RESULTS

First, a transverse vibration method was performed on a simple support with a span of 1600 mm, and a first-order natural frequency was found at 37.5 Hz. The equation for calculating Young's modulus by the transverse vibration method is shown below.

$$E = \left(2\pi f L^2 / i m^2 \right)^2 \rho \qquad (1)$$

E : Young's modulus (N/m²)
π : circumference
f : Natural frequency (Hz)
L : the distance between fulcrums (m)
i : the secondary radius of the cross section (m)
m : Constant determined by vibration order and column boundary conditions
ρ : density(kg/m³)

Substituting a first-order natural frequency of 37.5 Hz into equation (1) yields a Young's modulus of 7.7 kN/mm^2. Since it is assumed that the end fixed condition changes when axial force is applied to the end of the wood, Table 1 shows the estimated natural frequencies when the end fixed condition changes. In calculating the estimated natural frequencies, all conditions except the support condition m were assumed to be constants.

Table 1: Change in natural frequency due to axial force loading

Boundary condition	E	n	m	f
Simple support	7.7	1	3.142	37.5
		2	6.283	150.0
		3	9.425	337.5
Both ends free or both ends fixed		1	4.730	85.0
		2	7.854	234.4
		3	10.996	459.4

n : Vibration order

Fig. 3 shows the change in natural frequencies of wood subjected to axial force. Because the center of the wood was struck in the test, the common trend among all test results was that the natural frequencies of the first- and third-order modes showed clear excitations in their

https://doi.org/10.52202/080513-0700

transfer functions, while the natural frequencies of the second-order modes showed less excitations in their transfer functions than the other modes.

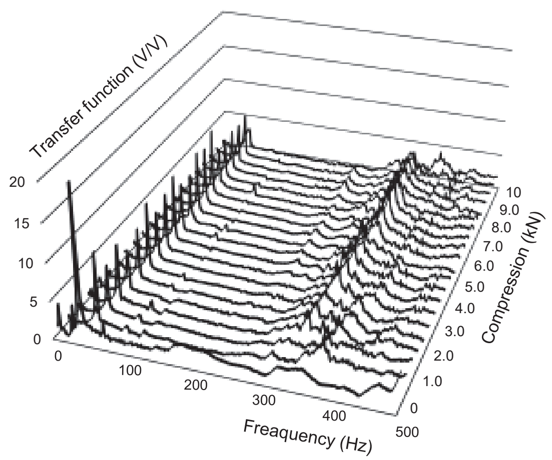

Figure 3. Result of percussion test with axial force applied

Fig. 4 shows the relationship between the axial stress acting on the column and the first-, second-, and third-order natural frequencies at which the transfer function excellencies were measured. Fig. 4 shows the range of natural frequency variation for simply supported, free at both ends, or fixed at both ends, based on Young's modulus calculated by the simply supported transverse vibration method. The results of each test confirmed a similar trend for the first-order and third-order modes, and the natural frequencies of the second-order mode varied more than those of the other modes. One reason for this is that the transfer function of the natural frequencies of the second-order modes in this test was smaller than that of the other modes, making it difficult to determine the natural frequencies. Therefore, the analysis of this test will deal with the results of the first-order and third-order modes. Confirmation of the first- and third-order modes showed that the natural frequencies also tended to increase as the axial stress increased. The increasing trend turned to a decreasing trend around 1.5 kN/mm^2. This suggests that, in wood subjected to axial stress, the fixation degree of the wood end may increase due to the axial force, which in turn increases the natural frequency of the wood. When an axial stress of approximately 1.5 kN/mm^2 was applied, the natural frequency decreased, indicating that the natural frequency also decreased with axial stress in wood. In terms of natural frequency fluctuations under end-support conditions, both first- and third-order modes for simple support are consistent with the range of natural frequencies for simple support. On the other hand, as the axial stress increased, the natural frequency increased and leveled off, but the natural frequency that leveled off was lower than the natural frequency with the end-coupling conditions fixed at both ends. The ratios of the natural frequencies with flat increases to those with fixed-end coupling conditions were 43 % for the first-order mode and 27 % for the third-order mode.

