EXPERIMENTAL STUDY ON APPLICABILITY OF LOW-QUALITY LOGS AS REINFORCED GROUND

Takumi Murata [1], Atsunori Numata [2]

ABSTRACT: Sustainable forest management and long-term and high-volume use of wood are effective climate change mitigation measures. However, the reforestation rate in Japan is not high, and it is difficult to say that sustainable forest management has not been fully realized. One reason for this is the low value of low-quality logs; thus, it is important to increase the value of these logs. In this study, the vertical bearing capacity characteristics of low-quality logs were investigated by vertical loading tests in order to apply these logs as a pile-type ground reinforcement with the expectation of shaft friction, which is used to increase the bearing capacity of soft ground. As a result, it was demonstrated that even low-quality logs may be suitable for pile-type ground reinforcement to increase bearing capacity if it is used in an ingenious way.

KEYWORDS: low-quality log, knot, jointed log, ground reinforcement, climate change

1 – INTRODUCTION

Climate change is an urgent problem, and technologies that address this challenge are required. However, few practical mitigation measures are available. Therefore, the authors propose using logs for ground reinforcement, which increases the bearing capacity of soft ground, as a climate change mitigation measure [1].

Trees absorb carbon dioxide from the atmosphere and sequester carbon through photosynthesis. This carbon remains sequestered even after the tree is harvested and processed into logs or other timber products. Therefore, if the combustion and decay of the wood are prevented and the wood continues to be used, the CO_2 corresponding to the amount of carbon sequestered in the wood is removed from the atmosphere for the duration of the wood's use.

Soft ground provides environmental conditions that can prevent the combustion or decay of wood, allowing the wood to remain in use for an extended period. The soft ground often has a high groundwater level. Below the groundwater level, where oxygen is limited, biological agents that cause degradation, such as rot fungi and termites, cannot function. Thus, biological degradation of wood does not occur. Therefore, using logs for ground reinforcement in soft ground stores the carbon sequestered in the logs in the ground for an extended period [2]. Consequently, climate change mitigation and the creation of a resilient society can be achieved simultaneously by using logs for ground reinforcement in soft ground.

2 – SOLUTIONS FOR SUSTAINABLE FOREST MANAGEMENT

The maximum effectiveness of wood use as a climate change mitigation strategy relies on the premise of sustainable forest management, which includes reforestation after felling. However, the reforestation rate in Japan is not high, at around 30% [3], and it is difficult to say that sustainable forest management has not been fully realized under the current conditions.

One reason for this is the low value of logs with many knots and bends, which are often included among the felled logs. They are difficult to saw into lumber, so they are typically chipped and used as biomass fuel. Chipped wood has a lower market price than sawn, decreasing profit for forest owners and diminishing the incentive to reforest in Japan.

[1] Takumi Murata, Research Institute of Technology, Tobishima Corporation, Chiba, Japan, takumi_murata@tobishima.co.jp

[2] Atsunori Numata, Soilwood, Saitama, Japan, atsunori_numata@outlook.jp

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Therefore, creating a new market for these low-quality logs and increasing their value would encourage sustainable forest management.

3 – USE OF LOW-QUALITY LOGS FOR GROUND REINFORCEMENT

This study evaluates the applicability of these logs for ground reinforcement to increase the value of low-quality logs, focusing on the characteristics of low-quality logs, particularly knots and bends, to verify experimentally the use of these logs and their performance for ground reinforcement.

3.1 CONCERNS ABOUT USING LOW-QUALITY LOGS

Logs with many knots will be driven into the ground without special processing, similar to standard logs. A concern, however, is that knots protruding like bumps may disrupt the surrounding ground during installation, potentially reducing the vertical bearing capacity.

Logs with bends risk breaking during installation into the ground. Therefore, they will be cut shorter, stacked vertically, joined, and driven into the ground. A concern is that since the logs are tapered, a step may form at the joints, resulting in gaps. This could reduce surface frictional force and, in turn, affect the logs' performance for ground reinforcement.

3.2 ASSESSMENT OF APPLICABILITY

The primary performance criterion for ground reinforcement is vertical bearing capacity. Therefore, knotted and joined logs were installed on-site, and vertical loading tests were conducted to assess their vertical bearing capacity characteristics. The vertical bearing capacity was compared with that of standard logs used for ground reinforcement to assess their applicability.

4 – OVERVIEW OF ON-SITE TEST

It was assumed that logs used for ground reinforcement would be installed with the log heads below the groundwater level to prevent biological degradation. Therefore, the vertical loading test was conducted with the log heads below the groundwater level. This section provides an overview of the ground conditions, the on-site tests, and the log installation method.

