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

CONTRIBUTION TO CLIMATE CHANGE MITIGATION THROUGH SOIL LIQUEFACTION COUNTERMEASURES USING LOGS

Atunori Numata[1], Takumi Murata[2]

ABSTRACT: In Japan, measures to mitigate soil liquefaction damage caused by earthquakes are needed. In addition, as climate change becomes more serious, mitigation measures are an urgent issue. As a measure to solve these two issues at the same time, it is thought that a large amount of trees could be harvested, the obtained logs could be used as soil liquefaction countermeasures, and then the harvested area could be reforested. Japanese forests currently have abundant wood resources that need to be harvested and utilized. The authors propose the use of logs in liquefaction countermeasures. The major advantage of this method is that it captures carbon dioxide from the atmosphere and stocks it underground. Thus, in addition to reducing carbon dioxide emissions, atmospheric carbon dioxide would also be reduced. This is the same as creating a forest underground. This paper provides an overview of liquefaction countermeasures using logs and shows the carbon stock effects of liquefaction countermeasures, using an actual case study of liquefaction countermeasures for a medium-sized farm house, and quantitatively comparing the amount of carbon stocks in logs and the amount of carbon dioxide emitted by construction work. Finally, the carbon stocking effect of the liquefaction countermeasures is described based on 22 cases of liquefaction countermeasures using log piles.

KEYWORDS: carbon stock, climate change mitigation, liquefaction countermeasure, log piling

1 – INTRODUCTION

In Japan, soil liquefaction can occur due to the country's frequent earthquakes, and the resulting damage is widespread. There are two ways to mitigate liquefaction damage: prevent liquefaction from occurring in the first place and allow liquefaction but reduce the damage to structures after liquefaction occurs. To suppress liquefaction, methods have been developed and implemented, including driving sand piles into the ground to make the ground denser, cementing the ground, and driving drainage materials into the ground to suppress excess pore water pressure. Although these methods cannot prevent the earthquakes that cause liquefaction, they can certainly reduce the resulting damage.

Meanwhile, climate change is becoming more serious and is also an urgent global issue. For this reason, climate change countermeasure technologies are needed to cut greenhouse gas emissions and to reduce the concentration of greenhouse gases already in the atmosphere. Climate change is a challenging issue because it affects the entire planet, and it will take many years to restore the concentration of greenhouse gases to previous levels. However, unlike earthquakes, climate change is an anthropogenic disaster, so it should be possible to mitigate climate change through artificial means, although it will take many years to do so.

Earthquake damage countermeasures and climate change countermeasures should not be considered separately. Future earthquake damage countermeasures should include methods for cutting greenhouse gas emissions as well as reducing greenhouse gases already in the atmosphere. The authors have previously proposed a liquefaction countermeasure that simultaneously reduces damage caused by liquefaction and mitigates climate change, Numata and Uesugi [1], Numata [2], Tomimatsu et al. [3]. This paper describes the mechanism by which the proposed liquefaction countermeasure mitigates climate change, presents an example of the developed liquefaction countermeasure, and discusses the effects of the liquefaction countermeasure and carbon stock.

2 – MECHANISM OF STOCKING CARBON BY LOG PILING

Trees absorb carbon dioxide from the atmosphere through photosynthesis, fix carbon as wood, and release oxygen into the atmosphere. The carbon fixed from the atmosphere in this manner continues to be fixed in harvested wood products. When the wood is burned or decays, the fixed carbon combines with oxygen and returns to the atmosphere as carbon dioxide again.

Ground prone to liquefaction is characterized by a shallow groundwater table. At depths below the

