FPInnovations

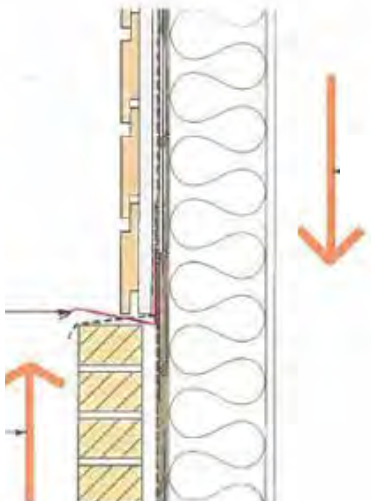
OUR NAME IS INNOVATION

Field Measurement of Vertical Movement in Wood Construction

Jieying Wang
Advanced Building Systems

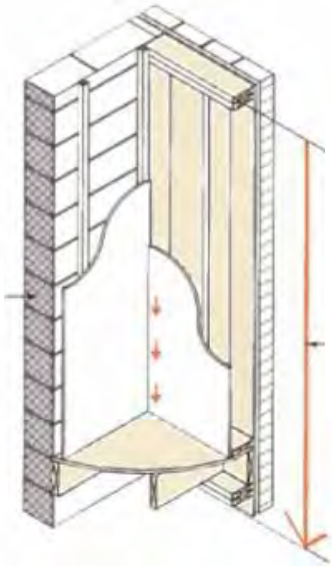
Background

- Differential movement is the concern
  - Occurring between wood frame and rigid components
- For building envelope design, key is to maintain a good slope for drainage
  - Flashing, balconies, roof decks



Masonry cladding

Balcony

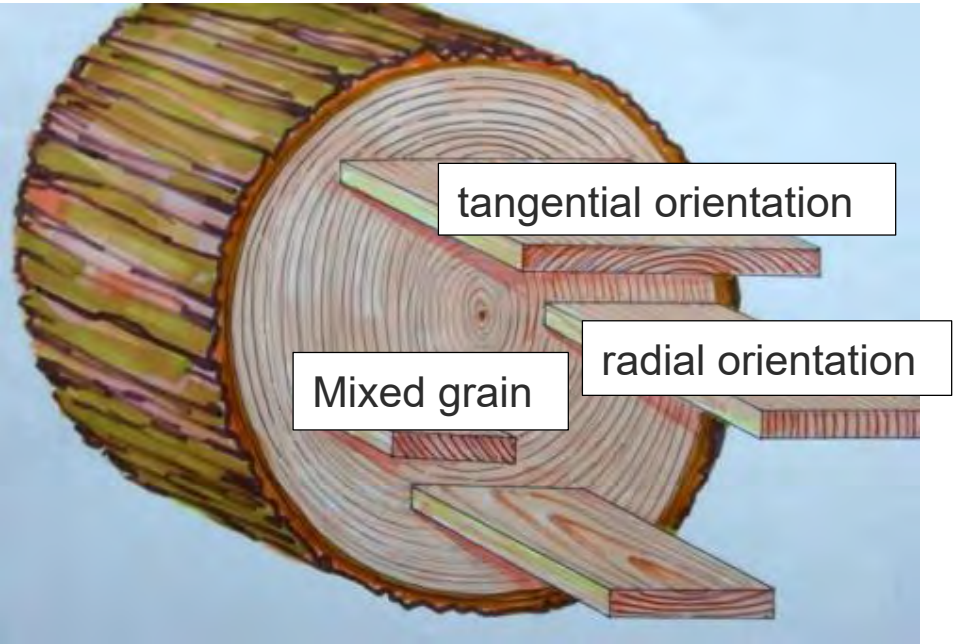


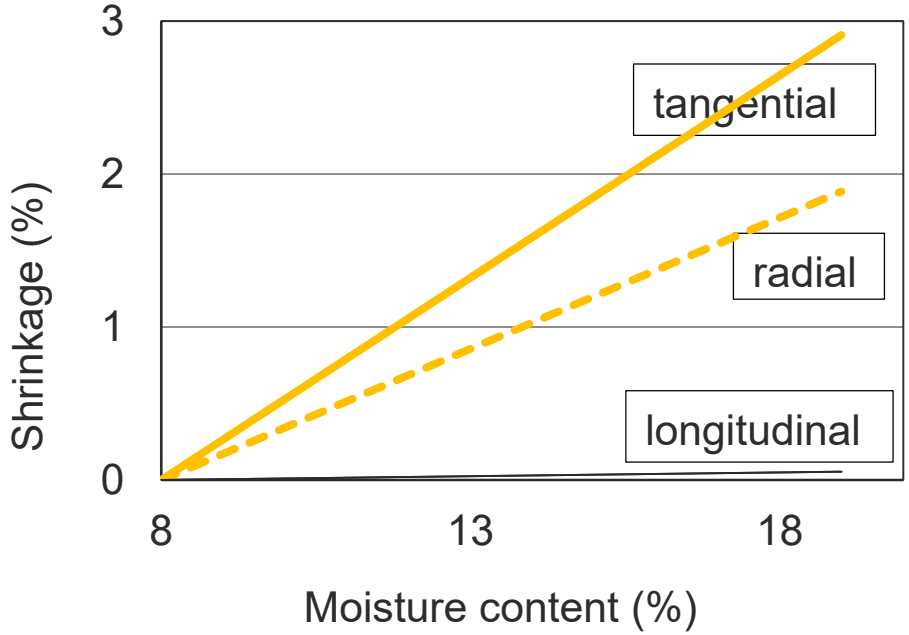
Masonry fire wall

Image source: HPO 2011

Causes of Vertical Movement

- Wood shrinkage (*routinely considered*)
  - Major cause of vertical movement
    - Primarily contributed by horizontal solid wood members
    - Contribution from studs (longitudinal direction) very small