4.1 GROUND CONDITIONS

The on-site test was conducted at a site in the Hachirogata reclamation area of Akita Prefecture, Japan. This area was formed by the reclamation of Japan's second-largest lake, and the surface is composed of the former lakebed. The ground is exceptionally soft and nearly uniform with horizontal stratification.

Fig.1 shows the depth-wise distribution from the geotechnical investigation. At a depth of approximately 1.5m from the surface, there is a layer of sand with gravel and sand with clay. Below this is a soft silt and clay layer with an *N* value of 0, extending to approximately ground level (GL) − 8.0 m. The silt or clay layers between GL − 1.5 m and GL − 8.1 m show slight differences in properties, and the upper layer (above GL − 4.5 m) has a higher water content and plasticity index than the deeper layer (below GL − 4.5 m).

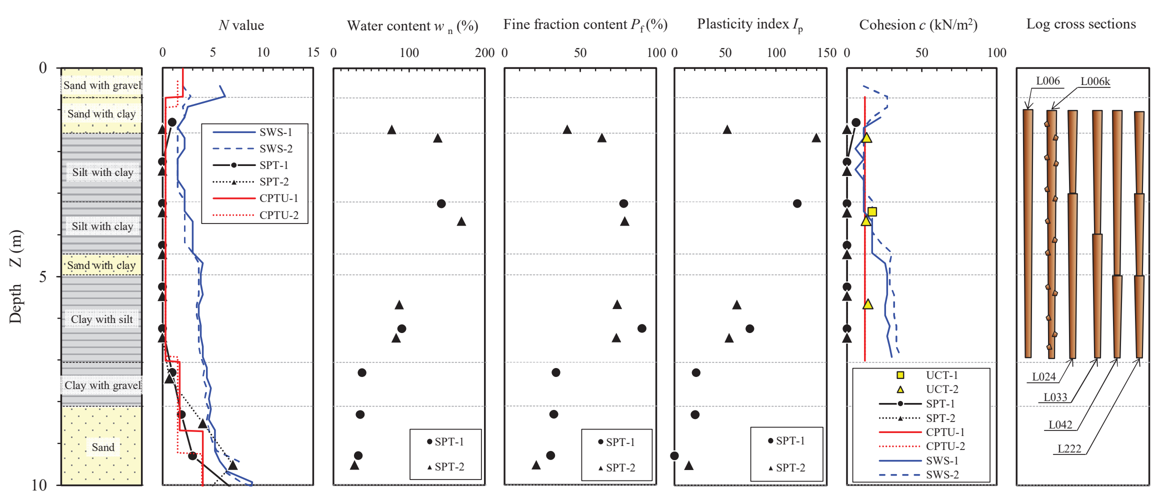

Figure 1 Depth-wise distribution from the geotechnical investigation

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The test cases all had the log head at GL − 1.0 m and the log tip at GL − 7.0 m. Thus, the log tip and the surrounding ground were in soft, clay soil with an *N* value of 0.

4.2 TEST CASES

All the logs used in the experiments were from Japanese cedar species. The logs were freshly cut, with only the bark removed, and without any drying or preservation treatments. Both ends of the logs were cut flat.

Logs with Knots

Tab.1 shows the test cases for logs with knots. Test case L006 was a log with few knots typically used for ground reinforcement, and test case L006k was a log with many knots. The length, tip-end diameter, and butt-end diameter were similar for both logs, but the number of knots differed substantially; L006 had 10 knots, and L006k had 32 knots.

Fig.2 shows an example of a knot in a log. Knot form where a tree branch has been cut off, resulting in an elliptical protrusion.

Fig.3 shows the relationship between the bottom area and height of knots. The horizontal axis represents the bottom area of the knot, calculated assuming that the knot's base surface is elliptical, with the major and minor axes derived from the dimensions. The vertical axis represents the height of the knot, measured as the length from the surface of the log to the apex of the knot. L006k not only had more knots, but also the bottom area and height of the knots were larger than those of L006.

Joined Logs

Tab.2 shows the test cases for joined logs. The joined logs' total length and tip-end diameter were matched as closely as possible. Test cases L024, L033, and L042 had the same number of joints but different lengths of the bottommost logs. Test cases L042 and L222 had the same length of the bottom end log but a different number of joints.

