BCBEC Luncheon
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FPInnovations

Mid-rise Wood-Frame Construction Handbook
Chapter 5: Design for Vertical Differential Movement

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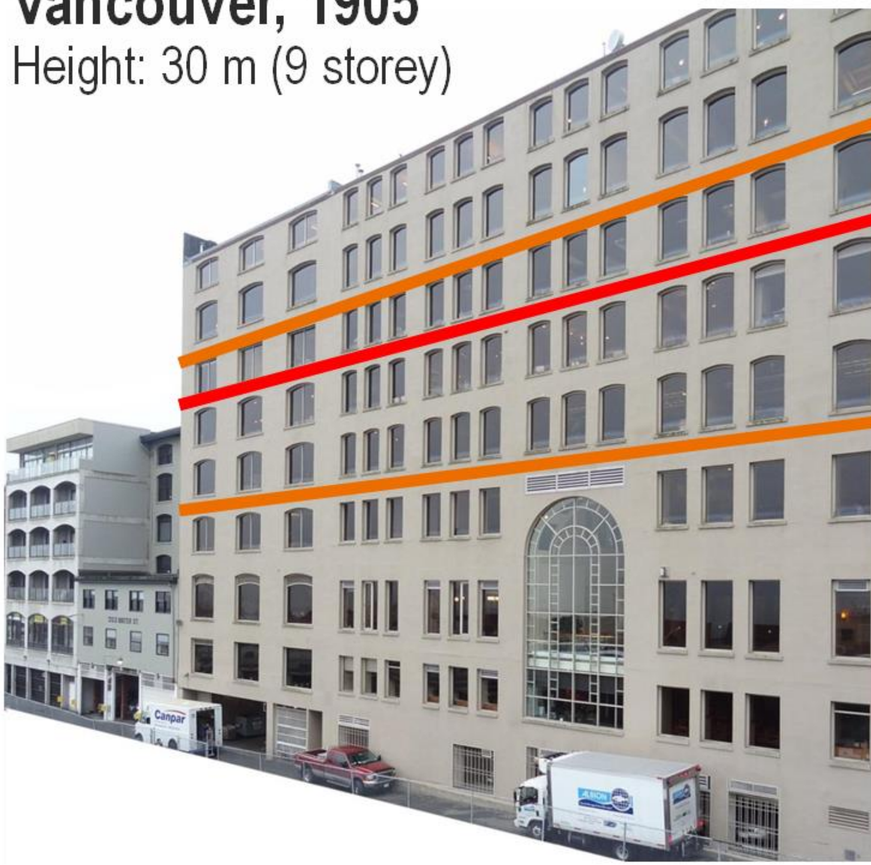
Advanced Building Systems

Outline

- Background and Handbook Overview
- Chapter 5: Design for Vertical Differential Movement
  - Causes of Vertical Movement
  - Laboratory Assessment
  - Field Measurement
  - Prediction
  - Detailing for Critical Locations
  - Summary of Solutions

Mid-rise Wood-Frame Construction: History

The Landing
Vancouver, 1905
Height: 30 m (9 storey)



National Building Code of Canada

NBCC 1941 (7)

NBCC 2015 (6)

NBCC 1953 (4)

Mid-rise Wood-Frame Construction: History

- Light Wood-Frame Construction
  - Originated in US in 1830s
    - Balloon structure, and then
    - Platform frame construction

Mid-rise Wood-Frame Construction: History

1910s

Mid-rise Wood-Frame Construction: History

1970s

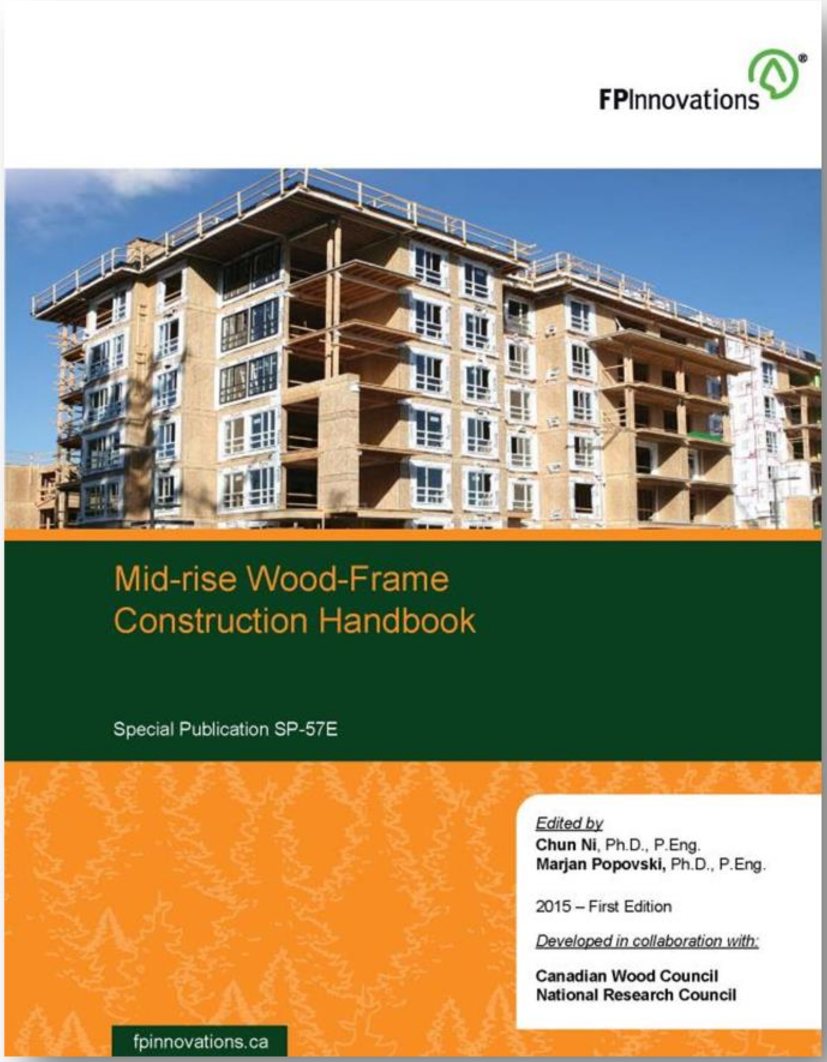
Mid-rise Wood-Frame Construction: History

