# A VERTICAL INSTALLATION METHOD OF CROSS LAMINATED TIMBER (CLT) FOR REINFORCING SOFT GROUND

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**ABSTRACT:** Wood generally contributes to environmental conservation by absorbing $CO_2$ through photosynthesis and fixing carbon, thus playing a significant role in mitigating climate change and global warming. As a result, the use of wood has been rapidly expanding in many fields. In the field of soft ground improvement, wood has been widely used for a long time by installing logs as piles into the ground. Building on this, the vertical installation of Cross-Laminated Timber (CLT) is expected to enhance the bearing capacity of structures, reduce settlement, and suppress ground displacement during earthquakes, including liquefaction. In this study, a full-scale experiment was conducted to examine the construction workability of installing full-scale CLT into the ground, as no prior examples of such installations have been reported. The results revealed that it is feasible to insert full-scale CLT into the ground using a mid-depth slurry soft ground improvement method called WILL method, in combination with the setting of a special frame on the ground surface as a countermeasure against CLT uplift. Additionally, this study demonstrated the potential of using CLT in soft ground reinforcement to contribute to climate change mitigation through carbon storage effects and the reduction of $CO_2$ emissions by decreasing cement usage compared to traditional cement-soil mixing ground improvement works.

**KEYWORDS:** Cross Lamniated Timber (CLT), soft ground improvement, WILL method, vertical ground reinforcement

## 1 – INTRODUCTION

Wood plays an extremely significant role in environmental conservation as a means to mitigate global warming. Trees absorb $CO_2$ from the atmosphere through photosynthesis and fix carbon in ther biomass. Even after being harvested and used as wood products, the carbon remains stored, providing long-term environmental benefits [1, 2]. If the wood does not undergo degradation such as burning or decay, it continues to store carbon without releasing $CO_2$ into the atmosphere, making it possible to store carbon for many years without special maintenance. The use of wood in construction and other application not only reduces reliance on carbon-intensive materials bu also enhances the carbon storage potential of built environmental [3].

Generally, wood is considered to have very little corrosion or degradation in saturated ground, which suggests the potential for its use in underwater and underground applications such as soft ground reinforcement [4]. Humar et al. and Cherkasova have reported that wooden piles in waterlogged conditions have a long service life, and many historical cities near rivers, waterfronts, and seas still stand on the original wooden piles, such as those in Stockholm, Hamburg, Amsterdam, Venice, Saint Petersburg, etc. [5, 6].

The lifecycle of wood products, from harvesting to end-of-life disposal, is critical in determining their overall carbon storage capacity. Innovative approaches, such as using Cross-Laminated Timber (CLT) in construction, further enhance the structural and environmental benefits of wood [7]. Consequently, CLT has become widely used as a structural and interior material for buildings and as an alternative to steel and/or concrete in construction [8].

However, the use of CLT has not been popular in civil engineering and infrastructural developments. In Japan, efforts to promote wood utilization in civil engineering

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and construction are gaining momentum, with initiatives aimed at developing products that maximize carbon storage while minimizing environmental impact [9]. Since 2021, the Japanese CLT Association has formulated a project that includes the promotion of developing products for application in the civil engineering field, reflecting a growing recognition of wood's potential in contributing to a decarbonized society. As part of this project, soft ground reinforcement by installing and embedding CLT vertically into the ground was considered. Finite element analysis was carried out, and the analysis results confirmed the reinforcement effects by increasing the bearing capacity and suppressing ground displacement [10].

However, unlike the installation of wooden piles or logs into the ground, the use of full-scale (CLT) presents significant challenges in construction due to the substantial resistance of the original ground. This resistance can impede the installation process, necessitating innovative approaches to overcome it. To address this issue, the original ground is pre-liquefied before installation, which helps reduce resistance but may lead to the occurrence of buoyancy pressure. This buoyancy pressure can complicate the installation process, requiring careful management to ensure successful implementation.