Causes of Vertical Movement

- Wood shrinkage (*cont'd*)
  - Shrinkage amount depends on shrinkage coefficient, moisture content change, and dimension in gravity load path
  - Horizontal dimension lumber components (e.g., wall plate, floor joist)
    - 0.2% per 1% MC change (CWC 2011; CSA 2014)
    - Initial and in-service MC be measured, estimated or predicted
  - Engineered wood products typically have reduced shrinkage
    - Lower initial moisture content
    - May have lower shrinkage coefficient
    - Less well documented

Causes of Vertical Movement

- Wood shrinkage (*cont'd*)

Table 1 ***Typical MC ranges at manufacture***

Wood Materials	MC Range (%)
"S-Dry" lumber	15-19
Structural composites, such as plywood, OSB, LSL, LVL, OSL, PSL	6-12
Glulam, CLT	11-15

Causes of Vertical Movement

- Wood shrinkage (*cont'd*)

Table 1 ***Typical MC ranges in indoor service (CWC 2005)***

Location	Average EMC (%)	**Winter EMC (%)**	Summer EMC (%)
West coast	10 – 11	**8**	12
Prairies	6 – 7	5	8
Central Canada	7 – 8	5	10
East coast	8 – 9	7	10

Causes of Vertical Movement

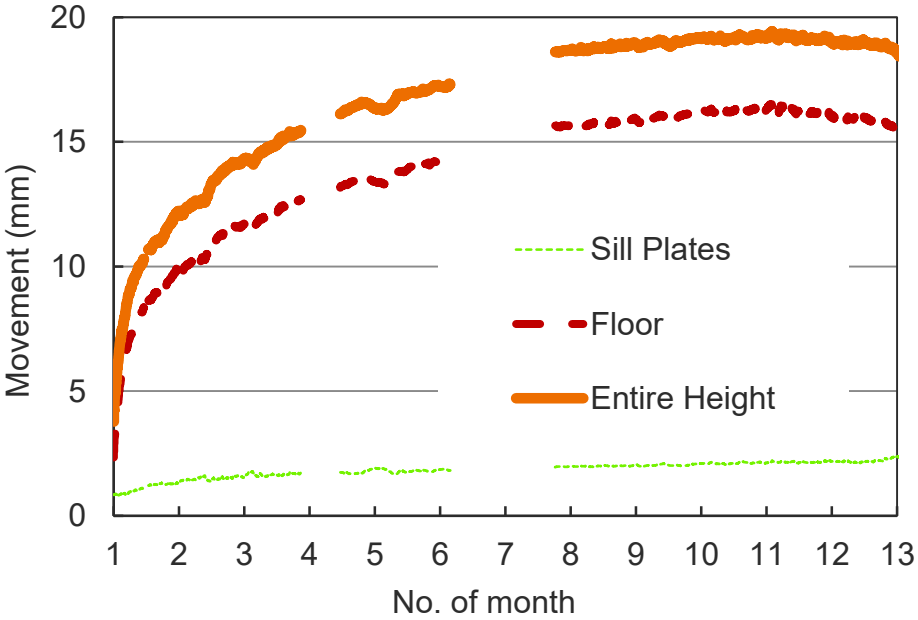
- Load (*not typically considered in NA*)
  - A smaller contributor to vertical movement
    - Closing of gaps between members (settlement or bedding-in)
    - Elastic compression
    - Time-dependent deformation (creep)
  - Influenced by load and wood MC
- Validation particularly important for taller wood-frame/mass timber buildings

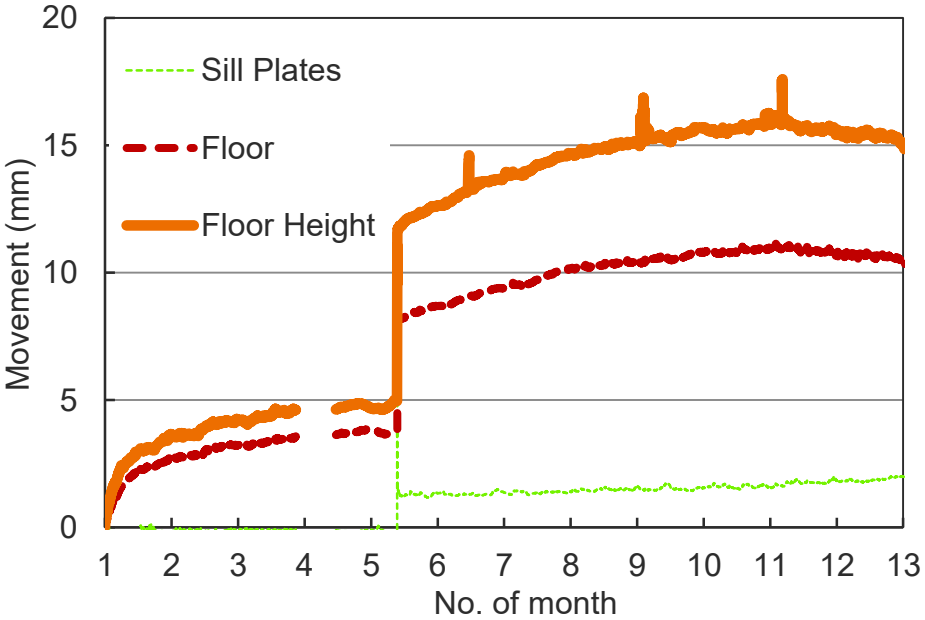
Laboratory Assessment

- Assess impact of MC and load on movement
- Collaborated with BCIT, Luke King/Dr. Rodrigo Mora
  - Two identical wood-frame structures used
  - Built with dimension lumber wall and floor joists
  - Structures pre-conditioned to achieve an initial MC of 20%
  - No. 1 was loaded at a MC of 20%, followed by drying
  - No. 2 was loaded after drying, at a MC about 10%
  - Load simulating dead load for bottom floor of 6-storey wood-frame

