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SOUNDNESS ASSESSMENT OF STRUCTURAL WOOD MEMBERS AFTER 60 YEARS OF SUBMERSION

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ABSTRACT: We conducted various tests to assess the soundness of logs used in civil engineering structures that had been submerged for nearly 60 years in the reservoir of the Arase Dam in Kumamoto Prefecture, Japan. Our aim was to clarify the soundness of wood members used in such structures along with their suitability for cascade recycling (reuse in secondary applications). Various tests performed immediately after recovery showed very little decomposition or rot after the approximately 60 years of submersion in water at or above the fiber saturation point. No appreciable change over time was observed in Young's modulus, demonstrating the long-term durability of the wooden members. This and other investigations confirm the soundness of submerged structural wooden members and suggest the potential for cascade recycling of such materials for liquefaction countermeasure work and other applications.

KEYWORDS: Logs, Decomposition/Rotting, Longitudinal Young's modulus

1 INTRODUCTION

From antiquity, woods have been used to build structural foundations throughout Japan. However, after the post-war period of high economic growth, builders and civil engineers began to shun the use of wood for various reasons, including an increasing availability of concrete, steel, and other construction materials; a high degree of variability in the sizes and shapes of wooden members; and uncertainty surrounding the long-term durability and mechanism of bearing capacity of wood. In addition, the cabinet established a policy for the rationalization of the utilization of wood resources in 1955 to discourage the use of wood in order to assure sufficient supply for major industries and to stabilize citizen's livelihoods. Furthermore, after the 1970s, specific mentions of wood were removed from *Design Specifications for Highway Bridges* and from the *Implementation Manual for Recommendations for Design of Building Foundations* [1]. Later, as global environmental issues came to the fore, attention turned to the creation and maintenance of a "sustainable society" as a way to address global warming [2]. Unlike steel or concrete, trees store carbons fixed by photosynthesis. By actively utilizing wood products in Japan, one of the most heavily forested nations in the world, we can contribute to efforts to reduce carbon dioxide emissions and carbon stock. In particular, the utilization of wood products is expected to rise in measures for stabilizing soft and weak ground [3]. Thus, the development of technologies for the utilization of wood is also expected in the field of civil engineering.

From the historical record, logs are well known to maintain their soundness and functional integrity over many years of groundwater exposure. However, when logs are excavated from a site, they are rarely reused. Because there is no track record for the reuse of such materials, they are instead simply discarded as industrial waste. According to the Ministry of the Environment, wood re-utilization is becoming more common, although usually as compost or fuel. As before, about half is simply ground into chips, directly buried, or simply burned as is [4].

In this research, we assessed the soundness of logs excavated upon the removal of the Arase Dam in Kumamoto Prefecture, Japan. Our aim was to investigate the long-term durability of wooden members in civil engineering structures and the potential for their cascade recycling (reuse) as structural members for other such structures.

To determine the long-term durability of those members, we conducted on-site Pilodyn wood testing immediately after excavation. Also, with the press fit of wooden piles vertically into the ground becoming increasingly common in civil engineering, we also subjected samples to static load testing to measure longitudinal Young's modulus. Furthermore, toward the ultimate objective of cascade recycling, we compared the results with those obtained by the longitudinal vibration method, which is nondestructive and can be easily conducted on site.

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Table 1: Parameters for the Arase Dam, Fujimoto Power Plant

Location	Sakamoto Town, Yatsushiro City, Kumamoto Prefecture
Form	Concrete gravity dam
Dam height	25.0m
Crest length	210.8m
Dam volume	47,167m^3
Contributory area	1,721km^2
Total reservoir capacity	10,140,000m^3
Flooded area	1,230,000m^2
Volume of surcharge	EL32.5m
Power generation method	Dam and conduit type
Maximum volume of water consumption	134m^3/s
Maximum power output	18,200kW
Annual supply power	About 74,680,000kWh