1990s

Mid-rise Wood-Frame Construction: Code Change

- 2009: Introduction in BC Building Code
- 2013: Régie du Bâtiment du Québec (RBQ)
- 2015: Ontario Building Code
- 2015: Alberta Building Code
- 2015 NBCC

Mid-rise Wood-Frame Construction Handbook



- Focus on mid-rise (5- and 6-storeys) light-frame wood construction
- In accordance with 2015 NBCC provisions and CSA O86-14

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Mid-rise Wood-Frame Construction Handbook

- Multi-disciplinary handbook involving 42 industry, research & design experts
- Address podium structures and wood-based vertical shafts
- Includes high capacity shearwalls and diaphragms
- Complementary to existing manuals

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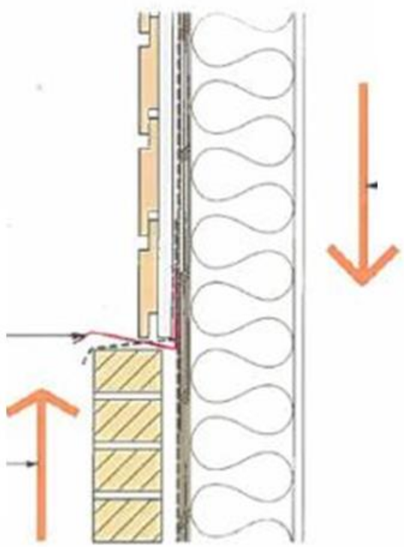
Chapter 5: Design for Vertical Differential Movement

Team Involved

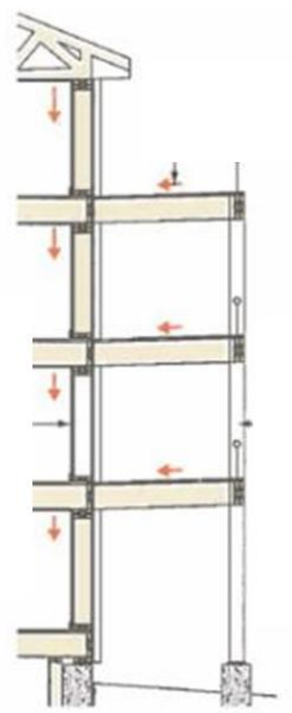
- Lead authors
  - Jieying Wang, Chun Ni (FPInnovations)
- Peer reviewers
  - Barry Craig (CMHC)
  - Graham Finch (RDH)
  - Mohammad Mohammad, Paul Morris (FPInnovations)
  - David Moses (Moses Structures)
  - Fred Tai (Simpson Strong-Tie)
  - Jasmine Wang (CWC)

Objective

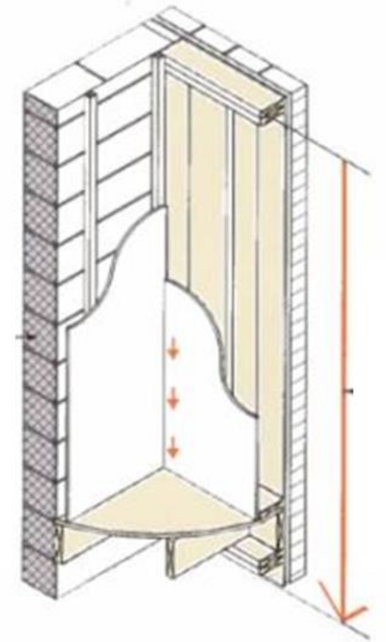
- Aim to address a key design concern about 5- and 6-storey platform frame buildings