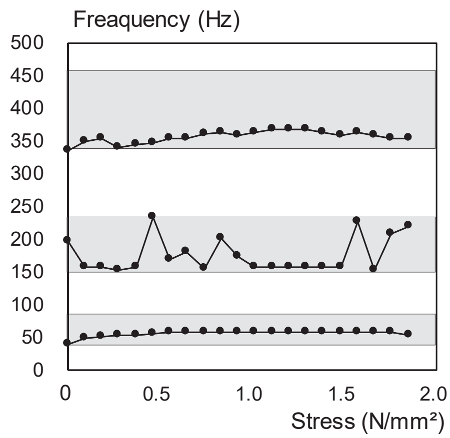

Figure 4. Relationship between axial stress and natural frequency

3 – CHANGE IN NATURAL FREQUENCY DUE TO SIDE PRESSURE AT WOOD ENDS

In general, the natural frequency increases when tensile stress is applied to a member and decreases when compressive stress is applied to a member. However, in Chapter 2, it was confirmed that the natural frequency of wood tends to increase when a compressive force is applied to the wood. The principle of the increase in the natural frequency caused by the axial force is assumed to be the increase in the moment of fixation of the end of the wood due to the axial force applied to the end of the wood, resulting in a change from simple support to a condition of fixation at both ends. In this chapter, the effect of lateral pressure on natural frequencies is clarified by fixing wood ends to a reaction jig with bolts and steel plates.

3.1 TEST METHOD

Fig. 5 shows an overview of the test. The wood used for the test is the same as the specimen described in Chapter 2. In this test, M12 bolts were inserted 50 mm from both ends of a 1600 mm long piece of lumber so that the distance between the fulcrum points was 1500 mm. A steel plate thick enough not to be deformed by the tightening pressure of the bolts was used to sandwich the wood and fix it to the reaction jig. A load cell is installed at one end of the steel plate, and the load is controlled by tightening a nut with the same amount of torque as the load cell at the other end. The load is applied in 0.5 kN increments, with a maximum value of 10 kN. The impulse hammer used to strike the wood, as well as the vibration measurement and analysis equipment, are the same as those used in Chapter 2.

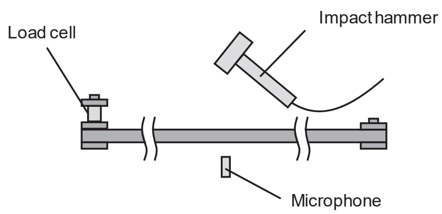

Figure 5. Overview of percussion test with side pressure applied

3.2 TEST RESULTS

First, the transverse vibration method was conducted on a simply supported beam with a span of 1500 mm, and the first-order natural frequency was confirmed at 40.6 Hz. Substituting the first-order natural frequency of 40.6 Hz into the formula for calculating Young's modulus using the transverse vibration method, Young's modulus of 7.0 kN/mm^2 was calculated. The calculated Young's modulus was 7.7 kN/mm^2 for 1600 mm in Chapter 2. However, because the range over which the specimen vibrates changes from 1600 mm to 1500 mm due to the change in span, Young's modulus of 7.0 kN/mm^2 calculated for 1500 mm is used again in this chapter as the Young's modulus for the specimen in this test. Since it is assumed that the fixed condition changes when pressure is applied to the sides of the wood ends, Table 2 shows the natural frequencies when the fixed condition changes. In calculating the natural frequencies, all conditions except the support condition m were assumed to be constants.

Table 1: Change in natural frequency due to side pressure loading

Boundary condition	E	n	m	f
Simple support	7.0	1	3.142	40.6
		2	6.283	162.5
		3	9.425	365.6
Both ends free or both ends fixed		1	4.730	92.1
		2	7.854	253.9
		3	10.996	497.7

