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VERTICAL MOVEMENT IN WOOD PLATFORM FRAME STRUCTURES:

Movement Prediction

Canadian Wood Council
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INTRODUCTION

It is, however, possible to obtain a good estimate of the vertical movement to avoid structural, serviceability, and building envelope problems over the life of the structure.

It is not possible or practical to precisely predict the vertical movement of wood structures due to the many factors involved in construction. It is, however, possible to obtain a good estimate of the vertical movement to avoid structural, serviceability, and building envelope problems over the life of the structure.

Typically "S-Dry" and "S-Grn" lumber will continue to lose moisture during storage, transportation and construction as the wood is kept away from liquid water sources and adapts to different atmospheric conditions. For the purpose of shrinkage prediction, it is usually customary to assume an initial moisture content (MC) of 28% for "S-Green" lumber and 19% for "S-Dry" lumber. "KD" lumber is assumed to have an initial MC of 15% in this series of fact sheets.

Different from solid sawn wood products, Engineered Wood Products (EWP) are usually manufactured with MC levels close to or even lower than the equilibrium moisture content (EMC) in service. Plywood, Oriented Strand Board (OSB), Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), and Parallel Strand Lumber (PSL) are usually manufactured at MC levels ranging from 6% to 12%. Engineered wood I-joists are made using kiln dried lumber (usually with moisture content below 15%) or structural composite lumber (such as LVL) flanges and plywood or OSB webs, therefore they are usually drier and have lower shrinkage than typical "S-Dry" lumber floor joists. Glued-laminated timbers (Glulam) are manufactured at MC levels from 11% to 15%, so are the recently-developed Cross-laminated Timbers (CLT). For all these products, low shrinkage can be achieved and sometimes small amounts of swelling can be expected in service if their MC at manufacturing is lower than the service EMC. In order to fully benefit from using these dried products including "S-Dry" lumber and EWP products, care must be taken to prevent them from wetting such as by rain during shipment, storage and construction. EWPs may also have lower shrinkage coefficients than solid wood due to the adhesives used during manufacturing and the more mixed grain orientations in the products, including the use of cross-lamination of veneers (plywood) or lumber (CLT). The APEGBC Technical and Practice Bulletin emphasizes the use of EWP and dimension lumber with 12% moisture content for the critical horizontal members to reduce differential movement in 5 and 6-storey wood frame buildings.

Predicting wood shrinkage due to changes in MC

The shrinkage of solid sawn lumber and glued–laminated timbers can be estimated using the equation

$$S = D \times M \times C$$

where

S	=	shrinkage (mm)
D	=	actual dimension (thickness or width or length, mm)
M	=	percentage of MC change below 28% (fibre saturation point)
C	=	shrinkage coefficient
		= 0.002 for shrinkage perpendicular to the grain
		= 0.00005 for shrinkage parallel to the grain
		* If initial MC exceeds 28%, the initial MC should be considered as 28%

Wood shrinkage is the major cause for vertical movement in wood-frame construction. Predicting wood shrinkage is mostly dependent on the ability to correctly estimate the start and end moisture condition for a wood member, and the accuracy of the shrinkage coefficient. For Part 9 buildings any MC higher than 19% at the time of installation is not allowed by the National Building Code, and installing lumber with MCs greater than 19% would also make it challenging to accommodate the consequent large vertical movement amounts with common design and construction practices. For proprietary engineered wood products, designers may need to contact the product manufacturers for shrinkage coefficients and expected changes in MC.

Estimating other forms of vertical movement in wood structures

Movement due to compression loads

Typically load bearing wood walls will be stacked from storey to storey and loads will be cumulated from lower storey walls to upper storey walls. In a wood platform frame wall, there will be vertical deformation due to compression loads in the studs, plates and headers of floor joists. Local vertical deformation of these wood members can be estimated using the following formula and their impact on the total vertical movement of the entire wood framing may need to be assessed and taken into consideration.

$$w_{inst} = P \times L_{stud}/(A \times E_{par}) + P \times t/(A \times E_{perp})$$

where,

w_{inst}	=	instantaneous deformation (mm)
P	=	specified dead load (N)
L_{stud}	=	length of the stud (mm)
A	=	cross sectional area of the stud (mm^2)
E_{par}	=	Modulus of Elasticity parallel to grain of the stud (MPa)
t	=	sum of the thicknesses of the wall plates and the headers (mm) on a load path
E_{perp}	=	Modulus of Elasticity perpendicular to grain of the plates and headers*

*which may be estimated as 300 MPa.

Creep may need to be considered in structures with high levels of sustained load or where wood members are subjected to frequent large changes in MC or continuously wet service condition. Creep deformation can be estimated using the following formula:

$w_{creep} = w_{inst} \times K_{creep}$

where:

w_{creep} = creep deformation (mm)
K_{creep} = creep deformation factor

Based on the European design provisions, long term creep may be estimated as 0.6 times the instantaneous dead load deformation for wood used in typical indoor conditions with a temperature of 20°C and the relative humidity of the surrounding air only exceeding 65% for a few weeks per year. For wood used in conditions where MCs are high, such as indoor swimming pools, long term creep may be twice the instantaneous dead load deformation.

Movement due to closing of gaps between members (settlement)

Another form of vertical movement caused by loads is settlement, often called "bedding-in movement". Structural members cannot be perfectly aligned when installed due to imperfections of product manufacturing and building construction. As a result, gaps between members exist and will be closed during construction. Further settlement may occur after building is occupied. Field monitoring and laboratory tests indicated that a settlement of 2 mm for each storey can be used in design to compensate the settlement in platform frame construction, depending on the construction sequencing.

