WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA

Advancing Timber for the Future Built Environment

EXPERIMENTAL STUDY OF MOISTURE MOVEMENT INSIDE CLT USED FOR WOOD FOUNDATIONS

Mahiro Kawamoto[1], Makoto Nakatani[2], Takuro Mori[3], Ying Hei Chui[4]

ABSTRACT: Permanent wood foundation (PWF) has been in use in Canada for a few decades in basement or foundation of housing and small buildings. Cross-laminated timber (CLT) is a mass timber product that can be used for PWF, which can provide higher load resistance, compared with the traditional PWF that is constructed with light wood frames. One area of concern when using CLT in foundation is the moisture movement in CLT. Laboratory experiments have been conducted to measure the moisture movement through CLT. Two set-ups were used. One was with the water entering the CLT surface from the top (i.e. through gravity) and the other with water entering the CLT surface from the bottom (i.e. no gravity). The results of the experiment showed that the moisture content reached was related to the distance of the position from the source of water. It is logical to note that the rate of moisture content increase was slower when CLT absorbs water without gravity. Field experiments were also conducted to observe moisture movement inside CLT which is embedded in the ground. The results of the experiment showed that the interior air space can slow down moisture content increase inside CLT.

KEYWORDS: CLT, moisture movement, wood foundation

1 - BACKGROUND

Cement is a primary ingredient in concrete. The cement industry produces 5% of global man-made CO2 emissions, which accounts for 69% of greenhouse gas on a weight basis [1]. Despite the high emission of CO2, concrete has been used for low-rise and high-rise buildings due to their robustness and stiffness. On the other hand, concrete buildings can present some challenges to builders and users, such as long construction time, water leakage through cracking, and thermal loss. To solve these issues, mass timber (e.g. CLT and Glulam) has been used for high-rise buildings due to their advantages for global environment and interior spaces. As for the foundation of buildings, mass timber has been suggested as an alternative material. If CLT is to be used in foundations, it is clear that CLT will be covered by moisture barrier material as shown in PWF basics [2]. Even if CLT is protected by a water barrier membrane in foundations, limited water penetration in CLT may still occur due to damage in membrane or leakage through gaps. High moisture content (MC) causes some negative impacts on wood material, such as biological degradation, termite damage, and reduced strength Therefore, it is necessary to understand the moisture movement inside CLT when it is in contact with water. In this study, lab experiments were conducted to monitor MC changes inside CLT when CLT is in direct contact with water. Also, field experiment was conducted to evaluate moisture movement and CLT degradation when it is in contact with moist soil.

2 - PROJECT DISCRIPTION

2.1 – LAB EXPERIMENT

As for CLT moisture movement, Fernanda [3] and Suga [4] examined the MC changes of CLT when CLT was protected by a water barrier membrane or seasoned in a constant temperature and humidity chamber. However, in practical situations, water can contact wood directly during construction or when the membrane breaks. For the lab experiment, two methodologies have been suggested to see the effect of gravity on the moisture movement. As shown in Fig. 1(a), water is placed on the top of CLT in methodology 1 (standard methodology), where water can permeate into CLT via gravity. In methodology 2, water is placed under CLT, which water permeates CLT against gravity. In methodology 2, to reduce as much influence other than gravity as possible, water depth was controlled to be the same water pressure as methodology 1.

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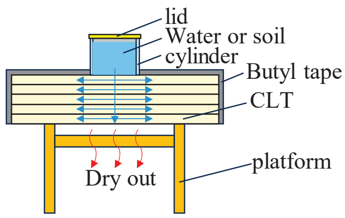
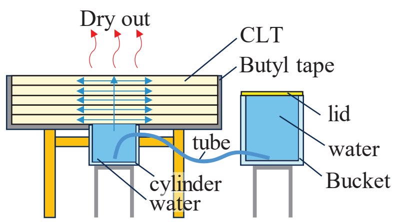
https://doi.org/10.52202/080513-0087