The logs were joined as follows. First, a hole was drilled in the center of the tip-end face of the upper logs and the

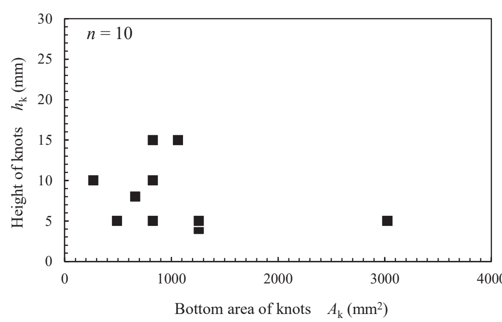
Table 1 Test cases for logs with knots

Test case	Length L (m)	Diameter: Tip-end D_T (m)	Diameter: Butt-end D_B (m)	Number of knots n
L006	6.13	0.143	0.205	10
L006k	6.12	0.147	0.209	32

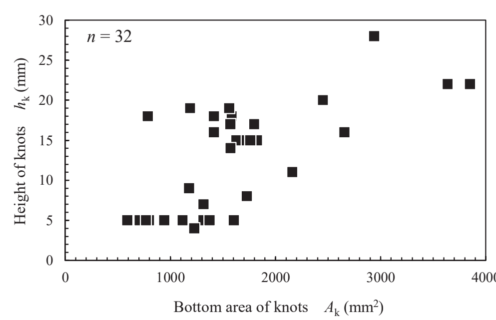
(a) Top view

(b) Side view

Figure 2 Example of a knot in a log



(a) L006



(b) L006k

Figure 3 Relationship between the bottom area and height of knots

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Table 2 Test cases for joined logs

Test case	Total length	Bottommost log			Second log from bottom			Third log from bottom		
		Length	Diameter		Length	Diameter		Length	Diameter	
			Tip-end	Butt-end		Tip-end	Butt-end		Tip-end	Butt-end
	L	L	D_T	D_B	L	D_T	D_B	L	D_T	D_B
	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
L024	6.2	4.1	0.157	0.203	2.1	0.166	0.183	–	–	–
L033	6.2	3.1	0.150	0.193	3.1	0.168	0.187	–	–	–
L042	6.2	2.1	0.155	0.193	4.1	0.171	0.218	–	–	–
L222	6.3	2.1	0.152	0.194	2.1	0.152	0.187	2.1	0.152	0.163

butt-end face of the lower logs. Next, a round steel rod (SR 235, diameter of 19mm) was inserted into the hole in the upper log as a joint material. Finally, the upper and lower logs were joined. Thus, the joint between the logs was a pin joint, and the upper and lower logs did not shift during press-fitting. Pin joints were used horizontal forces need not be considered in ground reinforcement.

Fig.4 shows a photograph of joining logs. The diameter of the lower log was larger, resulting in a step at the joint. This is the case in all cases.

4.3 LOG INSTALLATION METHOD

Fig.5 shows a photograph of log insertion. A small pile-driving machine was used to drive the logs. First, a rotating steel pipe with a closed end about 0.1m in outer diameter was inserted to a position 0.5 to 1.0m shallower than the intended depth. The steel pipe was then removed while being rotated. The logs were placed in the ground by static press-fitting them into the holes.

For joined logs, the lower log was press-fitted into the ground as described, and the pressing was stopped when the butt-end face was near the ground surface. Then, the upper and lower logs were joined. The joined upper and lower logs were then press-fitted together into the ground.

4.4 VERTICAL LOADING TEST

Fig.6 shows the Schematic of the vertical loading test, and Fig.7 shows a photograph. The vertical loading test was conducted in accordance with JGS-1811-2002. A 20-mm-thick circular steel plate with the same diameter as the butt-end diameter of the log was placed at the top of the log to ensure uniform load distribution during the test, thereby preventing localised deformation at the log head. A PVC pipe (diameter, 200 mm; length, 1000 mm) was also placed around the log head to protect the hole wall from collapsing between the ground surface and the log head during the curing period. Any soil or debris that entered the PVC pipe during installation or the curing period was removed just before the loading test. The curing period was approximately 2 months to minimise the effects of ground disturbance caused by the log installation.

Figure 4 Photograph of joining logs

Figure 5 Photograph of log insertion

The reaction force for the vertical loading test was provided by an excavator (weight 21 t, bucket capacity 0.8 m³). The test system included a load cell with a spherical

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seat (capacity, 500 kN), a centre-hole hydraulic jack (lifting capacity, 500 kN; stroke, 150 mm), a plate for measuring displacement (diameter, 300 mm; thickness, 30 mm), and a steel pipe (diameter, 100 mm; length, 1.0 m). The load and displacement were automatically measured by a data logger at a frequency of once every 2 seconds.