Laboratory Assessment

- Loads important for movement to “show up”
- No. 1: total movement reached 19 mm
  - Wood shrinkage accounted for 70%
  - Settlement and elastic compression about 20%
- No. 2: reduced movement due to drier wood





Field Measurement

- Measuring vertical movement and wood MC
- Conducted in three wood-frame buildings
  - 4, 5, 6 storey residential buildings
- Different floor joists
  - Dimension lumber and engineered wood
- Framed in different seasons
  - Wet and dry season

4-Storey Wood-Frame Building

- Major materials
  - “S-Dry” SPF top/bottom plates (double) and studs
  - Dimension lumber floor joists (2×10)
- Framed in winter (wet climate)
- Three lines of measurement
  - Hallway wall, interior partition wall, exterior wall
  - 12 displacement sensors
  - Together with moisture and RH/T sensors

5-Storey Wood-Frame Building

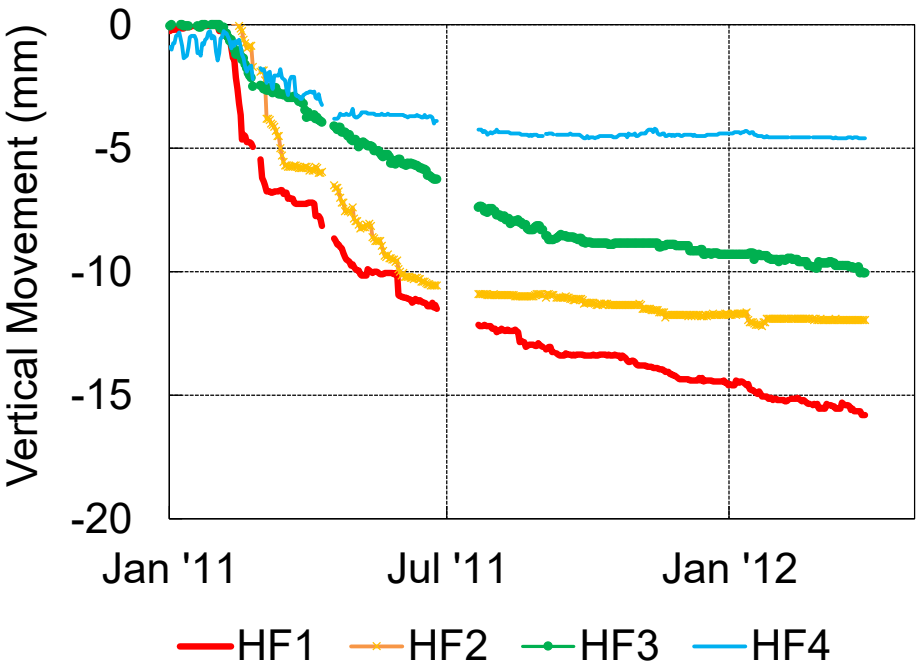
- Major materials
  - “S-Dry” top/bottom plates (double) and studs
  - Engineered wood rim joists and I-joists
- Construction in two phases
  - A: framed in winter (wet season)
  - B: framed in summer (dry season)
- Three lines of measurement
  - Hallway wall, interior partition, exterior wall
  - 30 displacement sensors
  - Together with moisture and RH/T sensors

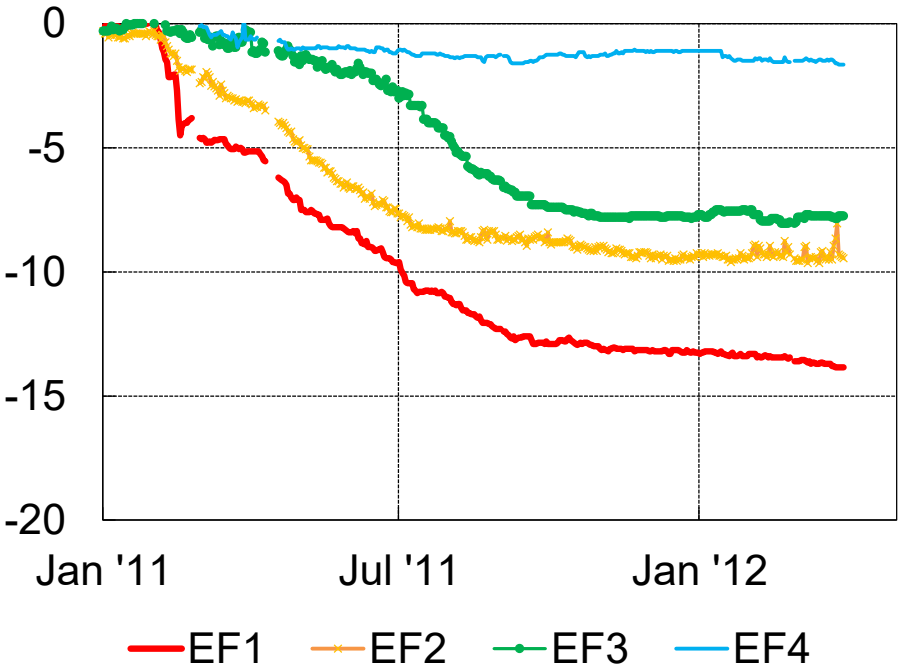
6-Storey Wood-Frame Building

- Major materials
  - “S-Dry” top/bottom plates (double) and studs
  - Engineered wood rim joists and I-joists
- Framed in a relatively dry season
- Four lines of measurement
  - Hallway wall, party wall, interior partition, exterior wall
  - 20 displacement sensors
  - Together with moisture and RH/T sensors