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

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

 https://doi.org/10.52202/080513-0256

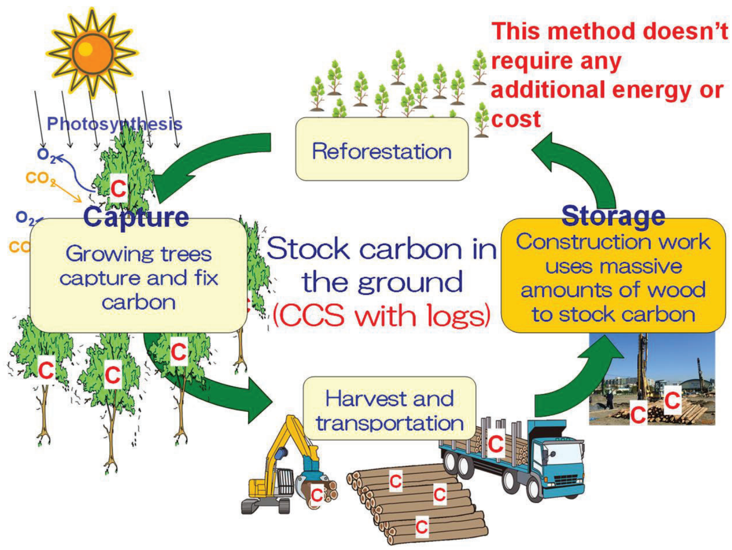


Figure 1. Mechanism of stocking carbon by using logs in construction projects

groundwater table, wood does not undergo biological deterioration such as decay and termite damage, Nakamura et al. [4], Nakamura et al. [5]. Therefore, if logs are placed in such ground and liquefaction countermeasures are applied, permanent liquefaction countermeasures can be implemented, and simultaneously, the logs will continue to stock carbon in the ground semi-permanently. Fig. 1 illustrates this mechanism. Through photosynthesis, trees growing in forests naturally capture carbon dioxide and fix carbon from the atmosphere, a process that is sustainable and does not require any energy or cost. In the proposed liquefaction countermeasure, trees are harvested from the forest and transported to the construction site as green logs with the bark peeled. Because the logs are not dried but only peeled, energy consumption is extremely low. At the construction site, a large number of logs is used as material for liquefaction countermeasures. Because liquefaction-countermeasure work is itself already performed as a business service, no additional energy and costs are required to stock carbon in the ground using the logs. Although small in scale, this method can fulfill the same function as carbon capture and storage, which captures carbon dioxide from thermal power plants and stores it deep underground, but without the need for additional energy or costs. The liquefaction countermeasure work creates a large underground forest, using wood to capture and store carbon.

3 – LIQUEFACTION COUNTERMEASURES BY LOG PILING

The log piling method for liquefaction mitigation and carbon stock (hereinafter abbreviated as "LP-LiC") for loose sandy ground is outlined below. Fig. 2 shows an overview of the LP-LiC. First, a steel pipe with a closed end is inserted into the loose sandy ground, with rotation in both the forward and reverse directions in order to compact the ground. After the steel pipe has reached a certain depth, it is pulled out with the pipe rotating again. Next, logs are inserted into the holes that have been created. At this time, the logs are joined vertically if necessary. The log head is basically inserted to a depth below the groundwater table. Because a hole is created at the top of the log, the log head is capped with cohesive soil to intercept air, and the hole is filled with crushed stone and compacted with a vibrator. The logs are not piles, so the logs themselves are not required to be strong; instead, the important objective is to maintain their volume. In this way, carbon fixed in the logs is stocked underground for a long period of time while simultaneously safeguarding against liquefaction during earthquakes.

Photo 1 shows the construction setup. This construction method can be performed with relatively small heavy machinery with a leader, with low vibration and noise, and no surplus soil is generated, and no curing period is required after piling.

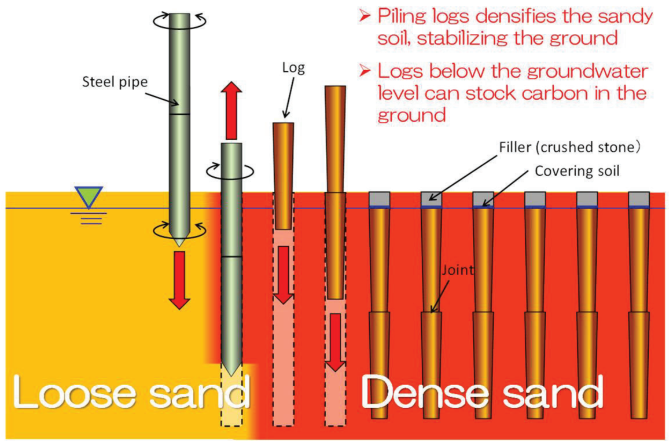


Figure 2. Method for mitigating liquefaction in sandy ground

Photo 1. Construction setup for the log piling method for liquefaction mitigation and carbon stock

4 – EXAMPLE OF APPLICATION TO A MEDIUM-SIZED FARM HOUSE

4.1 CONSTRUCTION OVERVIEW

This section presents a case study of the liquefaction countermeasure applied to the foundation of a medium-sized farm house in Fukui City, Japan. The construction site was formerly a rice paddy field, and the area liquefied during the 1948 Fukui Earthquake (magnitude: 7.1), causing many houses to collapse. At this site, 564 logs with a diameter of 0.15 m at the tip end and a length of 4 m were driven into the ground to mitigate liquefaction.

4.2 COUNTERMEASURES AGAINST LIQUEFACTION BY PILING LOGS

This section describes the design of LP-LiC and discusses its effectiveness.