The vertical loading test was conducted using the step loading method with a target number of eight steps, one cycle, and a load holding time of at least 30 minutes for each step. Before the first loading step, pre-loading was performed to remove displacements caused by small gaps between the loading devices. Pre-loading was carried out for three cycles, with less than one-third of the load of the first loading step. The initial value of the displacement was at least 10 minutes after the pre-loading, and the first loading step was started after the initial displacement was measured. Loading continued until the displacement reached 40 mm, and if the displacement did not reach 40mm after the eighth loading stage, the number of steps was increased. After unloading, the load was held at zero for at least 10 minutes, and the displacement after holding was used as the residual displacement.

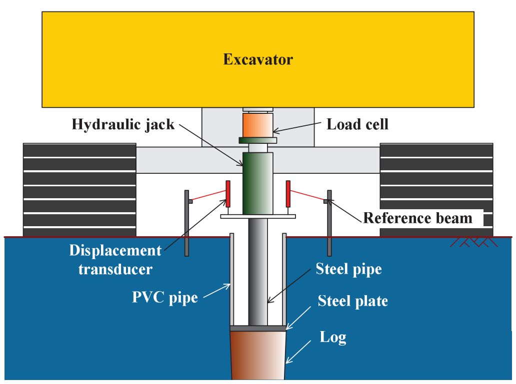

Figure 6 Schematic of the vertical loading test

Figure 7 Photograph of the vertical loading test

5 – RESULTS

The results of the vertical loading tests were evaluated using ξ, calculated as

$$\xi = \frac{R_{uS}}{R_{uD}} \tag{1}$$

where R_{uS} is the second-limit-resistance, defined as the maximum load within 10% of the pile diameter at displacement during loading test. R_{uD} is calculated using based on the “Recommendations for design of small building foundations” as [4]

$$R_{uD} = 6\, C_0\, A_p + D\, \Sigma(C_i\, L_i)\, \pi \tag{2}$$

where C_0 is the cohesive soil cohesion at the bottom of the log tip and C_i is the cohesive soil cohesion around the circumference of the log, obtained from the results of the screw weight sounding test(JIS A 1221). D is the diameter of the log tip, A_p is the cross-sectional area of the log tip, and L is the length of the log, or in the case of a joined log, the total length of the log.

5.1 LOGS WITH KNOTS

Fig.8 shows the relationship between the load and displacement in logs with knots. Although the number and dimensions of the knots differed substantially between L006 and L006k, the load−displacement relationship was similar. The first-limit-resistance, defined as the load at the point of maximum curvature that appears clearly in the log *P*-log *S* curve, was 64.0 kN for L006 and 65.5 kN for L006k, while the second-limit-resistance was 69.6 kN for L006 and 71.0 kN for L006k. Thus, the values were similar for both cases. ξ was 1.22 for L006 and 1.24 for L006k.

Therefore, logs with many knots had a similar vertical bearing capacity as those typically used for ground reinforcement logs, and the number and shape of the knots had little effect on the vertical bearing capacity.

5.2 JOINED LOGS

Fig.9 shows the relationship between the load and displacement in joined logs. The second-limit-resistance was 75.8 kN for L024, 62.7 kN for L033, 61.4 kN for L042, and 53.2 kN for L222. In all of these cases, the second-limit-resistance was reached at the step of rapid displacement increase, but the loads did not drop abruptly. This suggests that the logs and joints did not buckle during the tests.

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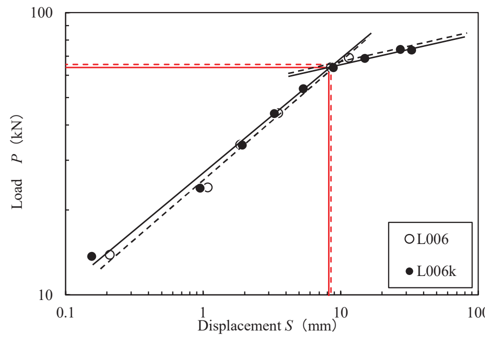
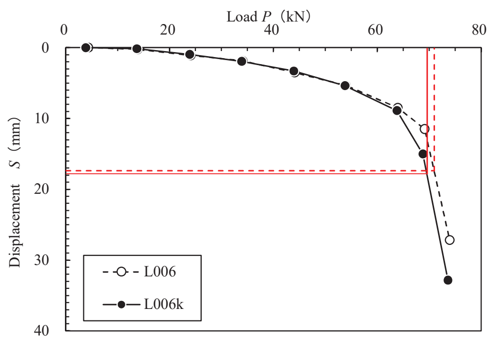