Fig. 6 shows the change in natural frequencies of the wood as the degree of fixation was varied. When the wood was subjected to axial stress, first-order and third-order mode transfer function excitations were observed, while second-order mode excitations were indistinct. Fig. 7 shows the relationship among the first-, second-, and third-order natural frequencies at which the side pressures acting on the wood ends and the transfer function excellencies were measured. Fig. 7 also shows the range of variation in natural frequencies for simply supported, free at both ends, and fixed at both ends, based on Young's modulus calculated by the simply supported transverse vibration method. The results of each test showed that the same trend was observed for the first-order and third-order modes and that the natural frequencies of the second-order mode varied more than those of the other modes. As in Chapter 2, the smallness of the transfer function can be cited as the reason for this, but compared to Chapter 2, it can be said that the tendency for the natural frequencies to change is relatively well identified. For this reason, the analysis in this study will deal with the results for first-, second-, and third-order modes. The results for the first-, second-, and third-order modes show that the natural frequency tends to increase as the axial stress increases. On the other hand, the decreasing trend of the natural frequencies above a certain stress level due to an increase in load, which was confirmed in Chapter 2, was not observed. This indicates that the increase in natural frequency is caused by an increase in the degree of fixation due to an increase in the rotational moment of the wood end. In contrast, the decrease in natural frequency is caused by a decrease in the natural frequency due to the vibrational theory of axial stress acting on the wood. In the case of simple support, the first-, second-, and third-order modes all coincide with each other. On the other hand, the natural frequency increased as the side pressure increased and then leveled off. The natural frequencies that leveled off were consistent with the range of natural frequencies fixed at both ends for the first- and second-order modes, and were lower than the natural frequencies fixed at both ends for the third-order mode. The ratio of the natural frequencies of the third-order modes with a horizontal increase to the natural frequencies of the two end-fixed third-order modes was 63 %.

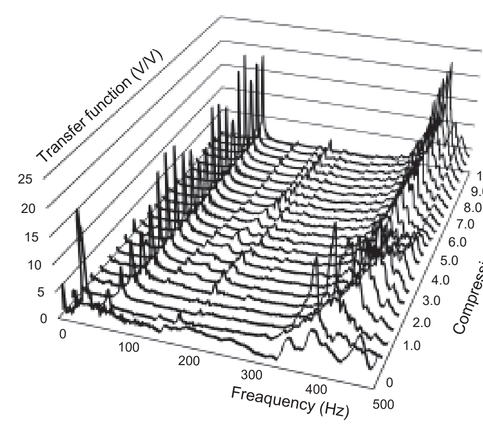

Figure 6. Result of percussion test with side pressure applied

https://doi.org/10.52202/080513-0700

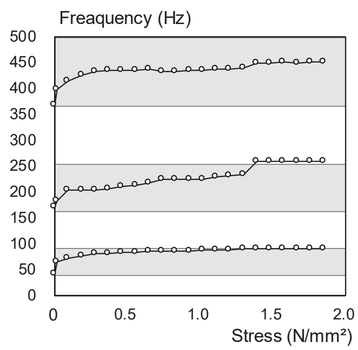

Figure 7. Relation between side pressure and natural frequency

4 – EFFECT OF AXIAL FORCE ON NATURAL FREQUENCY OF COLUMNS ATTACHED TO TIMBER BUILDINGS

In this study, the transverse vibration method is applied to the columns of existing buildings to determine the effect of axial forces acting on the columns on their natural frequencies.

4.1 OVERVIEW OF SURVEYED BUILDINGS AND COLUMNS

The existing building under study is a two-story timber building in Nakano Ward, Tokyo, Japan. The building is rectangular in plan, with a central atrium on the second floor and a corridor overlooking the first floor. The columns to be surveyed were those facing the stairwells, where the attachment of the horizontal members was clear.

4.2 TEST METHOD

Fig. 8 shows an overview of the columns surveyed. The columns are 150 mm x 150 mm in cross-section and 5180 mm in length and are attached to the upstairs floor beam and floor framing at a height of 2275 mm above the first-floor level. The beams are attached at 4585 mm and 5180 mm above the first floor (each beam is referred to as Beem 1-3 in the following order from the bottom). An impulse hammer was used to strike the columns in the percussion test, and a rubber tip jig was used as the tip material of the impulse hammer to protect the columns of the existing buildings. In the vibration measurements of the columns, acceleration sensors were used instead of microphones, considering the ambient noise of the existing building. The acceleration sensor was attached to the columns via double-sided tape to measure the vibration of the columns. The vibration measurement and analysis methods were the same as for the elemental tests described in Chapter 2. After conducting the percussion test using the transverse vibration method, five investigators were placed on the second floor near the columns under investigation to increase the axial force acting on the columns, and an additional axial force with a total weight of 3145 N was applied.