4-Storey Wood-Frame Building

- Higher movement amount on lower floors
- Higher movement amount in interior walls





Hallway wall

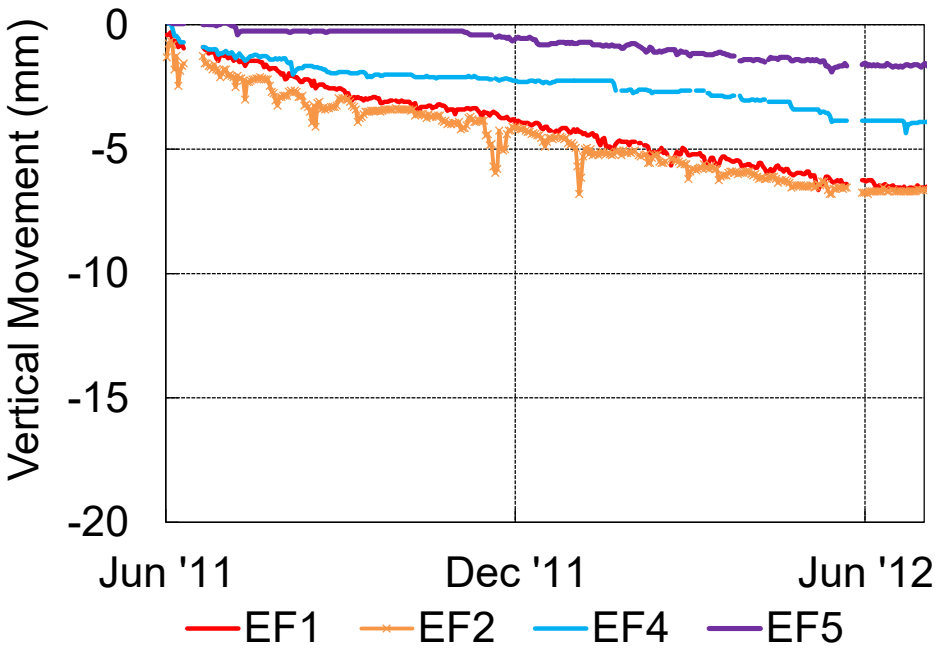
Movement 43 mm from slab to roof

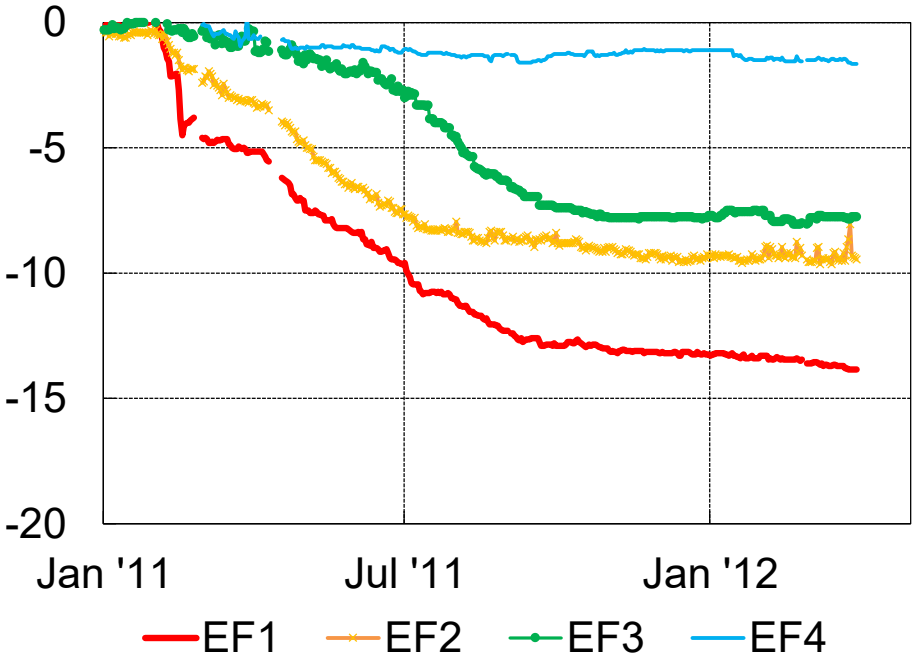
Exterior wall

Movement 34 mm from slab to roof

Comparison: 4-Storey and 5-Storey

- Lumber joists result in higher movement



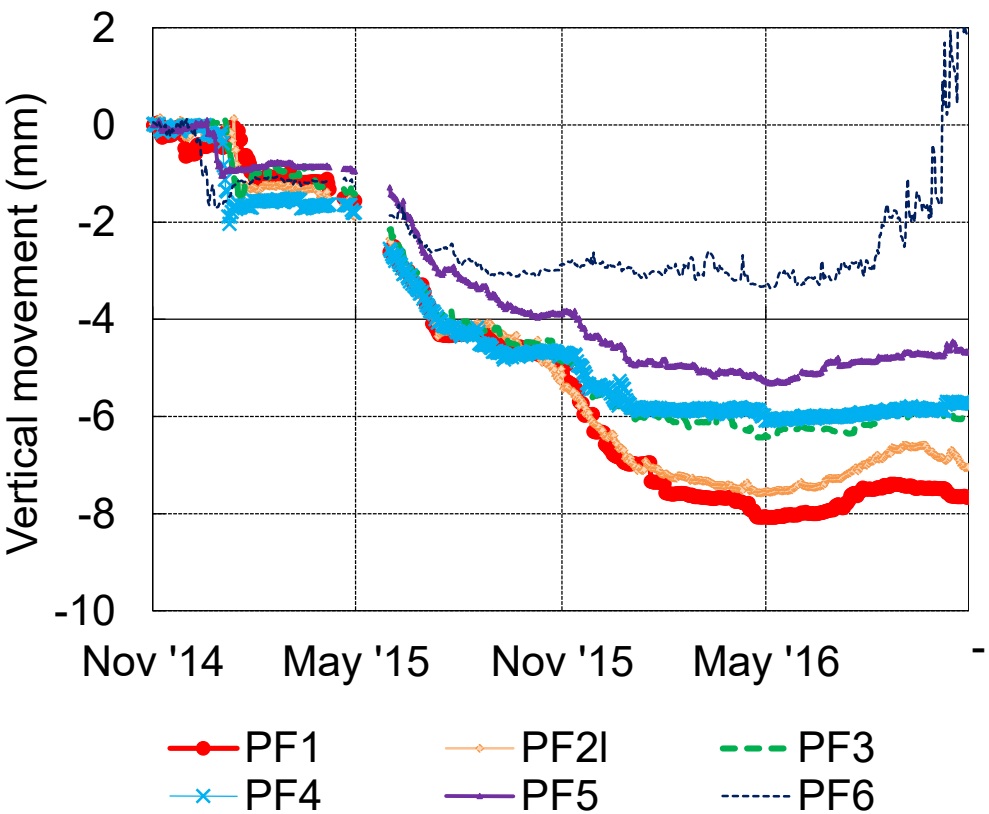


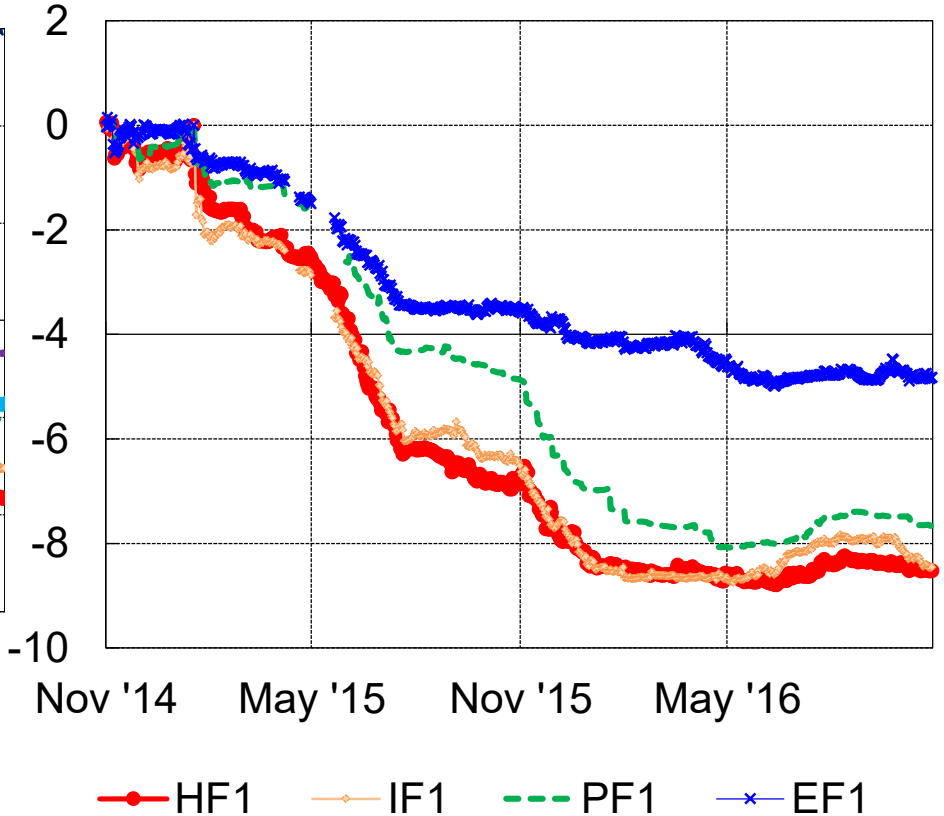
5-storey, engineered floor joists
Wet season start (Phase A)
Initial MC about 20%
Movement 28 mm from slab to roof

4-storey, lumber floor joists
Wet season start
Initial MC about 20%
Movement 34 mm from slab to roof

6-Storey Wood-Frame Building

- Higher movement amount on lower floors
- Higher movement amount in interior walls





4-Storey: Measurement and Prediction

4-storey, wet season	Average measured movement (mm)	Calculated shrinkage (mm)	Difference (mm)	Underestimation (%)
1	15.1	9.9	5.2	34.2
2	14.4	9.9	4.5	31.3
3	10.9	9.9	1.0	9.2
4	3.6	3.0	0.6	15.5
Entire building	44	33	11	**26**
/Floor (mm)	**11**	8	3	-
Shortening ratio (%)	0.40	0.30	-	-