(a) Methodology 1



(b) Methodology 2

Figure 1. Lab experiment specimens

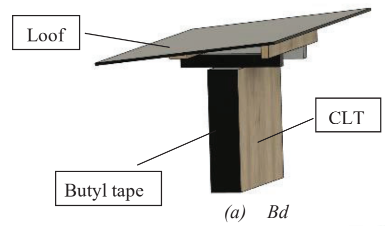
To study the effects of different parameters, 5 specimens (1 specimen for each parameter) were tested as shown in Table 1. Wo200 is the reference specimen. For the Wo200 test, water penetrated into the second layer easily through gaps between laminas of the surface layer of CLT. For Wo200s, gaps between each lamina at the top layer was sealed by silicon sealant so that the water was only in contact with the top surface of laminas. To see the effect of the size of the water-exposure area, the cylinder diameter was reduced from 200mm to 100mm in Wo100. In specimen So200, instead of water the top surface of the CLT was in contact with sand saturated with water to simulate the actual service condition in a foundation structure.

Table 1. Test matrix

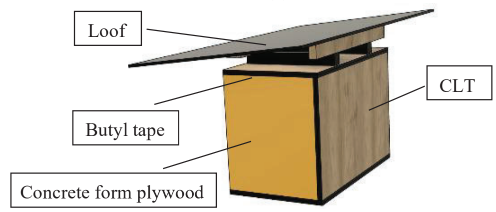
Name	Content	Cylinder diameter (mm)	Sealing of gaps in top layer of CLT	Methodology
Wo200	Water	200	No	1
Wo200s	Water	200	Yes	1
Wu200	Water	200	Yes	2
Wo100	Water	100	Yes	1
So200	Saturated sand	200	Yes	1

2.2 – FIELD EXPERIMENT

In order to study MC changes in exposed mass timber, Ariki [5] suggested the method to measure MC inside mass timber (e.g., Glulam and CLT), and Mori [6] measured MC inside CLT exposed outdoors or indoors. In this study, two different specimens were tested to simulate the more practical situation of CLT foundation, as shown in Fig. 2. Board specimen (Bd) is shown in Fig. 2(a). To see the moisture movement inside CLT when both sides of CLT were in contact with soil, CLT was embedded in the ground. Box specimen (Bx) is shown in Fig. 2(b). Considering the real situation in CLT building foundations, there would be a surface that was not in contact with the soil. In that case, the side face of the Bx specimen was made with veneers to replicate the interior space of the CLT foundation, as illustrated in Fig. 2(b).



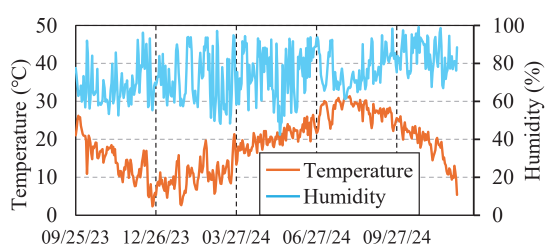
(a) Bd



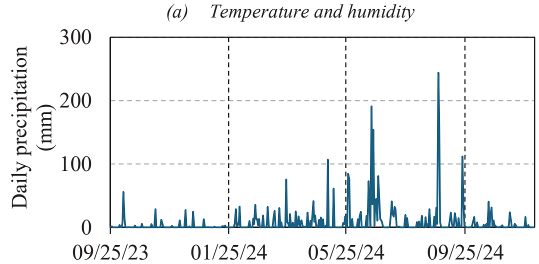
(b) Bx

Figure 2. Field test specimens

The field experiment has been in progress at Miyazaki Prefectural Wood Utilization Research Center since September 27th, 2023. Temperature, humidity and precipitation data in Miyakonojo city, Miyazaki are shown in Fig. 3. Temperature and humidity were measured with a thermo-hygrometer close to the specimens, and precipitation data was based on the Japan Meteorological Agency database [7].