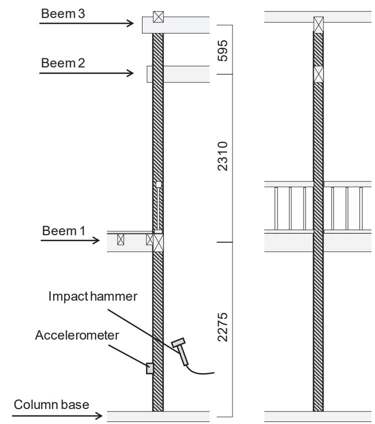

Figure 8. Summary of pillars surveyed

4.3 TEST RESULTS

4.3.1 CHANGE IN POWER SPECTRUM WITH AND WITHOUT ADDITIONAL AXIAL FORCE

Fig. 9 shows the change in the power spectrum with and without additional axial force. The vibration modes in the absence of additional axial force were found to be dominated by first-, second-, and third-order modes. On the other hand, when additional axial force was added, the first-order and second-order modes were found to be dominant, but the third-order mode did not appear dominant. The input power spectrum shows that the input vibration with a spectrum around 400 Hz, where the third-order mode was confirmed, was input to the column regardless of whether an additional axial force was applied or not. This suggests that the smaller excitations of the third-order modes are not due to variations in the input vibration caused by the hammer being struck manually, but rather to the addition of an additional axial force. Next, the relationship between the input and output power spectra of the first-order and second-order modes was checked, and it was confirmed that the power spectrum of the input vibration tended to be larger when the test was conducted with no axial force applied. This is due to the variation in input vibration caused by the hammer being struck manually. On the other hand, analysis of the output vibration showed that the power spectrum of the output was larger when the axial force was added than when it was not added. The reason for this is thought to be that the addition of axial force changed the anchorage of the columns, causing the first- and second-order vibration modes to dominate.

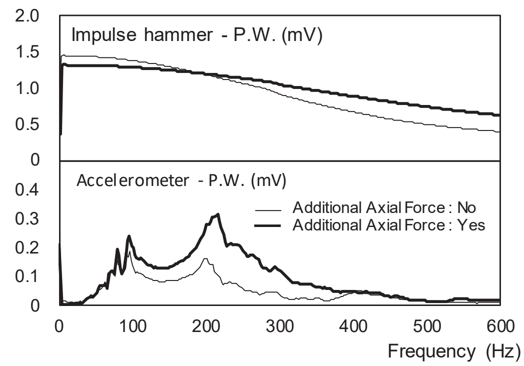

Figure 9. Change in power spectrum with and without additional axial force

4.3.2 VIBRATION MODES WITH AND WITHOUT AXIAL FORCE

The columns under study had four horizontal members to which they were attached, each of which could be a support condition for the columns. The changes in the vibration modes of the columns for each support condition in effect are then analyzed. Figures 10-15 show the results of the analysis for each vibration mode. First, when Beem 3 and the column base are the support conditions, the length of the timber is 5180 mm, and it is inferred that first-order and second-order modes exist below 68 Hz. On the other hand, the absence of dominance below 68 Hz in the sounding test of the columns confirms that the assumed vibration is not dominant under the conditions of this test.