5-Storey: Measurement and Prediction

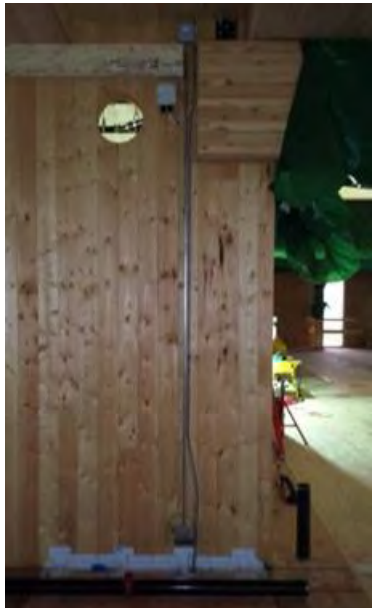
5-storey	A, wet season	B, dry season	Calculated shrinkage (mm)	A, difference (mm)	B, difference (mm)	Phase A, underestimation (%)	Phase B, underestimation (%)
1	11.0	8.0	4.7	6.3	3.3	57.3	41.3
2	9.0	7.0	4.7	4.3	2.3	47.8	32.9
3	7.0	5.0	4.7	2.3	0.3	32.9	6.0
4	9.0	1.0	4.7	4.3	-3.7	47.8	-
5	3.0	0.0	3.0	0.0	-3.0	0.0	-
Entire building	39	21	22	17	-1	**44**	0
/Floor (mm)	**8**	**4**	4.4	3.4	-0.2	-	-
Shortening ratio (%)	0.28	0.15	0.16	-	-	-	-

6-Storey: Measurement and Prediction

6-storey, relatively dry season	Average measured movement (mm)	Calculated shrinkage (mm)	Difference (mm)	Underestimation (%)
1	8.1	4.7	3.4	42.0
2	6.7	4.7	2.0	30.2
3	6.4	4.7	1.7	26.6
4	5.7	4.7	1.0	17.1
5	5.5	4.7	0.8	14.5
6	2.5	3.0	-0.5	-
Entire building	34.9	26.5	8.4	**24**
/Floor (mm)	**6**	4.4	1.4	-
Shortening ratio (%)	0.21	0.16	-	-

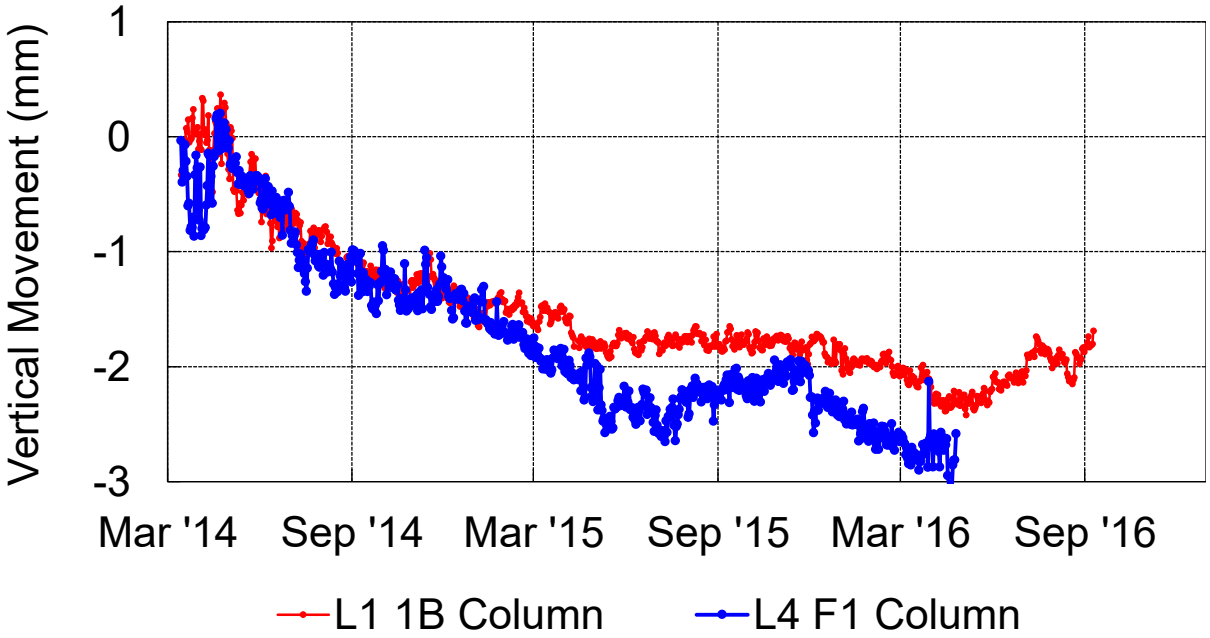
6-Storey Mass Timber Building

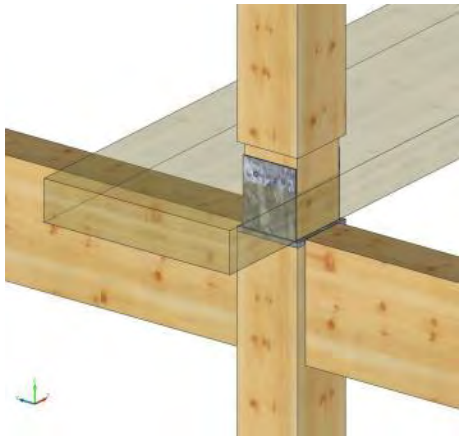
- Wood Innovation Design Centre (WIDC), Prince George
  - Sensors installed during construction to measure vertical movement
  - Glulam columns, CLT floor, CLT wall measured
  - MGA, Equilibrium Consulting, RDH, and PCL



6-Storey Mass Timber Building

- Glulam columns showed very small vertical movement, below 3 mm/floor (0.05%)
  - Cumulative shortening of 6 columns along building height estimated to be 12 mm (0.05%)