(a) Temperature and humidity



(b) precipitation

Figure 3. Meteorological data

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3 – EXPERIMENTAL SETUP

3.1 – LAB EXPERIMENT

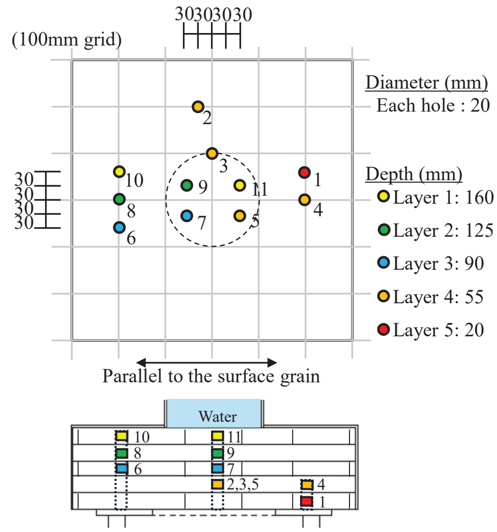
Five-ply Spruce-Pine-Fir (SPF) CLT (nonedge-glued) specimens, measuring approximately 600 mm (23.6 inches) square and 170 mm (6.75 inches) in height, were used in this experiment. The average density was 0.50 g/cm^3, MC before the test was 9.61%. As shown in Figure 1, specimens were covered with butyl waterproofing tape except for the water-touching area and the opposite face so the absorbed water could dry out on the opposite exposed face. To measure MC inside CLT, the method suggested by Ariki [5] was used. Eleven "Hygrochron Temperature/Humidity Logger" sensors were put in holes that were drilled to a certain depth of each layer (layout is shown in Fig. 4(a)). Holes were capped with wooden dowels with the edges sealed. The sensors measured temperature and relative humidity of the air every 30 minutes. By using these data, Equilibrium Moisture Content (EMC) inside CLT can be estimated using Equ (1) proposed by Saito [9]. Fig. 4(b) shows the experiment setup: an acrylic cylinder measuring 100 mm or 200 mm in diameter and 150 mm in height was fixed to CLT with adhesives and silicon sealant, then a cylinder was filled with water or soil.

$$EMC_1 = \frac{a + bx + cx^2 + dy + ey^2 + fy^3}{1 + gx + hy + iy^2 + jy^3} \qquad (1)$$

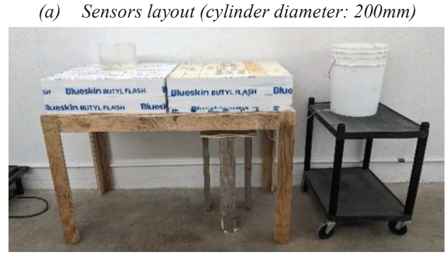
Where,
EMC_1: Equilibrium moisture content (%)
x: temperature (℃), y: relative humidity (%)
a: 1.33, b: -8.27*10^{-3}, c: -6.40*10^{-5}
d: 1.10*10^{-1}, e: -2.28*10^{3}, f: 1.47*10^{-5}
g: -1.16*10^{-5}, h: -2.42*10^{-2}, i: 2.54*10^{-4}, j: -9.85*10^{-7}

3.2 – FIELD EXPERIMENT

Pictures of the field experiment are shown in Fig. 5. Five-ply Japanese cedar CLT (nonedge-glued) was used for both specimens. For Bd, 800×600×150 mm CLT was embedded in the ground to a depth of 300 mm, the half height of the specimen (Fig. 5(a)). The sides and top were covered with butyl water-proofing tape so water could penetrate from the face surfaces and the bottom of the specimen. Also, a sloping roof was attached to the specimen to avoid water pools. For Bx, 900×600×150 mm CLT was assembled into a square with members consisting of water-proofed breathable membrane sandwiched between two sheets of 12mm thick plywood, covering the sides, top and bottom of CLT (Fig. 5(b), (c)). Then, the box was embedded in the ground to a depth of 300 mm (Fig. 5(d), (e)).