Photo 1: *Overview of the Arase Dam*

2 OVERVIEW OF THE STUDY SITE

The study site is the Arase Dam, located approximately 20 km upstream from the mouth of the Kuma River, which is considered one of the three fastest rivers in Japan (Photo 1). The dam was built to supplement a hydroelectric power plant (Fujimoto Power Plant) under a comprehensive development plan for the Kuma River basin. Table 1 lists various parameters for the dam and power station [5]. The facility began generating electricity in 1954 and at one time accounted for 16% of the total generation capacity of Kumamoto Prefecture. It was shut down in 2010 upon losing its water rights, and work to remove the dam began in 2012. In preparing to remove the portion corresponding to the right bank of the river channel, gating was installed to lower the water level. A number of wooden river training structures (*ushiwaku*: literally, “cow frames,” often translated as “rock cribs”), put into place during dam construction, began to emerge from the reservoir when the water level was lowered by approximately 6 m. A search of the literature reveals the following mention of piling and

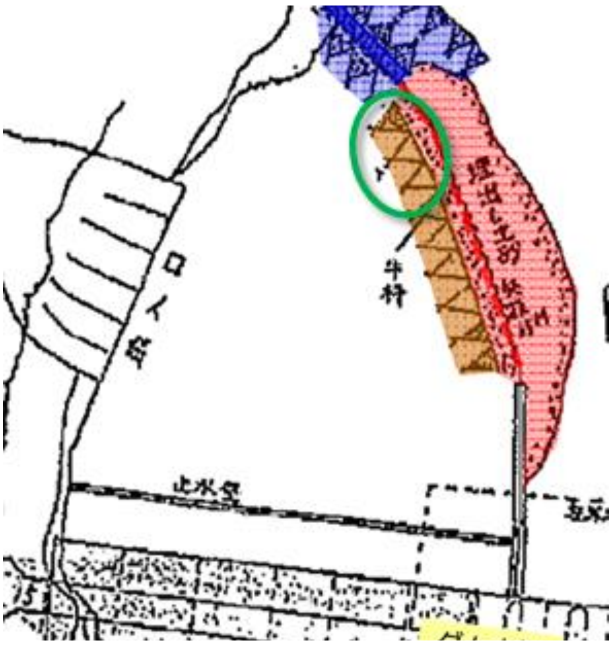
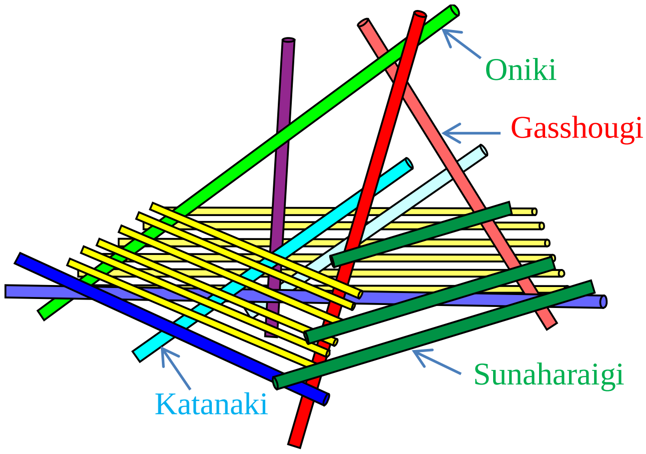


***Figure 1**: Rock cribs examined in our study [15]*



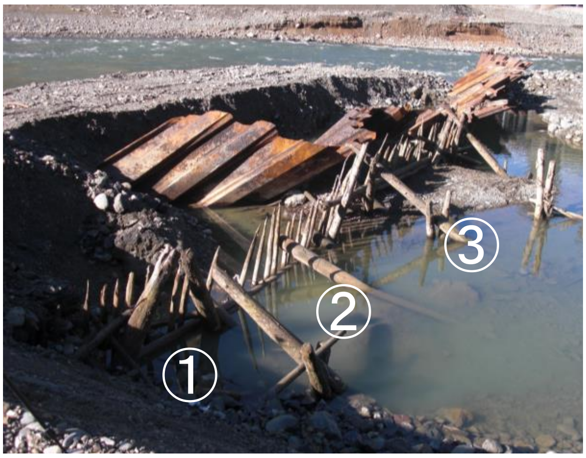


Figure 2*: Structural view of the rock crib*

Photo 2*: Recovered logs*

rock cribs: “A fill island was built upstream to block the river flow during dam construction. Piles were sunk for this purpose. To protect the piles, a total of nine rock cribs were placed behind them” [6]. The logs constituting these structures were thought to be Kumamoto *sugi* (cedar), presumably rafted down from the upper reaches of the river [7].