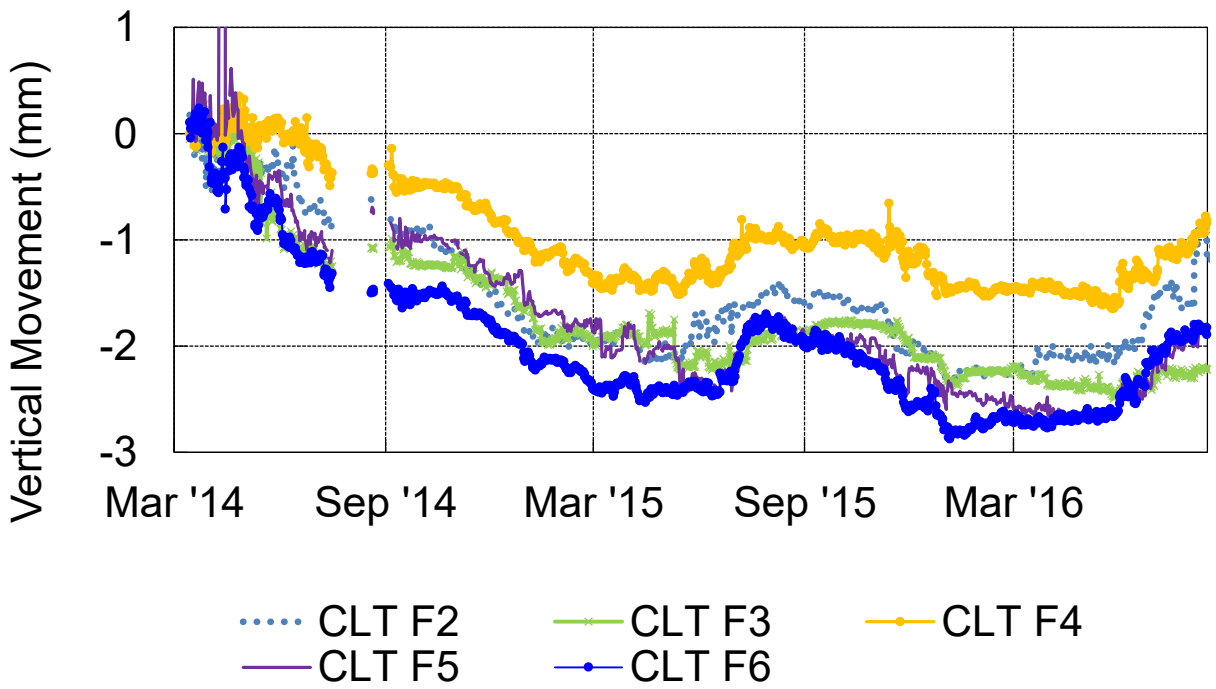




Courtesy: Equilibrium

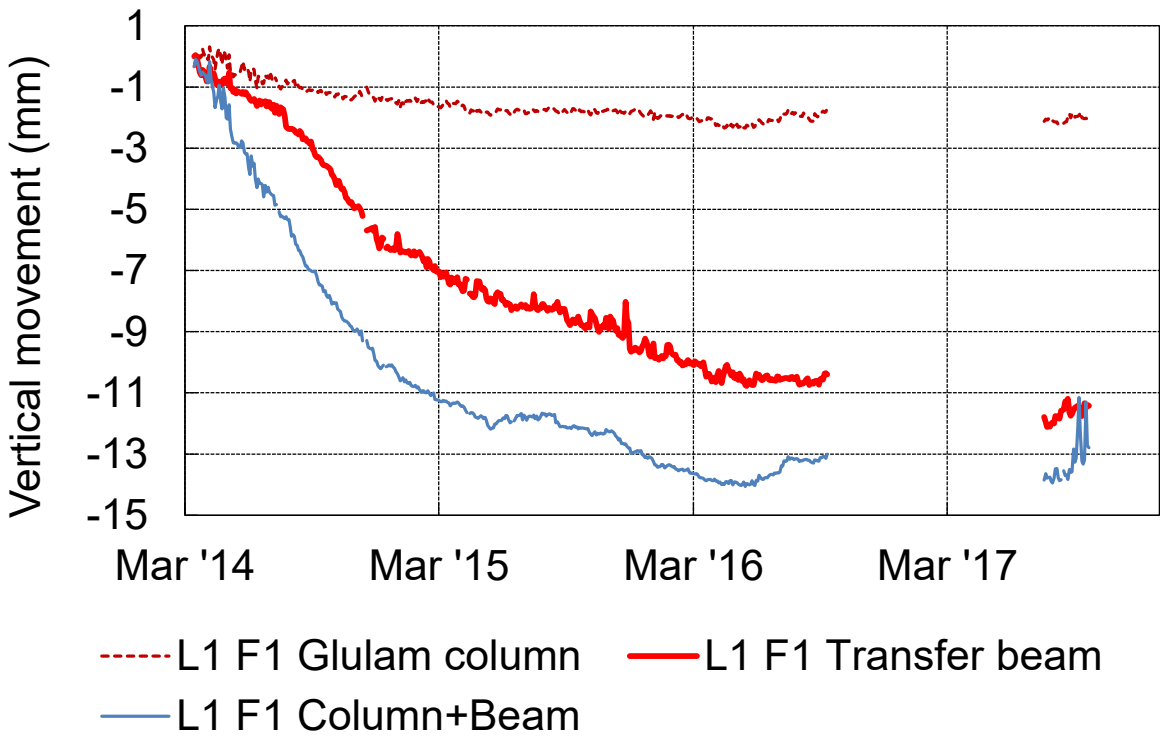
6-Storey Mass Timber Building

- CLT shear wall was also dimensionally stable along height
  - Entire CLT wall, from Level 1 to Level 6 with a height of 24.5 m, would shorten about 19 mm (i.e., 0.08%)