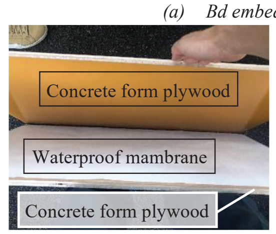


(a) Sensors layout (cylinder diameter: 200mm)

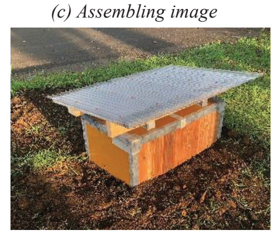


(b) Setup image
Figure 4. Lab experiment setup

(a) Bd embedded in the ground



(b) Plywood and membrane (c) Assembling image



(d) Bx embedded in the ground (e) Bx embedded in the ground
Figure 5. Specimens of field experiment

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The layout of the sensors in the field specimens is shown in Fig. 6. In Bd and Bx, 6 and 9 sensors were inserted into CLT respectively. Measuring points are named Bd1~Bd6 and Bx1~Bx9. To evaluate the effect of the depth differences on MC, sensors were placed in the middle layer which did not absorb much water from the face surfaces and MC would be stable (Bd-1~3, Bx-1~3). To check the MC differences between above and below ground, sensors were placed at the same distance above and below ground level (Bd-4~5, Bx-4~7). Also, sensors were placed at the same depth in each layer to reveal moisture movement through layers (Bd-3, 5, 6, Bx-3, 5, 7~9). Sensors for Bx were inserted into CLT from the interior side of the box to avoid putty spoilage and facilitate handling.

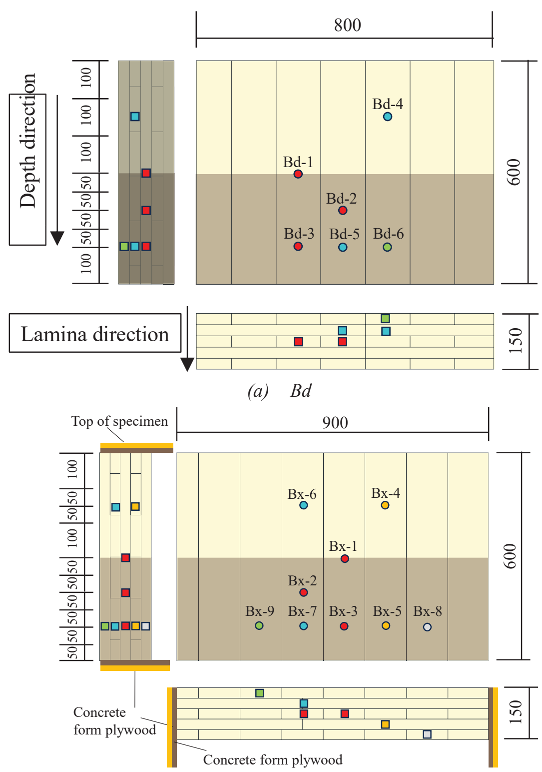

Figure 6. Layout of the sensors in field experiment (mm)

4 – LAB EXPERIMENT RESULTS

MC results are shown in Fig. 7. In all specimens, MC at measuring points of 1~7 and 8, which are were located in the third and the fifth layers, was stable. Thus, MC at measuring points 9~11 are mainly discussed in this paper.

For Wo200 (Fig. 7(a)), water in the cylinder was removed 25 days after the experiment started, and the change in MC after the removal was observed. MC in the surface layer, Wo200-10 and 11, increased significantly immediately after the start of the experiment and then decreased to about 10% within 5 days after the start, but MC in the surface layer increased significantly again as the MC of the second layer, Wo200-9, slowly increased to the same MC level. This is thought to be because a large amount of water penetrated into the surface layer immediately after the start of the test, but MC of the surface layer decreased as the moisture moved to the second layer, and then the second layer absorbed water until it reached the same MC as the surface layer, thus reducing the amount of water moving to the second layer and causing the moisture content of the surface layer to increase again.

On the other hand, in Wo200s (Fig. 7(b)), where water penetration through the gaps between the laminas was prevented, there was no significant MC increase immediately after the start of the test in the surface layer, that is different from Wo200. In addition, at Wo200s-11 in the surface layer, the MC change was similar to that at Wo200-9 in the second layer (increased to about 13% after 25 days). This result suggests that in Wo200, water directly contacted laminas of the second layer through the gaps between the laminas. In all other locations except for Wo200s-11, there was almost no increase in MC even after about 30 days, which could confirm the effect of sealing the gaps between laminas.