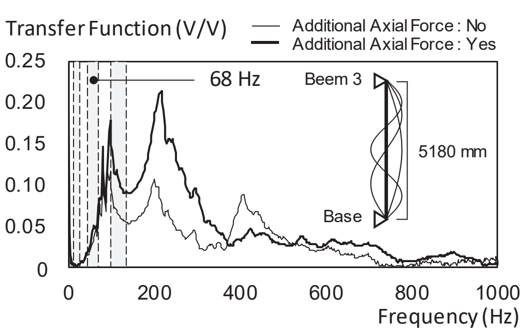

Figure 10. Analysis results for each vibration mode pattern1

Next, when Beem 2 and the column base were the support conditions, the length of the timber was 4585 mm, and it was inferred that first-order, second-order, and third-order modes existed below 170 Hz. On the other hand, the sound test of the columns showed that the transfer function was dominant in the range of the second-order mode, but not below 31 Hz, where the first-order mode is included, and not around 170 Hz, where the third-order mode is included. This confirms that the assumed vibration is not dominant under the conditions of this test.

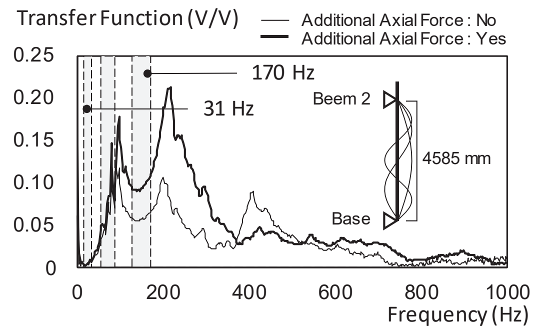

Figure 11. Analysis results for each vibration mode pattern 2

Next, when Beem I and the column base are the support conditions, the length of the column is 2275 mm, and it is inferred that the first-order and second-order modes of the column exist near the first-order and second-order modes, which were confirmed in the sounding test of the column, where the transfer function was found to be dominant. On the other hand, there was no corresponding mode in the range where the third-order mode was confirmed in the hammering test of the columns. The assumed vibrations were consistent with the first-order and second-order modes, but not with the third-order mode under the conditions of this test.

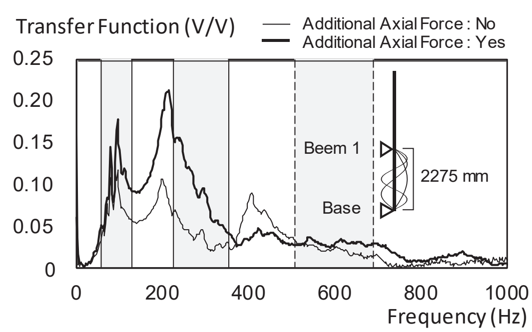

Figure 12. Analysis results for each vibration mode pattern 3

Next, when Beem 3 and Beem 2 were the support conditions, the length of the material was 595 mm, and it was inferred that the first-order mode existed after 825 Hz. On the other hand, many of the transfer functions were found to be dominant below 825 Hz in the sounding test of the columns, so the dominant vibration mode is

https://doi.org/10.52202/080513-0700

not dominant after 825 Hz. This confirms that the assumed vibration is not dominant under the conditions of this test.

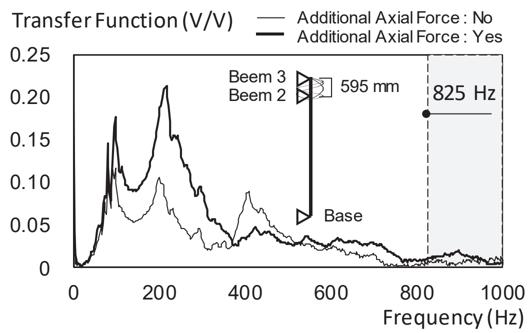

Figure 13. Analysis results for each vibration mode pattern 4

When Beem 3 and Beem 1 are the support conditions, the length of the column is 2905 mm, and it is inferred that the first-order, second-order, and third-order modes of the column exist near the first-order, second-order, and third-order modes that were confirmed to have dominant transfer functions in the sounding tests of the columns. The assumed vibrations were consistent with the first-order, second-order, and third-order modes under the conditions of this test.