3 ASSESSMENT OF THE SOUNDNESS OF WOODEN MEMBERS (LOGS) IN CIVIL ENGINEERING STRUCTURES

3.1 ON-SITE TESTING

We examined three rock cribs in this project (Figure 1). The rock cribs were composed of each part shown in Figure 2. The logs were removed from the ground by attaching wires and carefully pulling them out, one by one, with a backhoe. Photo 3 shows the extraction of one such structure. A total of 27 logs were thus recovered within the time available. A general view of the installation state of the rock cribs and the recovered logs is shown in Figure 2 and Photo 2. Measurements taken immediately after recovery indicate a variation in size depending on position within their respective rock cribs, with diameters ranging from 10.3 to 33.3 cm and lengths from 3.3 to 9.9 m. The recovered logs were can be divided into three types of “Gasshougi”, “Katanaki・Oniki”, “Sunaharaigi”.

Photo 3: *Field extraction of the log*

Photo 4*: Pilodyn testing*

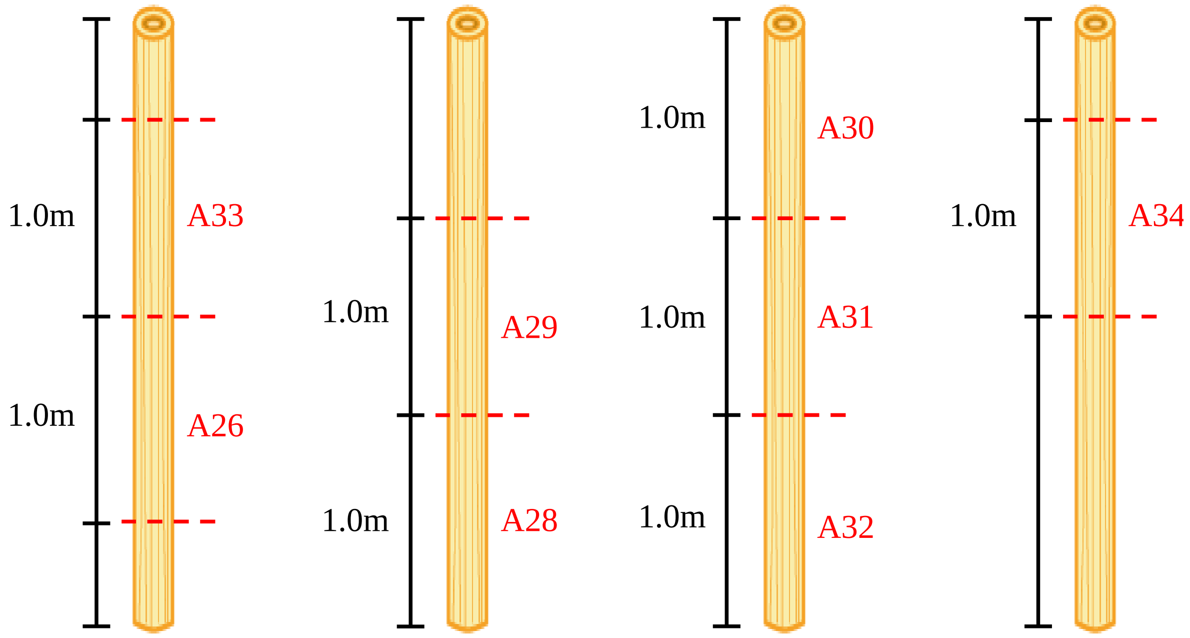


Figure 3: *Test specimen dimensions*

Visual inspections were conducted outdoors under the procedures of JIS K 1571 (2004): *Wood preservatives – Performance requirements and their test methods for determining effectiveness* (0: Health, 1: Partially mild decay or termite damage, 2: Overall mild decay or termite damage, 3: Partially intense decay on top of the state of 2, 4: Overall intense decay or termite damage, 5: Lost form by decay or termite damage).
The logs were subject to Pilodyn wood (penetration) testing with a PILODYN 6J-Forest tester (Proceq, Switzerland; pin diameter: 2.5 mm; measurement range: 0-40 nm). Pilodyn testing entails driving a pin into wood at a constant energy and then measuring its penetration depth. Here, measurements were taken along a straight line on one side of each log at 1 m intervals beginning at the top of the log (Photo 4).

Photo 5: *Overview of the recovered logs*

3.2 LABORATORY TESTING