Wu200 had great difficulties in preventing water leakage from the boundary between the cylinder and CLT (Fig. 8(a)), and water was filled and removed repetitively to improve the specimen. Thus, MC was excessively high, especially in the surface layer, suggesting that further improvement is needed for this methodology.

In Wo100, there was no MC increase during 20 days, indicating that if the area in contact with water was small, MC increase would be slight. However, in the case where water is in contact for a long duration MC can increase, and further study is required.

For So200, the specimen with CLT in contact with soil, MC at So200-9 in the second layer increased significantly suddenly after the experiment started, but MC in the surface layer increased slowly, which could be estimated that near So200-9, water flowed directly to the second layer for some reason. MC increase of So200-11 was almost the same with Wo200s-11, and it had little effect of soil on MC inside CLT, but the color of CLT surface turned black due to microbial effects (Fig. 8(b)).

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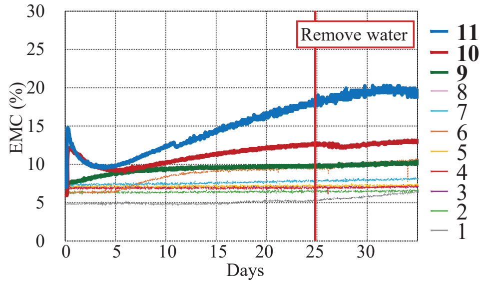
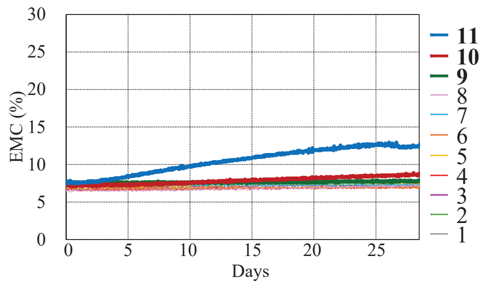
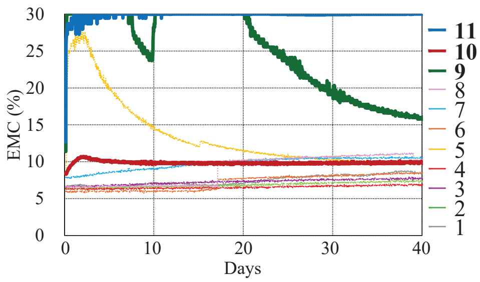


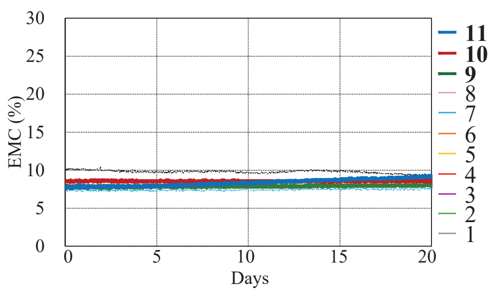
(a) Wo200



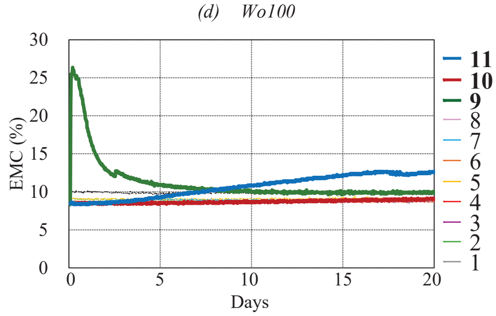
(b) Wo200s



(c) Wu200



(d) Wo100



(e) So200

Figure 7. Moisture content results


(a) Water leaking in Wu200


(b) Microbial growth in So200

Figure 8 Lab experiment images

5 – FIELD EXPERIMENT RESULTS

5.1 – REPAIRMENT AT EACH PHASE

On October 31, 2023, one month after the experiment started, specimens were taken out from the ground to observe and repair specimens. Due to condensation on the bottom plywood as shown in Fig. 9(a), ditches were made in the ground below specimens, and lay pebbles in ditches to improve drainage as shown in Fig. 9(b).