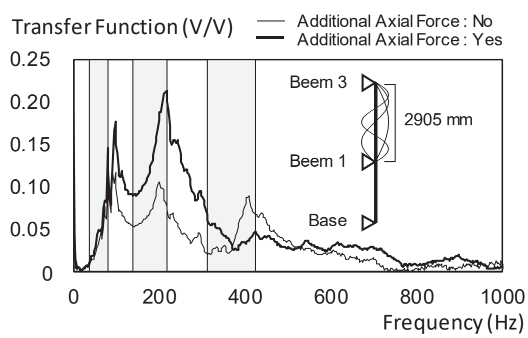

Figure 14. Analysis results for each vibration mode pattern 5

Finally, when Beem I and Beem II are the support conditions, the lumber length is 2310 mm, and it is inferred that the first-order and second-order modes of the columns exist near the first-order and second-order modes, which were confirmed in the sounding test of the columns, where the transfer functions are dominant. On the other hand, there were no applicable modes in the range where the third-order mode was confirmed in the pillar impact test. The assumed vibrations were consistent with the first-order and second-order modes, but not with the third-order modes under the conditions of this test.

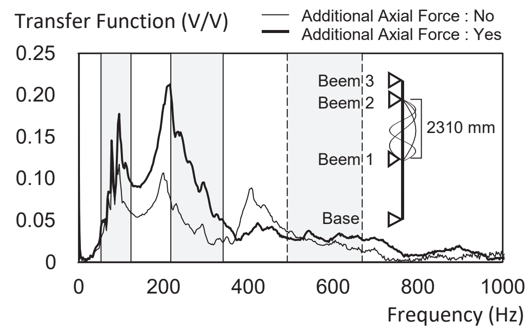

Figure 15. Analysis results for each vibration mode pattern 6

There is a technique called the harmonics technique for stringed instruments [13]. Fig. 16 shows an overview of the harmonics technique. The harmonics technique is a technique in which the string is held down lightly with the finger to create nodes of vibration, and although the string length does not change, the nodes are always at the points where the finger is held down. While a normal open string produces n overtones, the harmonic technique produces only 2n overtones, resulting in a clearer melody with fewer simultaneous notes than a normal string.

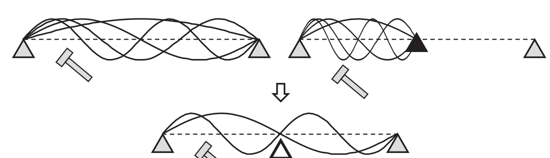

Figure 16. Harmonics technique

In the case of the columns studied in this research, the vibration mode is loosely constrained by the second-story floor beams, as in the Harmonics Technique, when there is no person on the second-story floor beams. The second-story floor beams are strongly constrained by a person, resulting in an apparent reduction in the length of the column. Fig. 17 shows the vibration mode of the column inspired by the harmonics technique. First, when there was no person on the upstairs floor beam, a blow to the column base caused the column to vibrate freely, and free vibration occurred at the natural frequencies of Beem 1 and the column base, Beem 3, and Beem 1. The free vibration was caused by a blow to the column base, Beem 3, and Beem 1, respectively. Since the natural frequencies of the third-order modes are only applicable in the range of Beem 3 and Beem 1, we can conclude that they are the natural frequencies of Beem 3 and Beem 1. On the other hand, for the first-order and second-order modes, the natural frequencies are applicable in both ranges, so it is not possible to determine which natural frequency it is. Next, the upstairs floor beams were strongly constrained by the presence of people on the second floor, which is thought to have shortened the apparent length of the timbers. In this case, the vibrations striking near the column bases are restrained by the upstairs floor beams and are less likely to be transmitted to the Beem 3 and Beem 1 ranges. The change in transfer function with and without load shows that the transfer function of the third-order mode is smaller, and the transfer functions of the first-order and second-order modes are larger. Therefore, the transfer functions of the third-order modes are the natural frequencies in the range of Beem III and Beem I. The predominant transfer functions of the first-order and second-order modes are the natural frequencies of Beem I and the column base.