Masonry cladding



Balcony

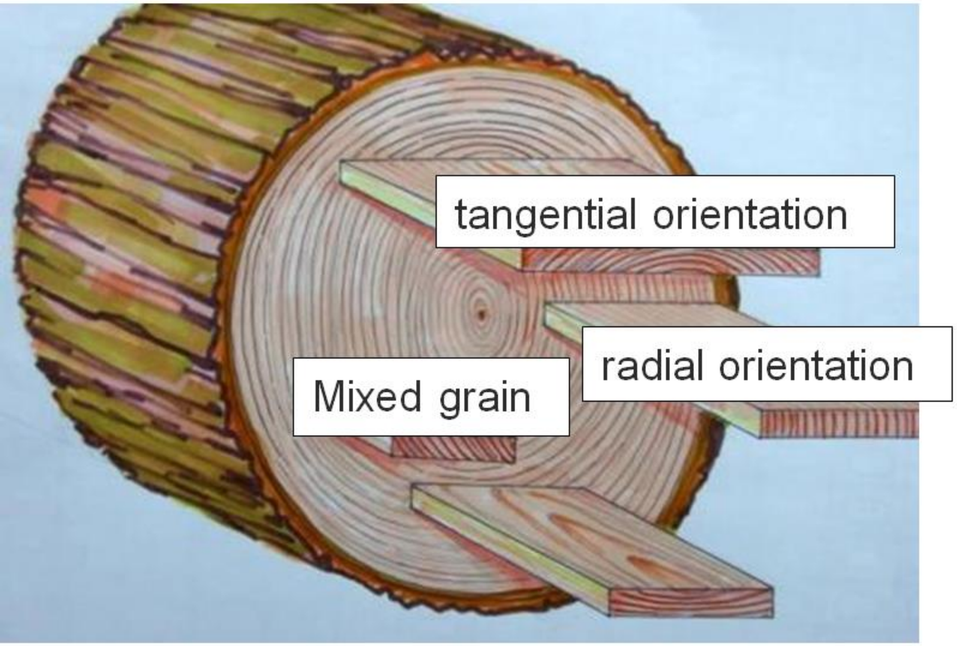


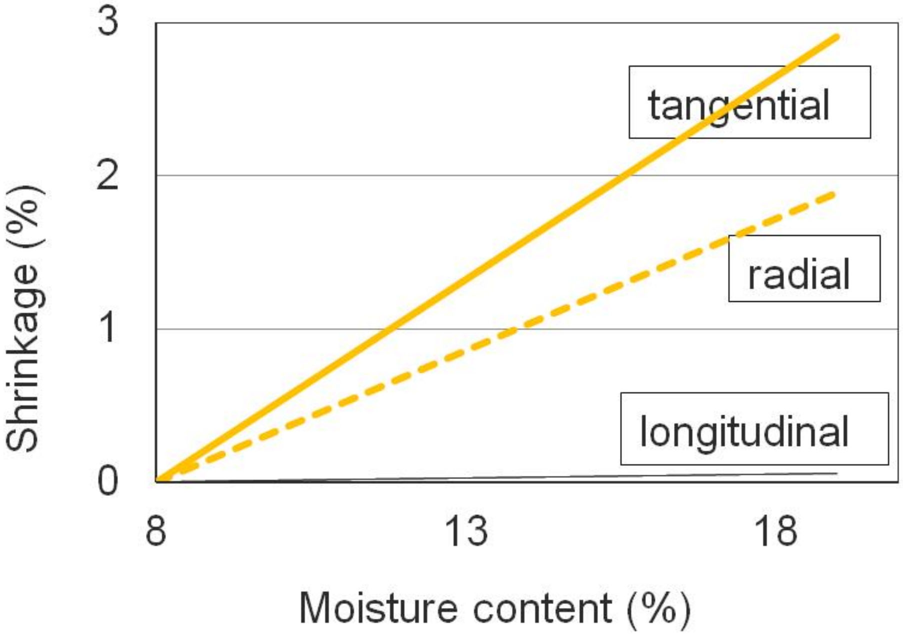
Masonry fire wall

Image source: HPO 2011

Causes of Vertical Movement

- Wood shrinkage (*routinely considered*)
  - Major cause of vertical movement
    - Primarily contributed by horizontal solid wood members (cross section)
    - 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)
    - 0.25% per 1% MC change used in this handbook
    - 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