We prepared test specimens to be used for laboratory tests. From these logs, we selected several that were relatively straight (and therefore considered suitable for reuse underground) with a small-end diameter of 12-18 cm. Selecting portions having few knots or scars, we cut the logs into 1.5 m lengths and then, as shown in Figure 3, cut them again to 1.0 m lengths while maintaining parallelism with the end surface. Photo 5 presents a general overview of prepared test specimens. Dimensions and test values are tabulated in Table 2.
Photo 6 shows actual longitudinal stress testing. We next utilized a Tensilon universal material testing instrument to measure the longitudinal Young's modulus. Loading was applied statically under strain control at a constant stroke displacement of 0.3 mm/s, with axial extensometers and strain gauges attached to measure displacement during loading [8]. Axial displacement was measured by axial extensometer as the change within a 50 mm distance included within an L-angle placed at a distance of 25 cm from the end surface. Select a few

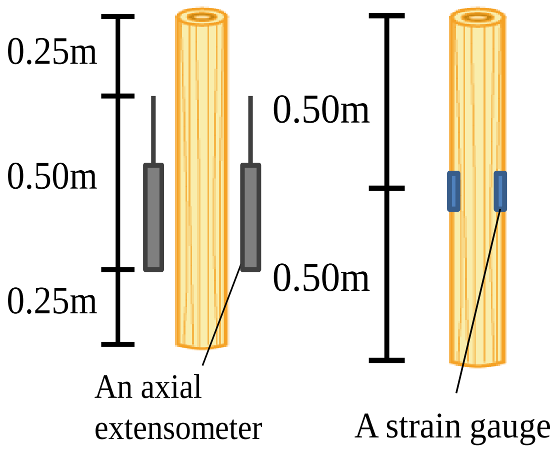


Figure 4*: The mounting position of axial extensometers and strain gauges*

different sites, it was measured axial strain placed at a distance of 50 cm from the end surface (Figure 4). Place where "knot" or "flaw" is seen is avoided, after shaving the Paste location using a knife to smooth, polished with sandpaper, paste the strain gauges directly. Because of instrument loading limitations, pulling was stopped at a load of approximately 60 kN. Thus, none of the samples was loaded until failure. Also, for each test sample, we zeroed the stress-strain relation and determined its Young's modulus from the resulting diagram (Figure 5).
Photo 7 shows longitudinal vibration testing. Here, a test specimen is set upon sawhorses that were acoustically damped with sponge cushions. Then, one end was hit with a hammer, and the first fundamental frequency of the resulting sound wave was measured. With that, we can determine the longitudinal Young's modulus by using Equation (1) [9].

$$E = (2L \cdot f)^2 \rho \tag{1}$$

Here, E is elastic modulus (N/mm^2); L, length (m); f, fundamental frequency (Hz); and ρ, density (kg/m^3).