Fig. 3 shows a geological columnar section of the ground, with loose silty sand and sand layers from ground level (GL) −1.75 m to GL −3.8 m and a sand and gravel layer below the clay layer at a depth of GL −5.9 m or deeper. The aim of the liquefaction countermeasure is to achieve a safety factor of 1.0 or more against liquefaction shallower than GL −5 m. The liquefaction evaluation method was based on the "Recommendations for the Design of Building Foundations," Architectural Institute of Japan [6], with an earthquake ground motion of magnitude 7.5 and horizontal acceleration at the ground surface of 200 cm/s^2. The design of the LP-LiC method was based on Fig. 4, which shows an extension of the A method used for the design the sand compaction pile method to the corrected N value. First, the required improvement ratio, as, is determined from the corrected N value in the original ground and the corrected N value that provides the target safety factor against liquefaction. Next, the log diameter and log piling interval are set based on the obtained improvement ratio. At this time,

https://doi.org/10.52202/080513-0256

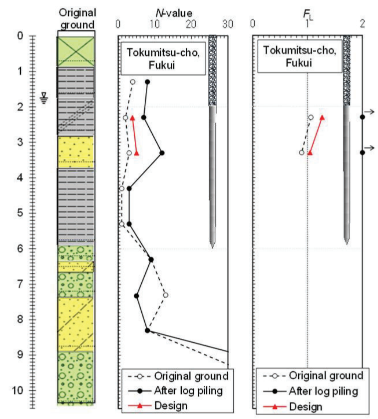


Figure 3. Geological columnar section of N-values and the safety factor against liquefaction before and after log piling

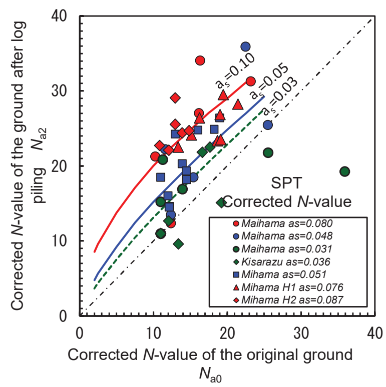


Figure 4. Relationship between the corrected N-value of the original ground and that of the ground after log piling

the log sizes that can be procured locally are considered. In this study, a log diameter of 0.15 m, a log interval of 0.90 m, and a log length of 4 m were selected. The depth of the log head was set at 2 m, based on the groundwater level and the depth of the layer susceptible to liquefaction. The logs were from Japanese cedar trees, which could be obtained locally, and a total of 564 logs were used. Fig. 5 shows the layout of the logs, which were placed so that the distance between all logs was less than 0.9 m.

Fig. 3 shows the effects of the liquefaction countermeasure along with the design values. After the logs were placed, the N value increased to $FL \geq 1.0$, indicating that FL was much larger than the design value.

4.3 CARBON STOCK EFFECT OF THE LIQUEFACTION COUNTERMEASURE

The carbon stock effect of the liquefaction countermeasure is quantified from the amount of carbon stock in logs used in the liquefaction countermeasure and the amount of carbon dioxide emitted by on-site construction. Here, the amount of carbon is converted into the amount of carbon dioxide.

The amount of carbon stocks in the logs was obtained from (1).

$$S_{\mathrm{Log}}=V_{\mathrm{Log}}\times\rho_{\mathrm{Log}}\times K_{\mathrm{C}}\times K_{\mathrm{CO2/C}} \quad (1)$$

Here, V_{Log} is the log volume (m^3), ρ_{Log} is the log volume density (kg/m^3) (= 314 kg/m^3 [cedar]), K_{C} is the mass fraction of carbon in the logs (= 0.5 [regardless of species]), and $K_{\mathrm{CO2/C}}$ is the coefficient for converting carbon to carbon dioxide (= 44/12)

The log volume was calculated by ignoring the pencil tip and assuming a cylindrical shape, squaring the tip end diameter used in the design, and multiplying it by the length of the log. The carbon dioxide emissions from the construction work were determined based on the fuel input for the machines listed in Table 1, assuming that the system boundary was within the site.