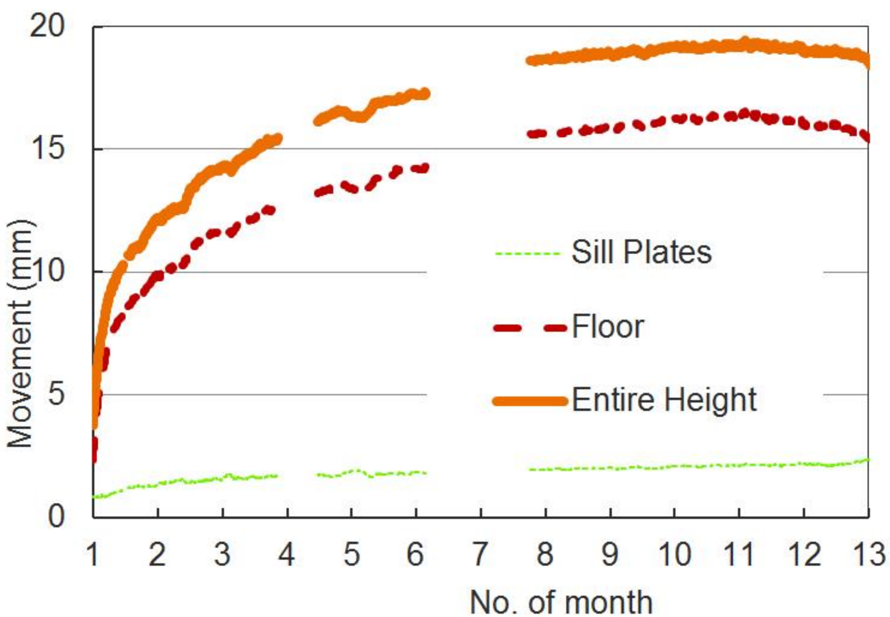
- Load (*not typically considered in NA*)
  - A small contributor to vertical movement
    - Closing of gaps between members (settlement or bedding-in)
    - Elastic compression
    - Time-dependent deformation (creep)
  - Influenced by load and wood MC
- Validation particularly important for taller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

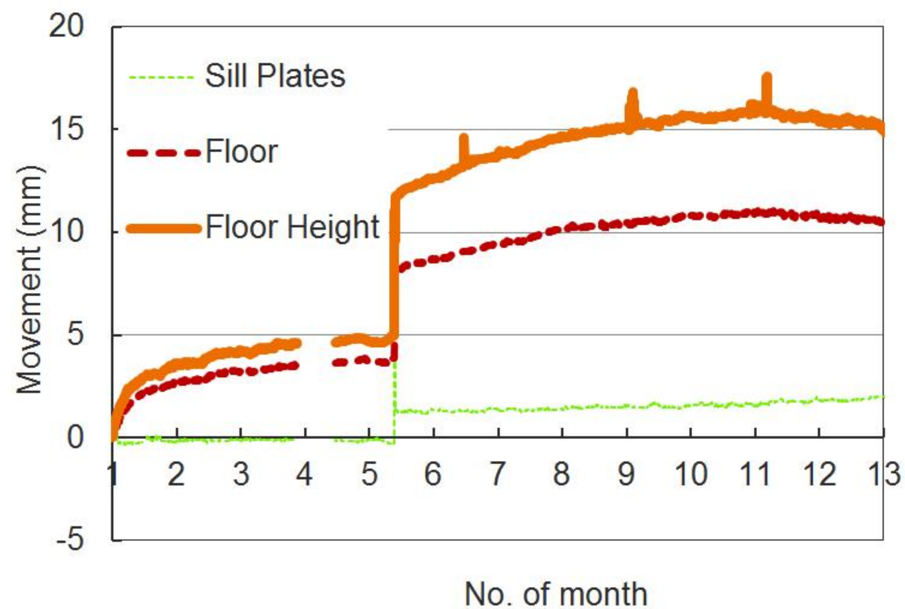
Laboratory Assessment

- Assess impact of MC and load on movement
- Collaborated with BCIT, Luke King
- Two small identical structures used
  - Built with dimension lumber wall and floor joists
  - Structures 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
  - Measurement started after roof sheathing installed
  - Timing relevant to calculating differential movement!
- Three buildings instrumented
  - 4, 5, 6 storey buildings
- Different floor joists
  - Dimension lumber and engineered wood
- Framing in different seasons
  - Wet and dry season

4-Storey Building

- Major materials
  - “S-Dry” SPF top/bottom plates (double) and studs
  - Dimension lumber floor joists (2×10)
- Framing in winter (wet climate)
- Three lines of movement measurement
  - Hallway shear wall, interior partition wall, exterior wall