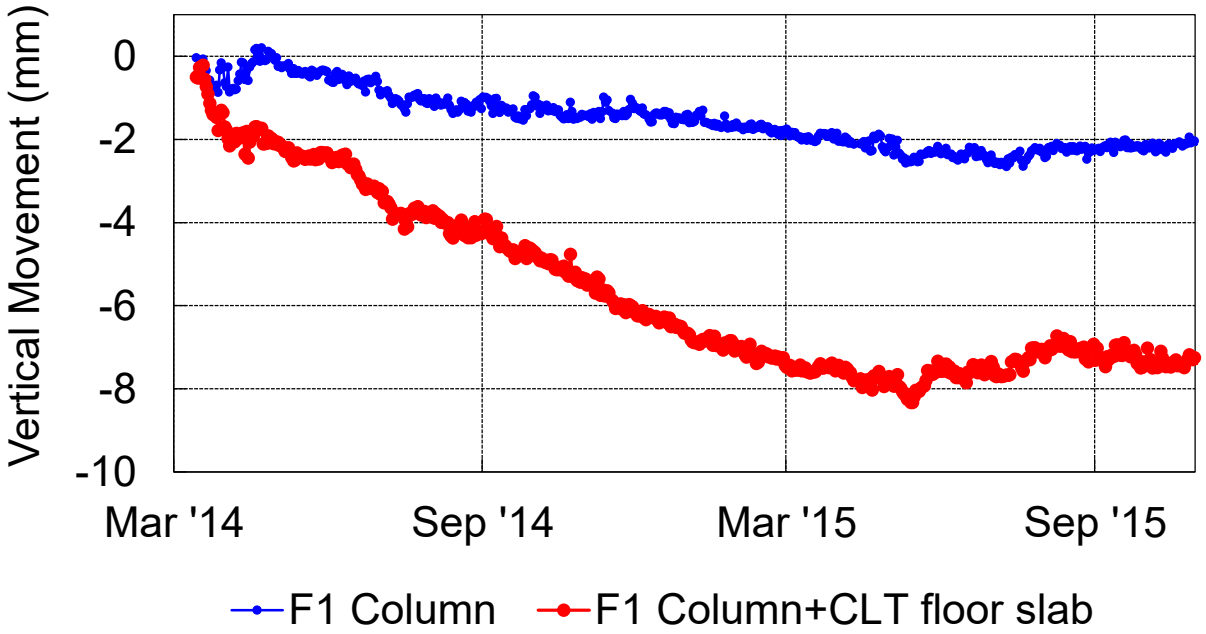
6-Storey Mass Timber Building

- PSL transfer beam (1.2 m deep) had expected shrinkage + deformation
  - With a vertical movement close to 12 mm (i.e., 1%)



6-Storey Mass Timber Building

- CLT floor slabs had expected shrinkage in thickness direction
  - It was estimated the CLT slab, 5-ply and 169 mm, had a vertical movement amount of about 5 mm (i.e., 3%)
  - Joints at curtain wall etc. important



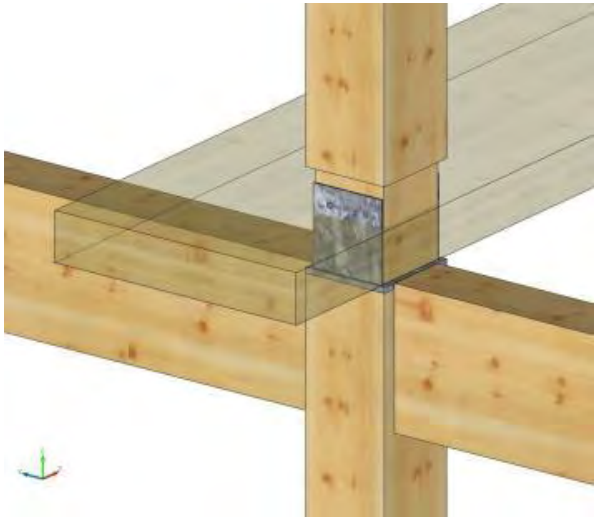
Courtesy: RDH

Messages: Prediction in Design

- Prediction of vertical movement should account for both wood shrinkage and load-induced deformation
  - Cross section (floor, plate etc.) greatly increase vertical movement
  - Wood with high moisture content greatly increase vertical movement
- Margin of safety should be added to the predicted wood shrinkage amount

Messages: How to Reduce Movement

- Reduce amount of cross section in load path
- Use engineered wood (e.g., floor joists) if possible
  - Rain protection may be more important than for solid wood
  - A Guide for On-site Moisture Management of Wood Construction recently developed



Courtesy: Equilibrium

Message: How to Reduce Movement

- Use and maintain drier wood in construction
  - Improve on-site moisture protection
  - Use space heating etc. to accelerate drying

Message: How to Reduce Movement

- Good sequencing reduces/accommodates differential movement
  - Install roof/wall membrane as quickly as possible
  - Remove water pools after rain events
  - Pour concrete topping as early as possible
  - Install rigid services (horizontal hard pipes, rigid cladding) as late as construction allows
  - Allow time to dry and settle before close-in
  - Start interior finishing from top floor

Acknowledgements

- Natural Resources Canada (funder)
- BC Housing (funder)
- All developers, construction companies, engineers, and architects involved
- SMT Research

FPInnovations

OUR NAME IS INNOVATION

Jieying.wang@fpinnovations.ca

Follow us on

www.fpinnovations.ca

© 2015 FPInnovations. All rights reserved. Copying and redistribution prohibited. ® FPInnovations, its marks and logos are trademarks of FPInnovations.