Moreover, selecting a method that is both effective in performance and cost-efficient for pre-liquefying the ground is crucial. Such a method must be capable of adequately preparing the ground while maintaining economic viability. The authors conducted a full-scale experiment to verify the workability of the method for vertically installing CLT relative to the ground surface. This paper provides a comprehensive report on the process and the results of the full-scale experiment conducted at the site, offering valuable insights into the practical challenges and solutions associated with this innovative approach.

## 2 – BACK GROUND

### 2.1 GROUND CONDITION OF EXPERIMENT SITE

Prior to the experimental construction, a boring survey was conducted. The plan view of the boring survey is shown in Fig. 1. The borehole log of Boring No. 1 near the experimental construction site is shown in Fig. 2. The range of the construction depth, approximately 6.0 m, consists of fill and cultivated soil from ground level (GL) 0.0 m to -2.0 m, soft sandy silt from GL -2.0 m to -3.9 m, and gravelly sand from GL -3.9 m to -6.0 m. The standard penetration test results (SPT_N-values) and equivalent stiffness classification of each soil layers are tabulated in Table 1.

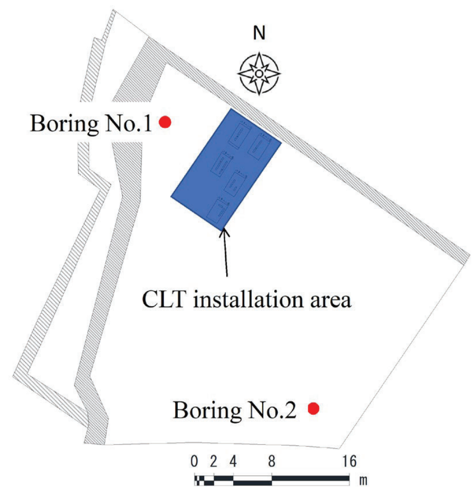


*Figure 1.Plan view of experiment site and boring locatons*

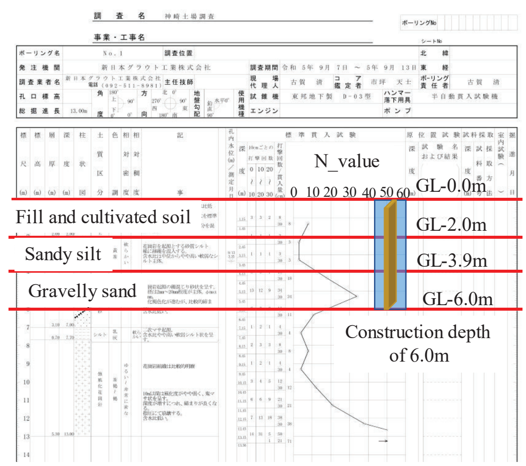


*Figure 2.Boring log of boring No.1 and CLT installation depth*

*Table 1: Types of soild in boring No.1 (within construction depth)*

| Soil layers | Depth (GL-m) | N _value (average) | Stiffness classification |
|---|---|---|---|
| Fill and cultivated soil | 0 ~ -2.0 | 8 | Loose |
| Sandy silt | -2.0 ~ -3.9 | 3 | Soft |
| Gravelly sand | -3.9 ~ -6.0 | 21 | Compact |

## 2.2 CLT SPECIFICATION AND ARRAGEMENT PATTERNS

The specifications for the CLT are as follows: the strength grade lamina composition is Mx60-5-5 [11]. The dimensions of the CLT are 6.0 m in length and 0.15 m in thickness, with two types of widths, 0.5 m and 1.0 m. The full-scale CLT used for the experiment is shown in Fig. 3. The experimental patterns included five variations, as tabulated in Table 2: CLT width (0.5 m and 1.0 m), CLT arrangement is set in series, parallel, and orthogonal, and the presence or absence of cement mixing in the original ground. Additionally, the range of loosening of the original ground due to cement slurry or water excavation was set to 1.3 m x 2.2 m for all patterns. Fig. 4 shows the plan view of the CLT arrangement for the experimental patterns.


