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Application of the Wood Degradation Model to an Actual Roof Assembly subjected to Rain Penetration

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Abstract

Rain penetration through building materials is frequently observed in actual damaged buildings with wooden frames in regions with coastal climate. The penetrated water finally causes decay of wooden materials and reduces their strength against natural disasters such as typhoon and earthquake. To assess the impact of hygrothermal behavior on structural performances, we developed a model integrating hygrothermal analysis with wood degradation process. This model can simulate wood decay extension and moisture production by the chemical reactions of wood-decay fungi.

This study focuses on the application of the integrated model to the damaged roof assembly of a house. A disassembly investigation of the damaged roof assembly was implemented to quantify the decay rate of plywood used as the sheathing board and to clarify the water flow path through the roof finishing and the underlayment. In addition, wood decay predictions were made using the model to estimate the initiation of wood decay and rain penetration into the plywood. The calculation and measurement results indicated that rain penetration started at least a few years after completion of the construction.

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Keywords: building envelope; hygrothermal analysis; disassembly investigation; wood decay

1. Introduction

Owing to the demand for energy-efficient houses, the thermal performances of building envelopes with insulation materials in wood frame constructions were enhanced. Airtightness of the stud cavity within the building envelopes is ensured, and vapor transfer from indoor rooms is prevented by installing vapor retarders. Recently, assessment

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systems linked to computer models [1] have enabled ensuring appropriate configuration of building assemblies against vapor transfer. However, moisture damage such as mold growth and wood decay, which are mainly caused by rain penetration, were observed in actual wood frame houses in regions with coastal climate with frequent wind-driven rain; examples of such locations are Tokyo [2] and Vancouver [3]. To avoid such moisture damage, practical studies on the drying capacity corresponding to evacuation performance against unexpected moisture penetration into the stud cavity were implemented with an engineering approach [4]. Further, the quantification of rain penetration through the interfaces of building materials such as roof tiles and roofing underlayment were considered in hygrothermal analysis to account for unexpected rain penetration [5]. With regard to the prediction of moisture damage, empirical models that can predict wood decay extension considering the hygrothermal conditions were proposed [6, 7, 8]. However, few studies adopted a comparative approach between prediction and measurement data related to decay extension at an actual construction site.

Against this background, this paper focuses on the application of a wood degradation model to an actual damaged roof assembly. Disassembly investigation was performed to quantify the wood decay extension in plywood used as the sheathing roof board. Additionally, the impact of rain penetration on the wood decay extension was discussed based on the prediction and measurement results.

Nomenclature

L	Mass loss (kg/kg)
t	Time (s)
k_m	Rate constant for mass loss (1/s)
θ	Temperature (°C)
W_L	Moisture production rate (kg/sm^3)
h	Moisture product ratio (-)
ρ_w	Density of water (kg/m^3)
ϕ	Moisture content per volume of material (m^3/m^3)
W_t	Rain water storage on surface of underlayment (kg/m^3)
F	Penetration rate (-)
v	Wind velocity (m/s)
R_h	Precipitation (mm/h)
α'	Surface coefficient for moisture transfer (kg/m^{2}s[kg/kgDA])
X	Absolute humidity by mass (kg/kgDA)
J_w	Liquid water flux (kg/m^{2}s)
c_w	Water flow coefficient for the fastener interface (-)
H	Water head (m)
T	Kelvin temperature (K)
c	Material specific heat (J/kg)
ρ	Material density (kg/m^3)
λ	Thermal conductivity (W/mK)
λ'_T	Moisture conductivity related to temperature gradient (kg/msK)
λ'_μ	Moisture conductivity related to the water chemical potential gradient (kg/ms[J/kg])
μ	Water chemical potential (J/kg)
r	Latent heat of moisture (J/kg)
φ	Relative humidity (%RH)

2. Investigations of the Actual Damaged House

Disassembly investigation was implemented for a three-story wood-frame residential house in which water leakage was observed the north-facing lean-to roof of the second floor, as shown in Fig. 1a. This house was constructed in the urban area of Tokyo 7 years ago. The buildings surrounding the house shade the lean-to roof from solar radiation during the day in winter. A water-sprayed test conducted before the disassembly investigation revealed that rain water