Fig. 6 shows the measured carbon stocks of logs and the measured carbon dioxide emissions from the construction. In this case, no joints were used, so there were no emissions from the joints. The carbon stocks of the logs are more than 10 times larger than the carbon

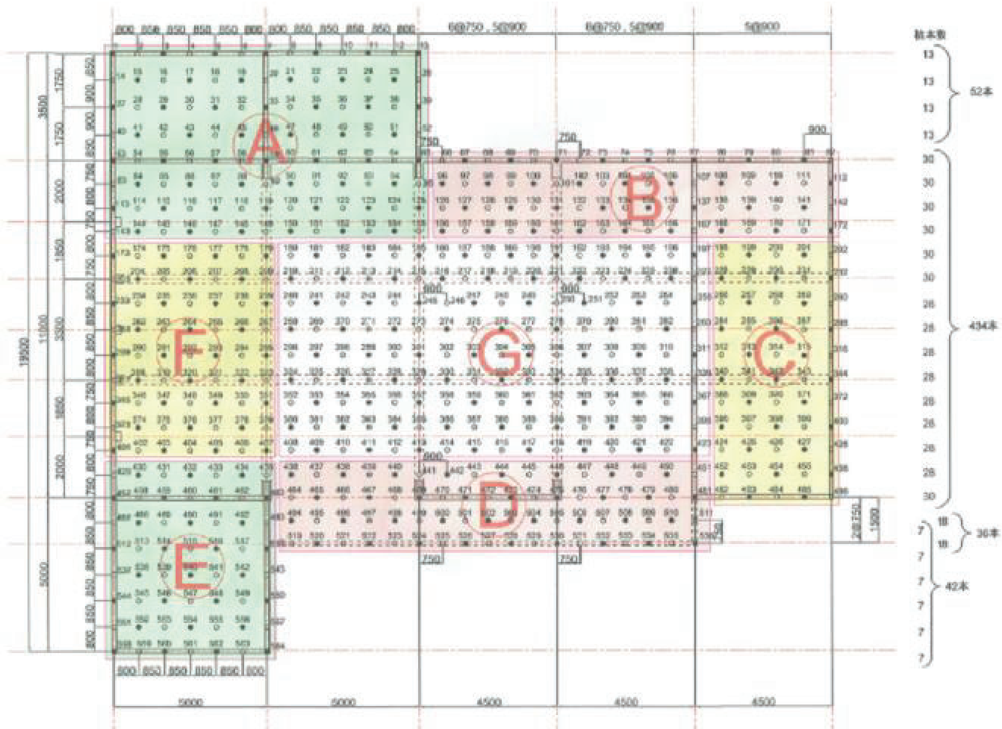


Figure 5. Layout of the logs

Table 1. Construction equipment used in this project and their specifications

Machine	Type	Use	Number
Log-piling machine	BA100 Own weight: 10 t	A steel pipe with a closed end is inserted into the ground with rotation but without soil discharge and is then pulled it out in the same way, after which a log is inserted into the ground.	1
Small backhoe	SAVER75UR Version S (0.28 m^3)	Moving logs, filler, and others	1

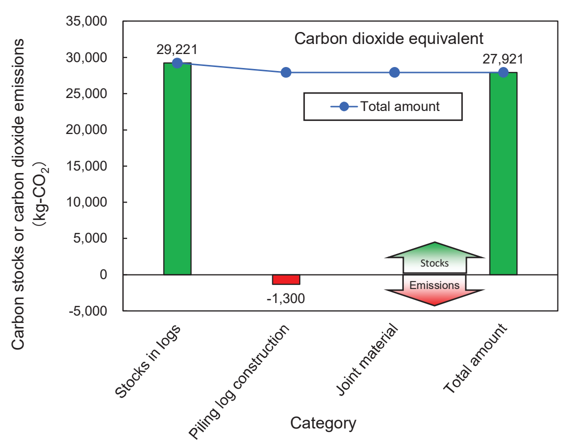
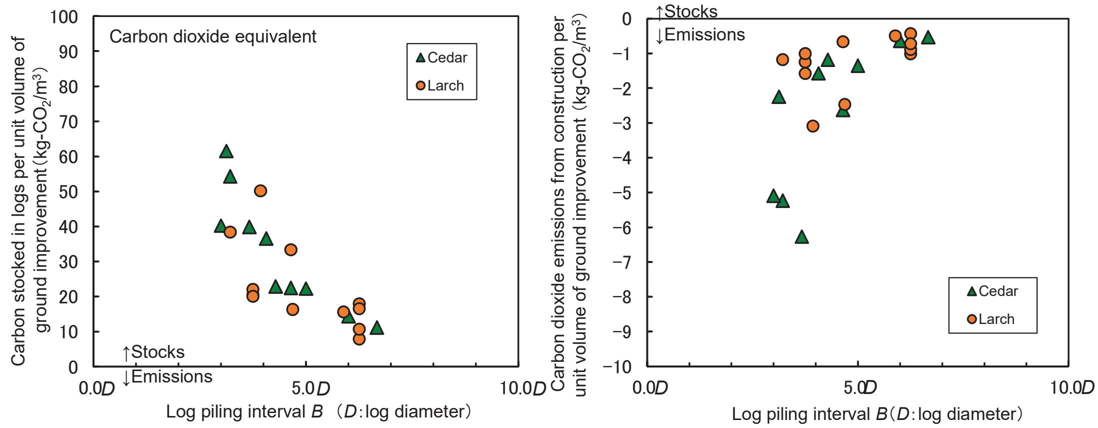