(a) Condensation (Bx)

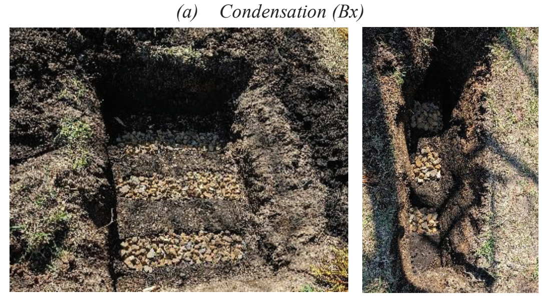

(b) Drainage improvement (left: Bx, right: Bd)

Figure 9 (a) Condensation in specimen, (b) drainage material under field CLT specimen

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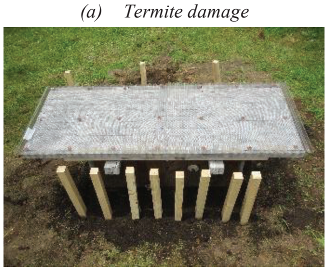
On May 16, 2024, seven and a half months after the experiment started, specimens were removed from the ground again to observe and repair specimens. Due to termite damage on CLT surface as shown in Fig. 10(a), anti-termite paint was applied to the surface and put decoy wooden sticks around the CLT specimen as shown in Fig 10(b). These improvements have prevented termite damage to the CLT specimens.

(a) Termite damage



(b) Decoy woods around the specimen

Figure 10 Termite damage in field specimens

5.2 – MOISTURE CONTENT CHANGES

Measured data were recorded from September 27th, 2023, to December 5th, 2024. The results are shown in Fig. 11 – 14. Gray lines in graphs are the data not included in the comparison. Some sensors have stopped measuring MC due to reaching the fiber saturation point that is not applicable for sensors to measure. The results are discussed below.

5.2.1 – MC changes in direction of depth

Fig. 11 shows MC changes from the middle layer (Bd-1~3, Bx-1~3). The deeper the measuring points, the higher the MC tended to be in both specimens. This can be due to the amount of water in the soil increases with depth. Also, due to the high trend of MC difference with depth and slow initial moisture content increased in the order of Bd-1, Bd-2, Bd-3, it is clear that the Bd absorbs much water from the bottom cross-section and water move upward by following fiber direction. Because MC increased more gradually and MC was more stable in Bx than Bd specimen, it was implied that the interior space could slow down MC changes in CLT.

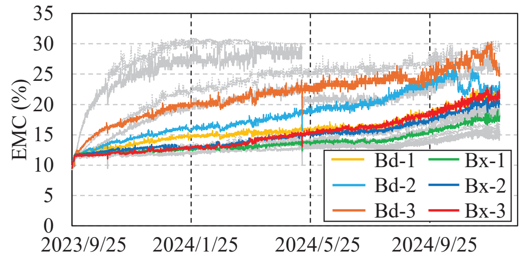


Figure 11 MC changes in the middle layer

5.2.2 – MC changes above and below ground

Fig. 12 shows MC changes of the second layer from the outer surface (Bd-4, Bd-5, and Bx-6, Bx-7). MC below ground (Bd-5 and Bx-7) kept increasing and reached approximately 30% due to the high moisture in the soil. Although MC above ground (Bd-4 and Bx-6) increased slightly, MC were between 10 to 15%. This shows that moisture content increase of CLT above ground due to water penetration through soil is partly moderated through the drying of CLT above ground.