*Figure 3.Full-scale CLT used for the experiment*

*Table 2: Experimental patterns*

| Pattern | Mixing material | Number of CLT | Type of CLT arrangement |
|---|---|---|---|
| 1 | Water only | 2 sheets | Series |
| 2 | Cement slurry 70kg/m$^3$ | (1.0m & 0.5m) | |
| 3 | | | Parallel |
| 4 | | | Orthogonal |
| 5 | | 4 sheets (1.0m & 0.5m) | Series & Parallel |

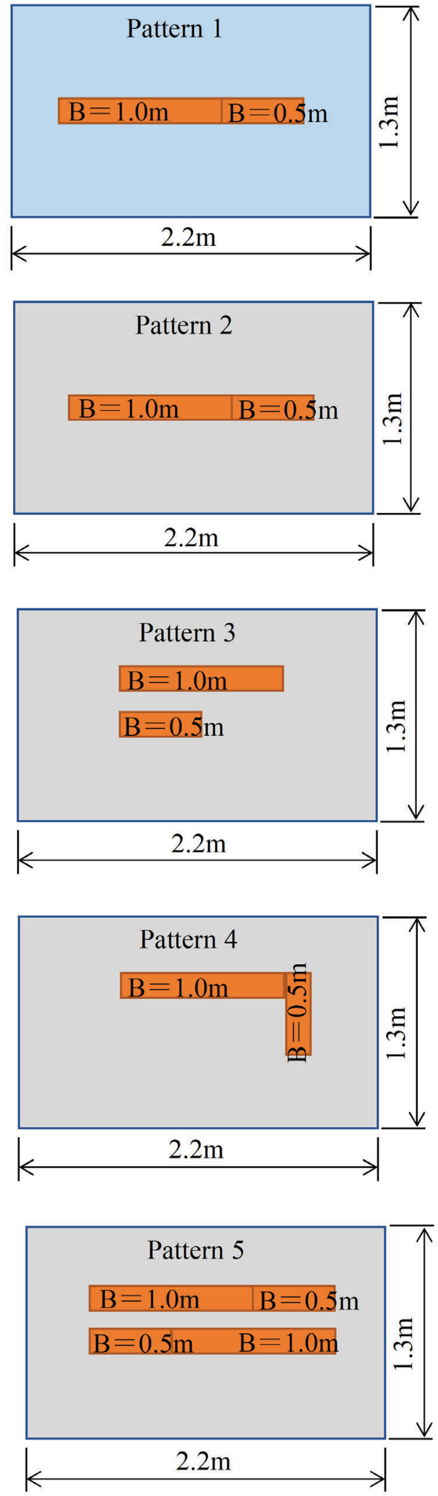


*Figure 4. Plan view of the CLT arrangements for full-scale experiment*


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## 2.3 OVERVIEW OF "WILL METHOD"

The WILL method is a technique classified as a mid-depth soil-cement mixing improvement method, which falls under the broader category of soft ground improvement techniques based on the depth of construction. This method involves the injection of a slurry-type cement-based solidification material, which is then thoroughly mixed with the original ground using specialized mixing blades or tools. The result is the creation of an improved body that enhances stability, increases load-bearing capacity, and reduces ground settlement.

One of the key advantages of the WILL method is its use of a backhoe (0.8m³, 1.4m³ class) as the base machine, providing exceptional mobility and flexibility. This allows the method to be effectively employed even in narrow or confined spaces, making it highly versatile for various construction scenarios. Furthermore, the method offers multiple specifications of mixing blades, enabling the selection of blades tailored to specific ground conditions. This adaptability makes the WILL method applicable to a wide range of soil types, with N-values from the standard penetration test reaching up to 40 for gravel and sand and up to 15 for silt and clay. Additionally, the maximum improvement depth is approximately 13.0 m, allowing it to cover the range of the most common soft ground depths [12]. A visual representation of the construction machinery used in this method is shown in Fig. 5.