(a) Log P–log S curve



(b) P–S curve

Figure 8 Relationship between the load and displacement in logs with knots

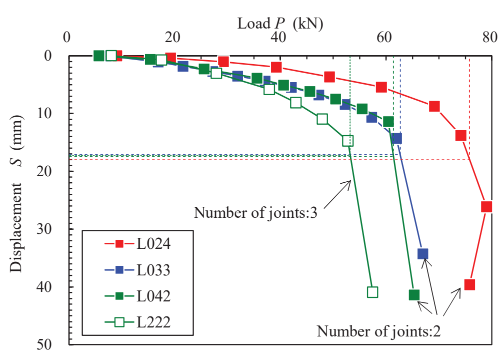


Figure 9 Relationship between the load and displacement in joined logs

Fig.10 shows the relationship between ξ calculated by (1) and ratio of bottommost log to total log length. ξ was 1.11 for L024, 1.07 for L033, 0.92 for L042 and 0.83 for L222, which were all smaller than that of 1.22 for L006, a log typically used as a ground reinforcement log. ξ increased with the length of the bottommost log. Thus, the vertical bearing capacity of the joined logs was strongly related to the length of the bottommost log, likely because the shaft friction of the bottommost log was fully engaged, whereas the shaft friction of the second and subsequent logs from the bottom was not fully engaged by the effect of the gap

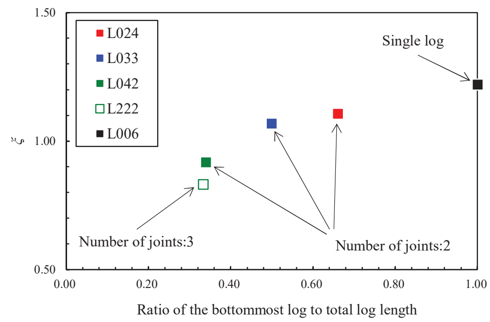


Figure 10 Relationship between ξ calculated by (1) and ratio of bottommost log to total log length

in the joints. Gaps in the joints of joined logs have been observed in model experiments in previous studies [5]. There was no significant difference in ξ between L042 and L222 with different numbers of joints.

In summary, the vertical bearing capacity of joined logs was smaller than that of a single log, the vertical bearing capacity increased with the length of the bottommost log, and the number of joints had little effect on the vertical bearing capacity.

6 – CONCLUSION

Vertical load tests were conducted on logs with knots and joined logs, and the findings were as follows.

The vertical bearing capacity of logs with knots was similar to that of a log typically used as a ground reinforcement log, and the load−displacement curves showed similar behavior. Thus, logs with knots could be used for ground reinforcement in the same way as logs without many knots.

The vertical bearing capacity of a joined log was smaller than that of a single log for the same log length. However, the vertical bearing capacity increased as the length of the bottom log increased. Thus, for ground reinforcement, the length of the bottommost log should be as long as possible, and the vertical bearing capacity should be designed by neglecting the circumferential friction of the second and subsequent logs from the bottom.

The results demonstrate that even low-quality timber may be suitable for ground reinforcement if it is used in an ingenious way. In the future, further data will be accumulated, and a design formula for vertical bearing capacity for low-quality logs will be developed to increase the value of these logs.

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8 – REFERENCES

[1] Tomimatsu, Y. Numata, A. Hamada, M. Miwa, S, and Motoyama, H. " Proposal of using wood in civil engineering field aiming for a sustainable society." Journal of Japan Society of Civil Engineers, Ser. F4(construction management), Vol.68, No.2, pp.80-91, 2012, in Japanese.

[2] Nakamura, H. Hamada, M. Motoyama, H., and Numata, A. " Case investigation about long-term durability of a use wood in the ground." Proceedings of the third Japan National Symposium on Environmental Geotechnology, Vol.9, pp.277-282, 2011, in Japanese.

[3] Forestry Agency " Annual report on forest and forestry in Japan fiscal year 2023." 2024, in Japanese.

[4] Architectural Institute of Japan "Recommendations for design of small building foundations." pp.181-186, 2008, in Japanese.

[5] Daisuke, S. Ryuto, N. Atsushi, K., and Yoshinori, F "Effects of the shape on vertical bearing capacity of the timber pile inserted in soft clay ground" Journal of Japan Society of Civil Engineers, Ser. E2(materials and concrete structures), Vol.77, No.5, pp.77-83, 2021, in Japanese.