5-Storey Building

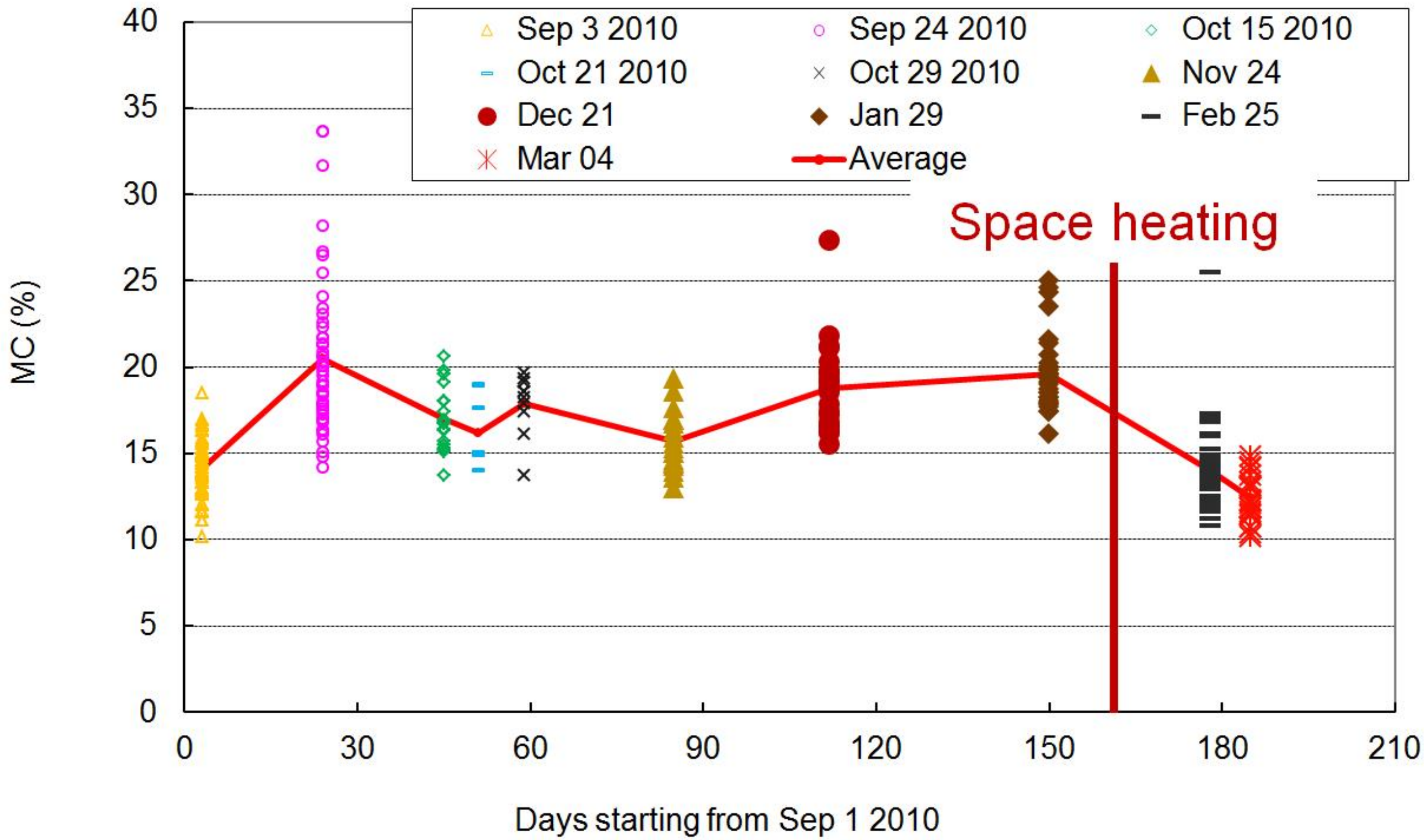
- Major materials
  - "S-Dry" top/bottom plates (double) and studs
  - Engineered wood rim joists and I-joists
- Construction in two phases
  - A: framing in winter (wet season)
  - B: framing in summer (dry season)
- Three lines of movement measurement
  - Hallway shear wall, interior partition, exterior wall

6-Storey Building

- Major materials
  - "S-Dry" top/bottom plates (double) and studs
  - Engineered wood rim joists and I-joists
- Framing in a relatively dry season
- Four lines of movement measurement
  - Hallway shear wall, party wall, interior partition, exterior wall
  - Input from Thomas Leung Structural Engineering