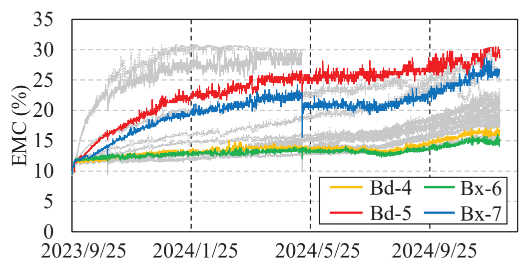


Figure 12 MC changes in the second layer from outer surface

5.2.3 – MC changes in lamina direction

Fig. 13 shows MC change of each layer of Bx at the same depth (Bx-3, Bx-5, Bx-7, Bx-8, and Bx-9). For Bx-3, Bx-5, and Bx-8, MC increase is slower than at other measuring points. This result indicated that for the CLT box specimen with an interior space, moisture in the soil has little effect on MC in the layers further away from the outer surface (approximately 60mm and beyond).

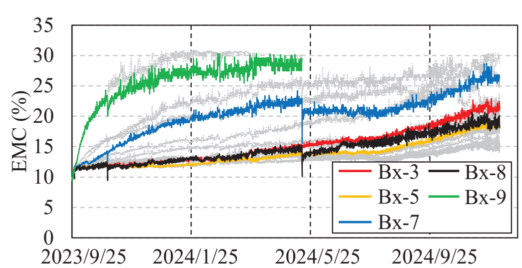


Figure 13 MC changes in each layer of Bx

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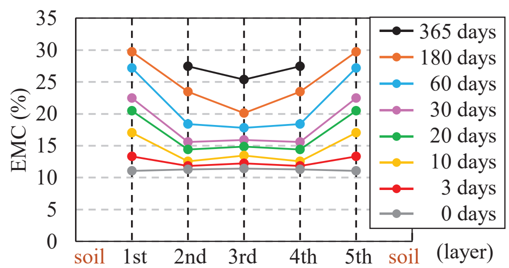
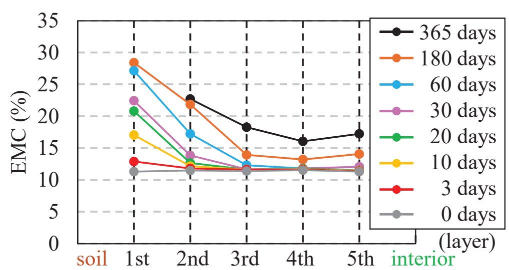
5.2.4 – MC changes of each layer over time

To visualize the relations of MC changes of each layer, Fig. 14 shows MC changes in each layer over time. For Bd, the moisture profile across the 5 laysers is symmetrical, see Fig. 14(a). For Bx, layer numbers on the horizontal axis start from the outer surface layer. As can be seen in Fig. 14, for the layers in contact with the soil (first and fifth layer in Bx, and first layer in Bx), the rate of MC increase is the greatest until 10 days after the experiment had started. In the second layers from the soil (second and fourth layer in Bd, and second layer in Bx), MC increase was the greatest from 10 days to 20 days after the experiment had started. These results show that the difference in the distance from the soil affects the timing of MC increase. For Bx, in comparison with Bd which is in contact with the soil, MC remains stable at low MC, which indicates that the interior space has a great effect on preventing MC increase in CLT.



(a) Bd



(b) Bx

Figure 14 MC change relations of each layer

6 – CONCLUSION

Laboratory and field experiments have been conducted to study moisture content changes in CLT when it is in contact with water saturated soil or water.

In the laboratory experiment, MC changes inside CLT in direct contact with water or soil were studied. As a result, the effect of water flowing through the gap between laminas was significant. When the gaps were sealed, MC increase was much slower and reached approximately 13% about after one month after the experiment started. Also, when the saturated sand was in contact with CLT, the result was the same as that using water, suggesting that there was no excessive MC increase by direct exposure to liquid water.

In the field experiments, MC changes in CLT embedded in the ground were observed and the effects of the interior space, simulating an indoor space in CLT foundation, were studied. It was found that due to the interior air space, MC increase in Bx was slower and more stable than Bd. Also, it was confirmed that the distance from the soil affected the rate of the MC changes in CLT.

ACKOWLEDGEMENTS

The authors would like to thank the Natural Sciences and Engineering Research Council (NSERC) of Canada for their financial support of the laboratory experiment and Grants-in-Aid for Scientific Research (Scientific Research (A) 21H04584, the Principal Investigator Takuro Mori) for their financial support of the field experiment.

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