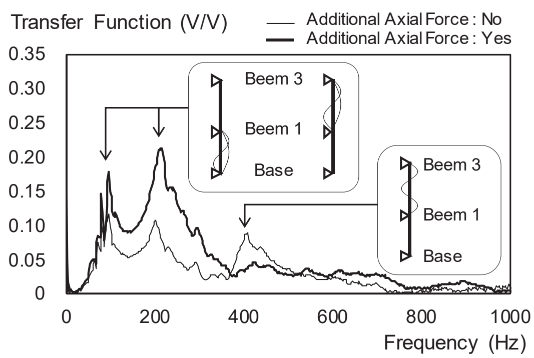

Figure 17. Vibration modes of columns

4.3.3 CHANGE IN NATURAL FREQUENCY WITH AND WITHOUT AXIAL FORCE

The fixed load calculated for an unoccupied second floor was found to be 4204 N. The axial force is 0.19 N/mm^2 in terms of stress. If five persons are placed on the second floor, the axial force acting on the column is 7349 kN, which is 0.33 N/mm^2 in terms of stress. The natural frequencies before and after a person was placed on the column in the percussion test showed an increase in natural frequency of 0 Hz for the first-order mode, 12.5 Hz for the second-order mode, and 15 Hz for the third-order mode in the excellence of the transfer function of the first-order and second-order modes. From the elemental tests in Chapters 2 and 3, it was confirmed that an increase in the axial stress of the wood and the lateral pressure at the end of the wood increased the anchorage of the wood support, increasing the natural frequency. In traditional Japanese wooden buildings, column heads and column bases are simply fixed by inserting mortises, and the rotational moments at small angles of deformation are mainly caused by the frictional resistance between the wood on the sides of the mortises. The frictional resistance of the wood edges is considered negligible in this study because there is a clearance between the mortise holes due to the drying shrinkage of the wood. The axial force acting on the columns below the upstairs floor beams increased from 0.19 N/mm^2 to 0.33 N/mm^2 due to the presence of people on the second floor in the impact test of the existing building. As a result, the anchorage of the supports in the first-, second-, and third-order modes increased, as did the natural frequency of the columns. Fig. 17 plots the results of the investigation of the actual building against the relationship between axial stress and natural frequency that was verified in Chapter 2. Although the columns in the existing building and the elemental tests conducted in Chapter 2 were made of the same species of lumber, the natural frequency of the columns was higher than that of the elemental tests, probably due to the higher Young's modulus of the columns in the actual building. On the other hand, the tendency of the natural frequency to increase with increasing axial stress is generally consistent with the results of the investigation of the existing building and the results of the element tests, and in particular, the tendency of the first-order mode to increase is confirmed to be stable and measurable.

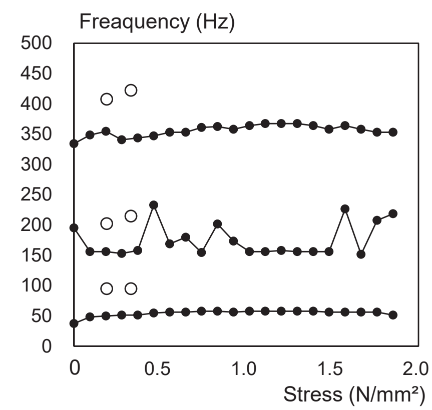

Figure 18. Relationship between axial stress and natural frequency

5 – CONCLUSIONS

To clarify the effect of axial stress on the natural frequency of columns in the evaluation of Young's modulus for columns attached to existing buildings, elemental tests were conducted using individual pieces of wood, and measurements were made on existing buildings. The findings are as follows.

1. The results of the elemental tests showed that the natural frequency of wood increased when axial stress was applied to the wood, and then showed a

https://doi.org/10.52202/080513-0700

downward trend when the axial stress was 1.5 kN/mm^2.

2. The results of the element tests showed that the natural frequencies increased as the side pressure at the end of the wood was increased and that the natural frequencies of the first-order mode generally matched those of the fixed end, while the third-order mode increased to 63% of the natural frequency of the fixed end.
3. The results of the investigation of the existing building revealed that the vibration modes of the columns are similar to those of the harmonic technique when the beams are attached to the columns other than at the ends.
4. The results of the investigation of the existing building showed that the natural frequency of the columns increased when the upstairs floor beams were loaded. Although a similar relationship between axial stress and natural frequency obtained from elemental tests was confirmed, there was a difference in the natural frequency obtained, possibly due to the difference in Young's modulus of the wood.