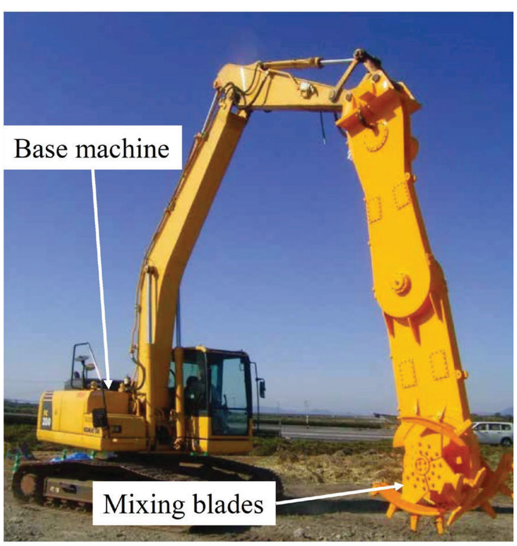


*Figure 5.View of construction machine of WILL method*

## 3 – VERTICAL INSTALLATION METHOD

Based on the soil investigation results, the upper layer exhibited an N-value of 8, indicating that it was not feasible to install the full-scale CLT by conventional driving or pushing methods. Therefore, the ground was initially temporarily loosened using the mid-depth mixing method, known as the WILL method, which involved either the use of water alone or a cement slurry. This preparatory step was crucial to facilitate the insertion of the CLT from the ground surface to a depth of 6.0 m.

In the WILL method, the ground was thoroughly mixed and liquefied, either with water alone or with a cement slurry. When employing the cement slurry, the amount of cement was set to a minimal mix of 70 kg/m³, adhering to the method's construction guidelines. This added amount aimed to achieve a strength level closer to that of the original ground.

Following the loosening and liquefying of the original ground, a special frame was strategically installed at the center of the liquefied area. This frame served as a guide for the precise insertion of the CLT. Subsequently, the CLT, equipped with specialized fittings, was lifted by a crane with a capacity of 16 tons and carefully set onto the special frame. The verticality of the CLT was meticulously checked to ensure proper alignment, and the CLT was inserted into the ground by its own weight while being suspended by the crane.

When the CLT could no longer be inserted by its own weight, the top end of the CLT was further push into the ground using the bucket of a backhoe (0.8 m³ class). This process continued until the CLT reached a height of approximately 1.0 m above the top surface of the special frame. To secure the CLT during this phase, it was temporarily fixed to the special frame using nylon slings and lever blocks, which were installed between the top end of the CLT and the special fittings beforehand.

Once the special fittings were removed, a CLT holding fitting was attached to the top end of the CLT. The CLT was then pushed to the specified depth by pressing down with the backhoe bucket. Finally, to prevent any potential uplift after the insertion was completed, a special head clamp attached to the top of the CLT was fixed using lever blocks on the special frame. This ensured the stability and permanence of the installation.

Fig. 6 to 8 illustrate the experimental construction status of the CLT installation, providing visual insights into the process. Fig. 9 demonstrates the construction flow of this

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experiment, offering a comprehensive overview of the steps involved.