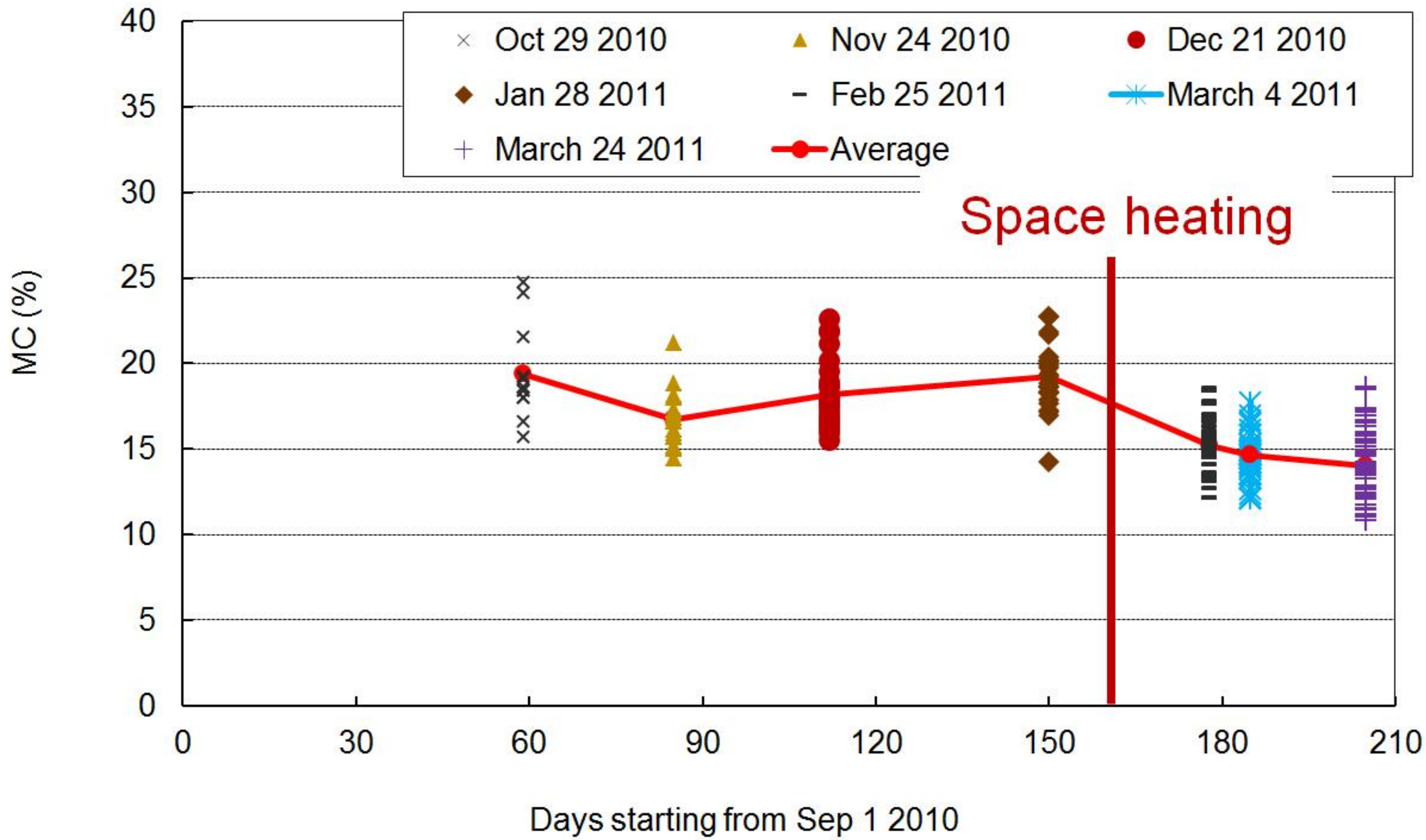
Lumber MC Change: 4-Storey Building

- Studs on ground floor, chest height
  - Average MC below 20% before space heating, large variation