4 RESULTS AND DISCUSSION

4.1 ON-SITE TESTING

It shows the results of the visual inspections. The logs, despite having been submerged for nearly 60 years, were observed to be comparatively sound, with no overall rotting or insect damage, although with some surface scarring from exposure to flowing water. They were thus rated as having a damage level of 2 or below [10-12].
It shows the results of the Pilodyn testing. Figure 6 shows the relation between penetration depth and measurement position as determined by the Pilodyn testing of the 27 logs. The red solid line shows the average of these measurements by position and the dotted red line shows the 68% conference interval ($\pm\sigma$). The penetration depth in the as-extracted condition (i.e., immediately after removal, while the moisture content was still high) was measured to range from 14 to 35 mm, with a mean of 24.8 mm and a standard deviation of 4.9 mm. While some scatter was apparent from log to log and among different positions along the same log, penetration depths remained in the general range of 20-30 mm, leading us to conclude that the logs to be sound throughout. From a series of survey results, only visual inspections and simple Pilodyn testing, to some extent of the soundness of the logs it was found that it can be determined while staying local. Further, in an environment where normally installed under water, such as a survey site, even when about 60 years later revealed that soundness of the logs maintained.

4.2 LABORATORY TESTING

Figure 7 presents a comparison of the longitudinal Young's modulus values between the two methods. The dotted lines in the figure show the national average range of the longitudinal Young's modulus values for cedar (6.9 to 8.8 kN/mm^2) [13]. The values obtained by the static flexure method show large scatter (5.47 to 10.37