Figure 6. Amount of carbon stocks and carbon dioxide emissions from construction

https://doi.org/10.52202/080513-0256



(a) *Amount of carbon stocks in logs (carbon dioxide equivalent)*

(b) *Amount of carbon dioxide emissions from construction*

Figure 7. Measurement results of carbon storage effects based on practical construction

dioxide emissions from the construction, with a balance of 27,921 kg-CO_2 (on the stock side), which is approximately 96% of the carbon stocks of the logs.

For reference, if the logs were transported outside the system boundary, the emissions would be calculated as follows. The logs would be transported by a 4-ton truck making seven round trips of approximately 15 km one way. The truck has a fuel consumption of 3.5 km/L and a 2.58 kg-CO_2/L carbon dioxide emission coefficient for diesel oil, resulting in a total carbon dioxide emission of about 155 kg-CO_2. Despite this, the amount of carbon stock in the logs is clearly much larger.

5 – CARBON STOCK EFFECT OF LOG-PILE

The carbon stock effects of the LP-LiC method are shown through 22 cases of construction.

Fig. 7 shows the measurement results obtained from actual implementation of the LP-LiC method. The stock and emission volumes on the vertical axes are divided by the volume of the ground improvement to obtain a value per cubic meter of ground improvement. Note that in Fig. 6(a) and (b), the vertical axis for the stock volume in (a) is 10 times larger than the mitigation volume in (b). The horizontal axis is the interval of log piling, shown as a multiple of the log diameter. The carbon stock was determined from the volume of the logs used. The logs were from Japanese cedar and Japanese larch trees. Emissions were calculated for the system boundary within the construction site and did not include emissions from transportation of materials and equipment or from workers commuting to and from the site. Within the site, only the main heavy equipment was considered. Electricity emissions from generators and site offices were ignored because they are relatively small compared with the emissions from heavy equipment.

The stock volume from the logs used is larger when the piling interval is smaller because the volume used per cubic meter increases. The amount of carbon dioxide emissions increases with decreasing interval between logs because the amount of work per cubic meter increases with decreasing interval. However, the amount of carbon dioxide emissions was less than one-tenth of the stock volume, indicating that the amount of carbon dioxide emissions was quite small. Therefore, the amount of carbon stocks in the logs was larger than the amount of carbon dioxide emissions from the construction work. Although general construction methods have been trying to reduce carbon dioxide emissions in order to achieve carbon neutrality through energy-saving effects, the LP-LiC method goes even further and realizes negative emissions, based on the assumption of reforestation after logging.

6 – CONCLUSIONS

(1) The mechanism by which the log piling method for liquefaction mitigation and carbon stock (LP-LiC) stocks carbon in the ground was shown.

(2) The effects of liquefaction countermeasures and carbon stock by LP-LiC were illustrated with concrete examples.

(3) Examining 22 cases of construction involving implementation of the LP-LiC method, the amount of carbon stocks in the logs driven into the ground was more than 10 times larger than the amount of carbon dioxide emitted by the construction.

7 – REFERENCES

[1] Numata, A. and Uesugi, A. “Possibility of utilization of wood as a countermeasure of global warming.” 14th

Global Environment Symposium, JSCE(2006), pp. 97-102. (in Japanese)

[2] Numata, A. “Global warming mitigation measures by wood utilization in the ground.” The Japanese Geotechnical Society, Vol.67 (4) (2019), pp. 24-27. (in Japanese)

[3] 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 JSCE (F4), Vol. 68 (2)(2012), pp. 80-91. (in Japanese)

[4] 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 9th Symposium on Environmental Geotechnical Engineering, JGS (2011), pp. 277-282. (in Japanese)

[5] Nakamura, H., Hamada, M. and Numata, A. “Historical case of the wood used in the ground for the field of civil engineering works” Proceedings of the 11th Symposium on Use of Wood for Civil Engineering, JSCE (2012), pp. 95-101. (in Japanese)

[6] Architectural Institute of Japan “Recommendations for Design of Building Foundations.” (2001), pp. 61-72. (in Japanese)

https://doi.org/10.52202/080513-0256