*Figure 6. Temporary loosened ground by WILL method*


*Figure 7. Inserting CLT into the ground*

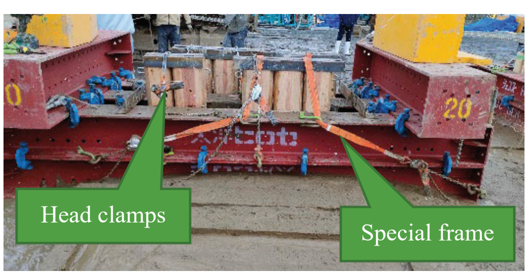


*Figure 8. Uplif prevention apparatus*

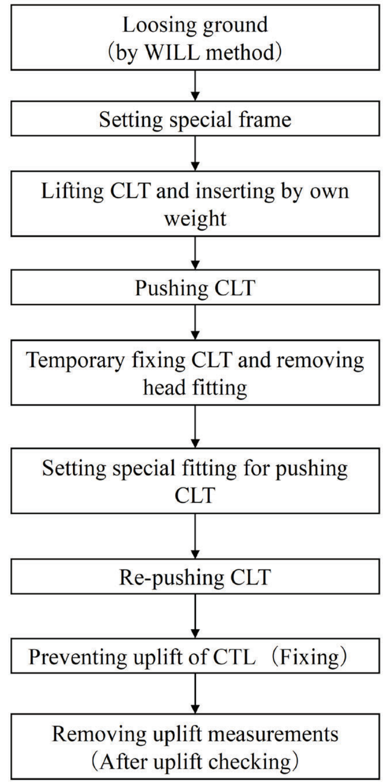


*Figure 9. Uplif prevention apparatus*

## 4 – RESULTS

In all five experimental patterns, it was confirmed that the insertion of Cross-Laminated Timber (CLT) could be successfully carried out by first loosening the original ground using the WILL method. This method involved the use of either a cement mixing slurry or water alone to prepare the ground for CLT installation. Additionally, a special frame was installed as an uplift countermeasure to ensure the stability of the CLT during and after installation. Fig. 10 illustrates the situation of the vertically installed CLT after the removal of the head clamps and the special frame, specifically for pattern 5.

In scenarios where a low cement mixing slurry (70 kg/m³) was employed, the special frame could be safely removed just two hours after the completion of construction. This rapid removal was possible because the strength of the original ground had recovered sufficiently due to the hydration reaction of the cement. The increased resistance of the ground effectively suppressed any potential uplift of the CLT, ensuring its stability.

Conversely, in cases where only water was used for ground preparation, uplift of the CLT was observed


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approximately five hours after the completion of construction. However, by the following day, no further uplift was detected. Despite this, given the conditions of the experimental schedule, the removal of the special frame and uplift prevention apparatus was carried out five days later. In this scenario, the absence of cement meant that it took a longer period for the original ground's strength to recover. This delay is believed to be the reason why it took a considerable amount of time for the uplift of the CLT to be fully eliminated, relying on the effect of surrounding friction to stabilize the structure.

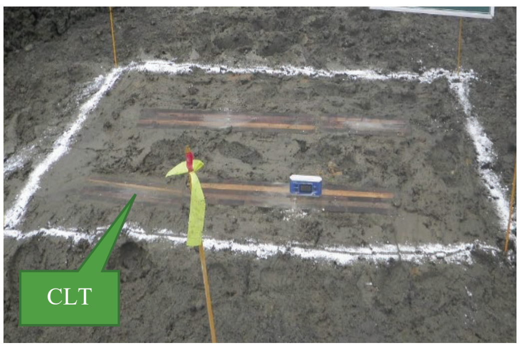


*Figure 10. After removed the uplift preventation apparatus (pattern 5)*

## 5 – CONCLUSIONS AND ACKNOWLEDGEMENTS

This study confirmed that the construction of vertical ground reinforcement using Cross-Laminated Timber (CLT) is not only feasible but also offers significant advantages. By employing CLT, which is both light and strong, for ground reinforcement, the benefits extend beyond the carbon storage effect. This innovative approach allows for a substantial reduction in the amount of cement required in ground improvement work, thereby greatly contributing to the mitigation of climate change. The dual benefits of carbon sequestration and reduced cement usage highlight the potential of CLT as a sustainable solution in civil engineering.

Looking ahead, further research is essential to fully realize the potential of CLT in ground reinforcement applications. Future studies should focus on quantifying the vertical reinforcement effect through vertical load tests, which will provide valuable data on performance, reliability, and parameters for designing CLT for soft ground reinforcement. Additionally, it is important to examine the impacts of time progression, seismic activity, and fluctuations in groundwater levels on the durability of the installed CLT. Improving CLT installation methods will also be crucial to enhance efficiency and adaptability in diverse environmental settings.

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