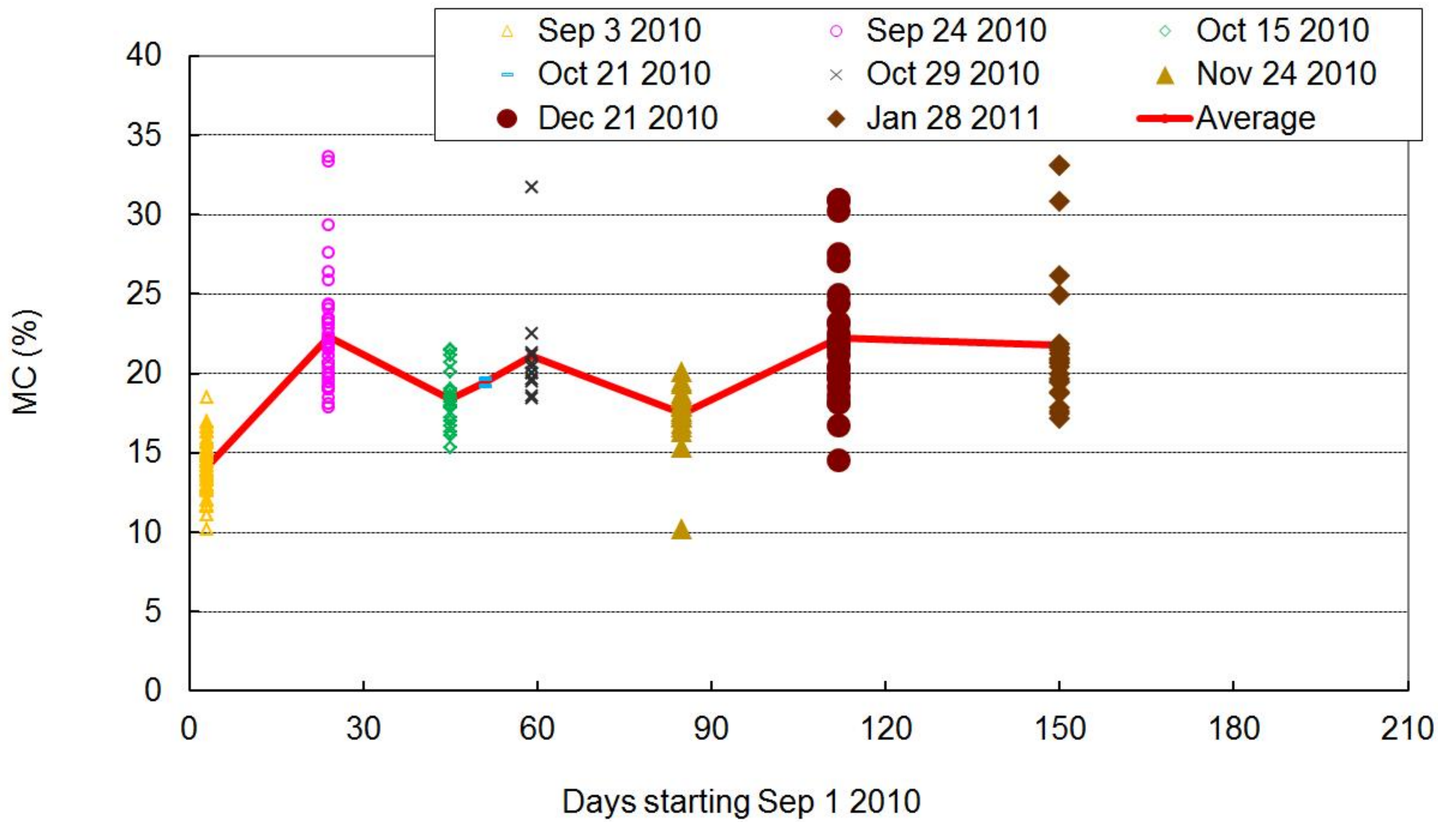
Lumber MC Change: 4-Storey Building

- Studs on 4th floor, chest height
  - Average MC below 20% before space heating, smaller variation

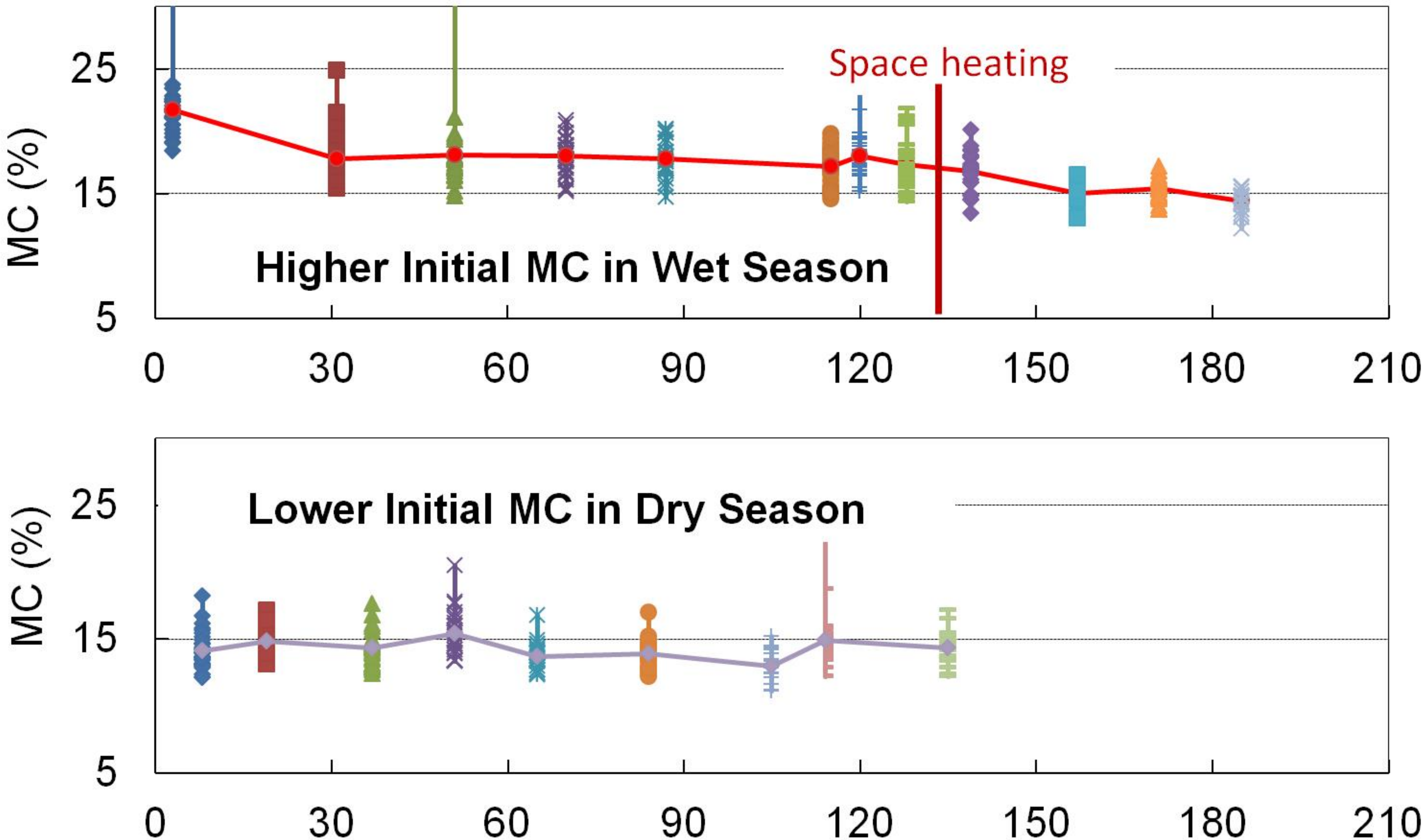


Lumber MC Change: 4-Storey Building

- Sill plates
  - Average MC higher than 20% before space heating, large variation