Photo 6: *Longitudinal Young's modulus testing*

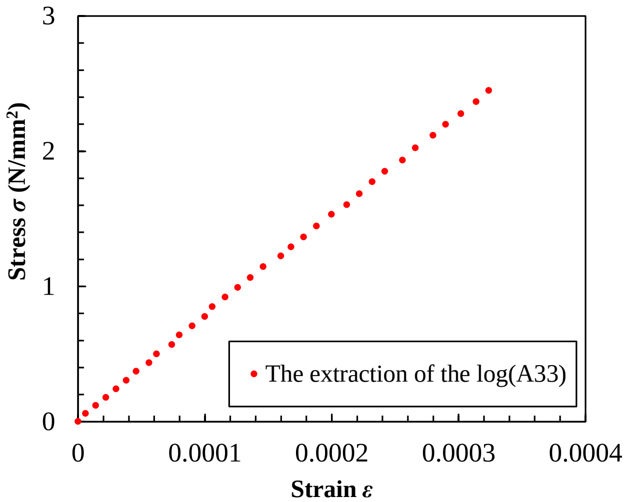


Figure 5: *Stress/strain diagram (A33 example)*

Photo 7: *Longitudinal vibration testing.*

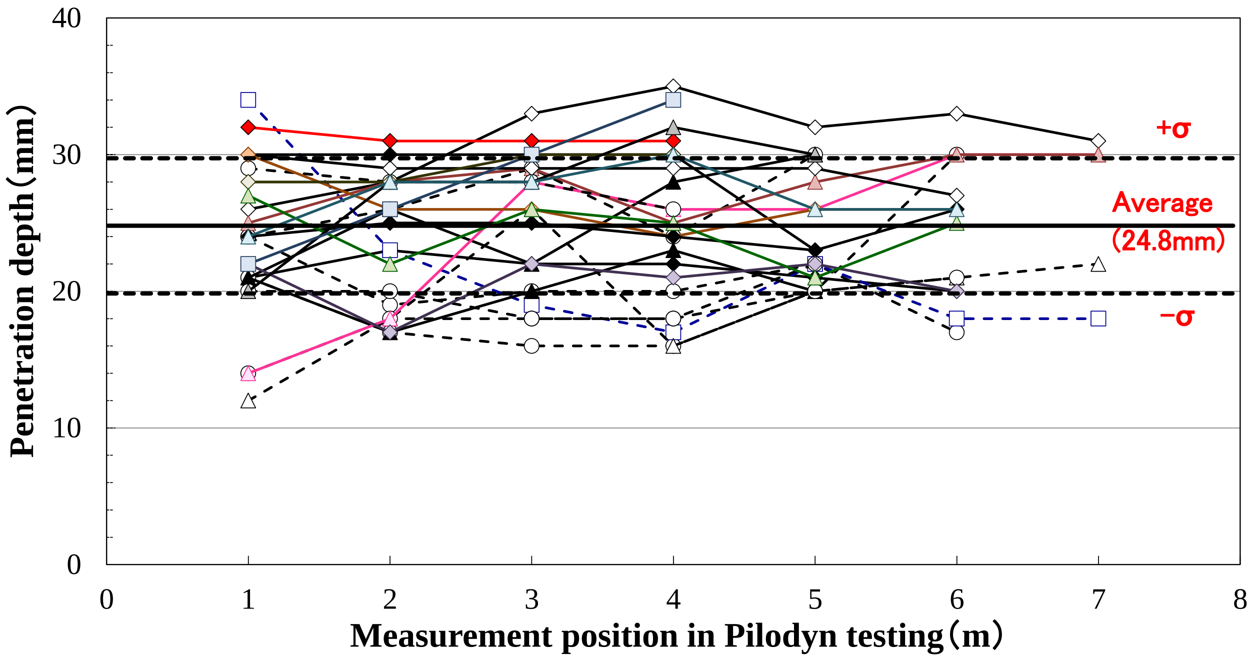


Figure 6: *Relation between penetration depth and measurement position in Pilodyn testing*

Table 2: *Sample dimensions and test values*

No.	Top end diameter (mm)	Bottom end diameter (mm)	Log length (mm)	Mass (kg)	Density (kg/m^3)	f_r (Hz)	E_{fr} (kN/mm^2)	$E_{c\text{-}d}$ (kN/mm^2)	$E_{c\text{-}s}$ (kN/mm^2)
A26	162.3	169.3	1005	22.65	1043	1338	7.54	7.47	6.54
A33	172.2	180.8	1004	26.25	1068	1351	7.86	7.50	7.93
A28	135.6	190.3	998	18.25	853	1416	6.81	5.47	-
A29	169.3	186.8	1006	26.50	1055	1393	8.29	10.37	-
A30	145.8	147.1	1000	11.75	698	1963	10.76	9.51	7.80
A31	128.6	138.8	1000	10.35	736	1878	10.38	9.80	9.39
A32	123.5	127.3	1000	8.95	724	1719	8.56	7.58	-
A34	157.9	168.1	1000	22.05	1056	1217	6.26	5.61	6.31

kN/mm^2) but nonetheless had an average within the national average range. The values obtained using the longitudinal vibration method tended to be slightly larger than those obtained using the static flexure method, by a factor of 1.07. This result agrees well with an earlier research finding that Young's modulus measured by the longitudinal vibration method tends to be 5-10% higher than that measured by the static flexure method [14].

Figure 8 shows the relation between the longitudinal Young's modulus values measured by each of the two methods. Also shown in the figure is a best-fit (least squares) line relating the two sets of values. While some experimental scatter is apparent, the relation between the two appears essentially linear. Therefore, this relation between the longitudinal Young's modulus values measured by the two methods holds true even for the wood members of rock cribs that had been submerged for nearly 60 years, and the long-term durability of submerged wood was quantitatively demonstrated.

5 CONCLUSION

Through onsite testing, we found that we could determine the degree of soundness of recently unearthed/exposed wooden members by only visual observation and simple Pilodyn measurement. Furthermore, through indoor testing of logs recovered from the Arase Dam site, we found that the average Young’s modulus of longitudinal elasticity of those specimens was essentially equal to the national average for cedar, although there was some scatter in the data. In other words, the logs recovered from the Arase Dam site, although submerged for approximately 60 years, still maintained performance characteristics on the level of the national average. We also observed a correlation between Young's modulus as measured by the application of static stress and Young’s modulus as measured by the longitudinal vibration method, suggesting a possibility that the relatively simple longitudinal vibration method can be applied on site to