Vertical movement prediction and field measurement

In recent years, FPInnovations has been monitoring the vertical movement in a 4-storey and a 5-storey wood frame building in coastal British Columbia, with the support from developers, BC Housing-Homeowner Protection Office, and Natural Resources Canada. For the 4-storey building, the floors consist of 38 mm × 240 mm 'S-Dry' solid sawn floor joist with concrete topping. The walls consist of 38 mm × 140 mm 'S-Dry' solid sawn plates and studs. Double top plates and double bottom plates are used in all storeys. Stud length of all storeys is 2.44 m. For the 5-storey building, the floors consist of wood I-Joist with concrete topping. The I-joists flange is made of LVL and its depth and width above and below the web are 35 mm and 64 mm. The wall materials and stud length are the same as those used in 4-storey building.

For the purpose of estimating the stress related deformation, it is assumed that for both buildings specified roof dead load and specified floor dead load is 0.5 kPa and 1.3 kPa, respectively. The joist spacing is 400 mm, joist spans are 3.75 m and the stud spacing is 400 mm.

The estimated vertical movements of the two buildings are provided in Tables 1 and 2. The movement of subflooring is not considered in the calculation. It can be seen that shrinkage accounted for 80% to 90% of the total vertical movement. And the use of EWP can reduce the shrinkage significantly.

Table 1: Estimated vertical movement in a 4-storey building (mm)

Storey	member	Dimension [mm]	Area [mm^2]	MOE [MPa]	Shrinkage Coefficient	Initial MC	final MC	Δ_m [mm]	Force [N]	Δ_s [mm]	$\Delta_m + \Delta_s$ [mm]
4th	T&B plate	152	5320	300	0.002	19	8	3.34	750	0.11	3.46
	studs	2440	5320	9500	0.00005	19	8	1.34	750	0.06	1.40
3rd	Joist	240	5320	300	0.002	19	8	5.28	1950	0.47	5.75
	T&B plate	152	5320	300	0.002	19	8	3.34	2700	0.41	3.76
	studs	2440	5320	9500	0.00005	19	8	1.34	2700	0.21	1.55
2nd	Joist	240	5320	300	0.002	19	8	5.28	1950	0.47	5.75
	T&B plate	152	5320	300	0.002	19	8	3.34	4650	0.71	4.05
	studs	2440	5320	9500	0.00005	19	8	1.34	4650	0.36	1.70
1st	Joist	240	5320	300	0.002	19	8	5.28	1950	0.47	5.75
	T&B plate	152	5320	300	0.002	19	8	3.34	6600	1.01	4.35
	studs	2440	5320	9500	0.00005	19	8	1.34	6600	0.51	1.85
Total movement								34.58		4.78	39.37

Note:
Δ_m is the estimated shrinkage or swelling due to moisture change.
Δ_s is the estimated instantaneous and creep deformation due to load.

Table 2.1: Estimated shrinkage (mm) due to changes in MC in a five-storey building

Storey	member	Dimension [mm]	Area [mm^2]	MOE [MPa]	Shrinkage Coefficient	Initial MC	final MC	Δ_m [mm]	Force [N]	Δ_s [mm]	$\Delta_m + \Delta_s$ [mm]
5th	T&B plate	152	5320	300	0.002	19	8	3.34	750	0.11	3.46
	studs	2440	5320	9500	0.00005	19	8	1.34	750	0.06	1.40
4th	I-Joist	70	8960	300	0.002	8	8	0.00	1950	0.08	0.08
	T&B plate	152	5320	300	0.002	19	8	3.34	2700	0.41	3.76
	studs	2440	5320	9500	0.00005	19	8	1.34	2700	0.21	1.55
3rd	I-Joist	70	8960	300	0.002	8	8	0.00	1950	0.08	0.08
	T&B plate	152	5320	300	0.002	19	8	3.34	4650	0.71	4.05
	studs	2440	5320	9500	0.00005	19	8	1.34	4650	0.36	1.70
2nd	I-Joist	70	8960	300	0.002	8	8	0.00	1950	0.08	0.08
	T&B plate	152	5320	300	0.002	19	8	3.34	6600	1.01	4.35
	studs	2440	5320	9500	0.00005	19	8	1.34	6600	0.51	1.85
1st	I-Joist	70	8960	300	0.002	8	8	0.00	1950	0.08	0.08
	T&B plate	152	5320	300	0.002	19	8	3.34	8550	1.30	4.65
	studs	2440	5320	9500	0.00005	19	8	1.34	8550	0.66	2.00
Total movement								23.43		5.66	29.09

The vertical movement was measured after the roofs were installed. The total movement amount in the 4-storey building reached about 34 mm at an exterior wall, 43 mm at an interior hallway shear wall, and 45 mm at an interior partition wall, after a total monitoring period of 22 months. In the 5-storey wood frame building, the total movement amount reached about 25 mm at exterior wall, 36 mm at hallway wall, 32 mm at interior partition wall after 17 months.

As noticed, the predicted shrinkage is to be in good agreement with the exterior walls in 4- and 5-storey buildings. However, the predicted movement for interior loadbearing walls and partition walls is smaller than the actual measurement. This is probably attributed to the building settlement which is not included in the calculation.

Conclusion

It is difficult to precisely predict the vertical movement in platform frame buildings, as building designs and construction practices vary greatly from one project to another. The above discussion and calculation examples illustrate a simple way to predict the vertical movement in wood platform frame buildings. Design and construction detailing should then be provided to accommodate the differential movement at the key interfaces, such as with the elevator shafts, plumbing, mechanical services, and cladding (see Vertical Movement in Wood Platform Frame Structures: Design and Detailing Solutions). Good construction sequencing and material handling certainly play a very important role in effectively reducing wood shrinkage and then reducing the amount of differential movement that requires to be accommodated by building design.

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