Based on these findings, we believe that the accuracy of estimating Young's modulus of columns in real buildings subjected to axial stress can be improved by collecting data on the relationship between axial stress and natural frequencies for lumber with different Young's moduli in the future.

6 – REFERENCES

[1] Mina Sugino, Xiang Li, Keiji Yuki, Hajime Tateishi, Yasuhiro Hayashi : Material Property Evaluation of Columns in Traditional Wooden Buildings Using Impact Elastic Wave, Journal of Structural and Construction Engineering, Vol. 84, No. 759, pp. 677-684, 2019

[2] Kazutaka Namie, Jian Jiao, Mina Sugino, Noriko Takiyama, Yasuhiro Hayashi : Young's Modulus Estimation of Timber by Non-Destructive Test Based on Stress Wave Velocity Measurement, Journal of Structural and Construction Engineering, Vol. 78, No. 686, pp. 833-838, 2013

[3] Hayami Norifumi, Murase Shiori, Sugino Mina, Hayashi Yasuhiro : Study on Estimating Material Properties of Large Diameter Wood with Non-Destructive Test Using Impact Elastic Waves, Aij Journal of Technology and Design, Vol. 24, No. 57, pp. 649-654, 2018

[4] Norifumi Hayami, Sunao Kobayashi, Mina Sugino, Yasuhiro Hayashi : Study on an Ultrasonic Velocity of Wood, AIJ Journal of Technology and Design, Vol. 23, No. 54, pp. 469-474, 2017

[5] Yasuhiro Nambu, Yuki Moriya, Mina Sugino, Chiaki Watanabe, Yasuhiro Hayashi : Structural Investigation and Seismic Performance Evaluation of Traditioal Wooden Houses in Seki in Mie Prefecture, AIJ Journal of Technology and Design, Vol. 23, No. 53, pp. 129-134, 2017

[6] Kinsaku Nakata, Toshiro Kajitani, Yoshishiro Takemura, Atsushi Santa : Modulus of Elasticity of Wood by Flexural Vibration Test, Wood industry, , Vol. 69, No. 10, pp. 430-435, 2014

[7] Kazuki Kawakami, Satoshi Iwai : Investigation of Nondestructive Measuring Accuracy of the Elastic Modulus of Timbers Using the Tapping-Tone Method, Bulletin of Hiroshima Institute of Technology. Research volume, Vol. 42, pp. 199-206, 2008

[8] Kazuki Kawakami, Satoshi Iwai : Accuracy in Estimating the Elastic Modulus of Timbers for Individual Part Using the Nondestructive Tapping-Tone Technique, Bulletin of Hiroshima Institute of Technology. Research volume, Vol. 43, pp. 265-270, 2009

[9] Takafumi Sakashita, Naoyuki Matsumoto, Mikio Koshihara : Experimental Study on Non-Destructive Measurement of Stiffness and Strength of Timber for Buildings of Cultural Properties, Journal of Institute of Industrial Science, The University of Tokyo, Vol. 74, No. 4, pp. 331-334, 2022

[10] Iwai Satoshi, Ohbayashi Makoto : Use of the Acoustic Grading Method as Nondestructive Inspection to Measure the Elastic Modulus of Timbers for Experimental Education in Engineering, Bulletin of Hiroshima Institute of Technology. Research volume, Vol. 6, pp. 15-18, 2007

[11] Kodera Yuki, Hosokawa Yuga, Takaiwa Yuya : Influence of Fixation of Timber Frame Structures on Frequency Characteristics of Timber Member, Summaries of Technical Papers of Annual Meeting. Architectural Institute of Japan, pp. 9-10, 2021

[12] Fumihiro Urakawa, Kazuhisa Abe, Hiroshi Takahashi : Improvement of the Accuracy of the Method for Measuring the Axial Force of a Rail Based on the Natural Frequency, RTRI Report, Vol. 29, No. 8, pp. 41-46, 2015

[13] F. Absil : Guitar Harmonics ; an Overview in Diagram, Physics, Engineering, 2018