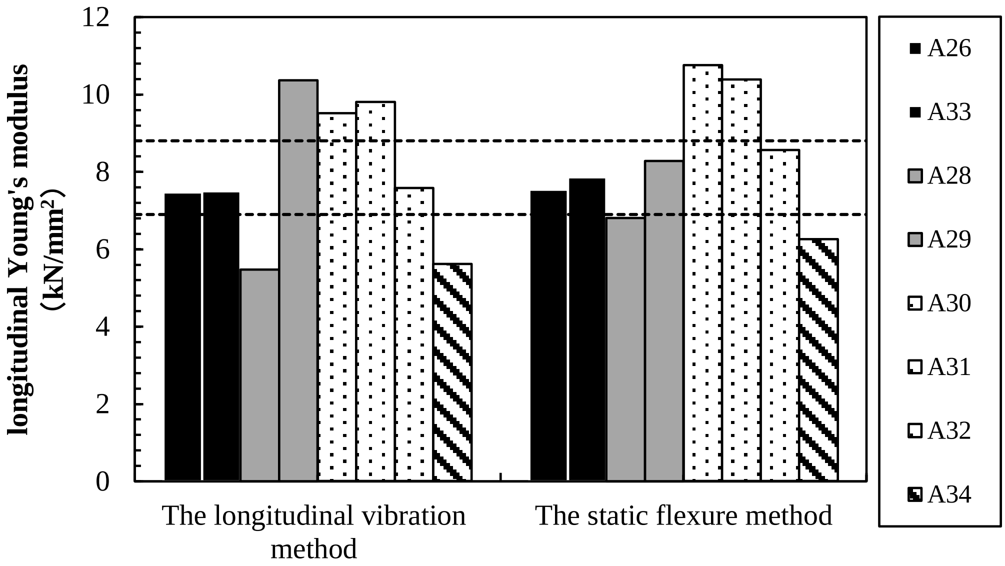


Figure 7: *Longitudinal Young's modulus as measured by the longitudinal vibration method and the static flexure method*

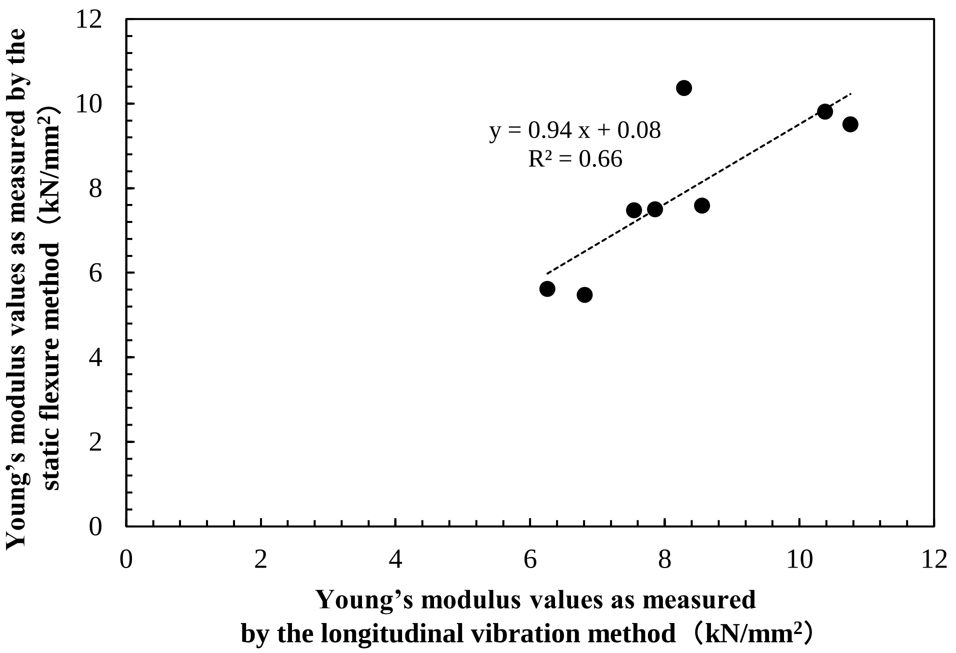


Figure 8*: Relation between Young's modulus values as measured by the static flexure method and longitudinal vibration method*

judge the basic performance characteristics of unearthed/exposed logs.

We have shown that wooden members can retain their soundness even after 60 years of continuous submersion in water. This demonstrates the long-term durability of such materials in civil engineering applications and suggests that these materials are suitable for cascade recycling.

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