Lumber MC Change: 5-Storey Building



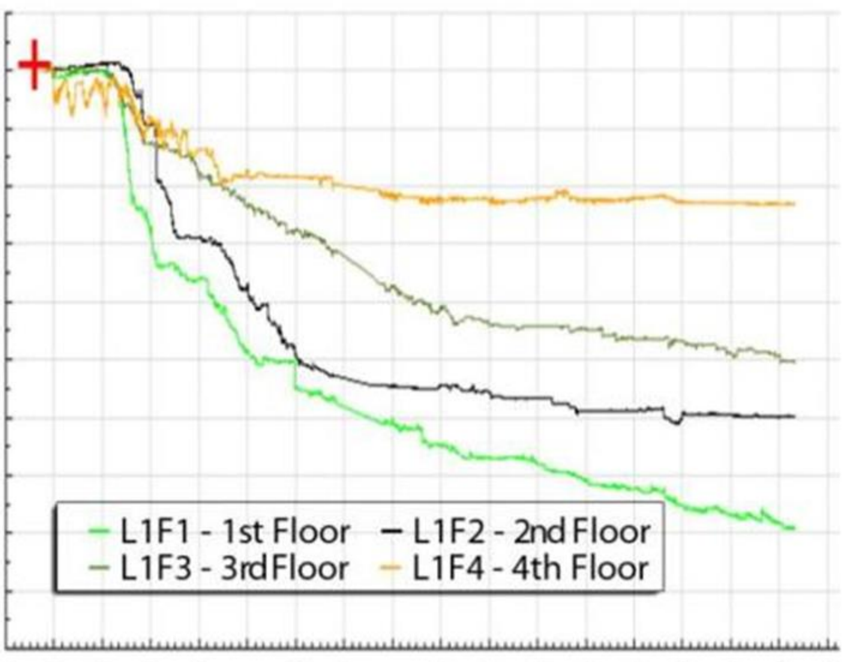
Changes in MC at chest height of studs, first floor

Lumber MC Change

- Framing in a wet season
  - 20% on average before space heating
  - Within a wide range
  - It is challenging to maintain MC below 19% before enclosure
  - Forced drying becomes necessary to improve construction efficiency
- Framing in a dry season
  - 15% on average
  - Within a narrow range
- Indoor MC around 8% in winter in Coastal BC
  - Discrepancy in MC between exterior walls and interior walls

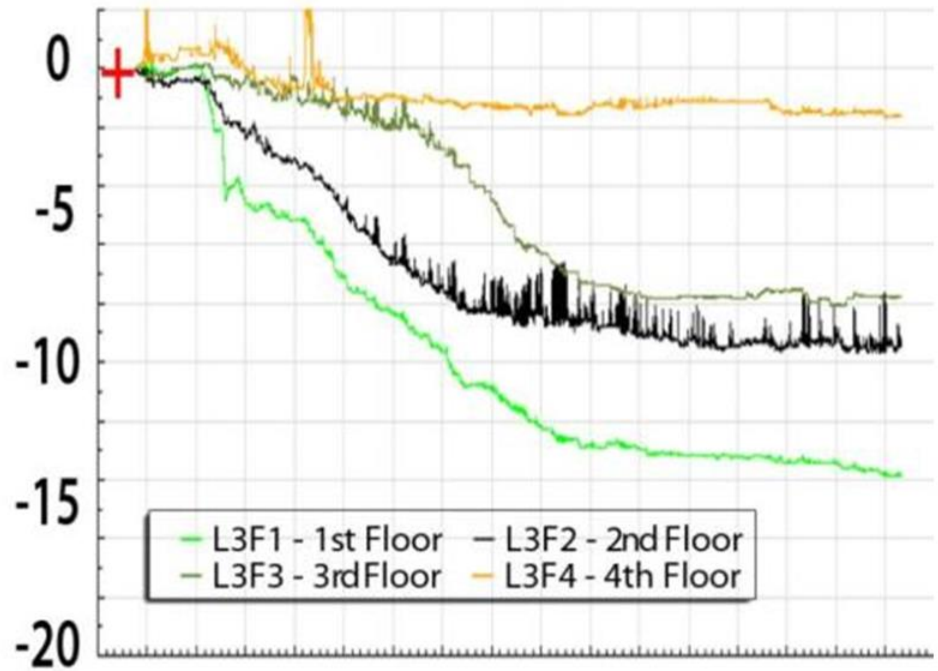
Vertical Movement: 4-Storey

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



Hallway shear wall

Movement 46 mm from slab to roof

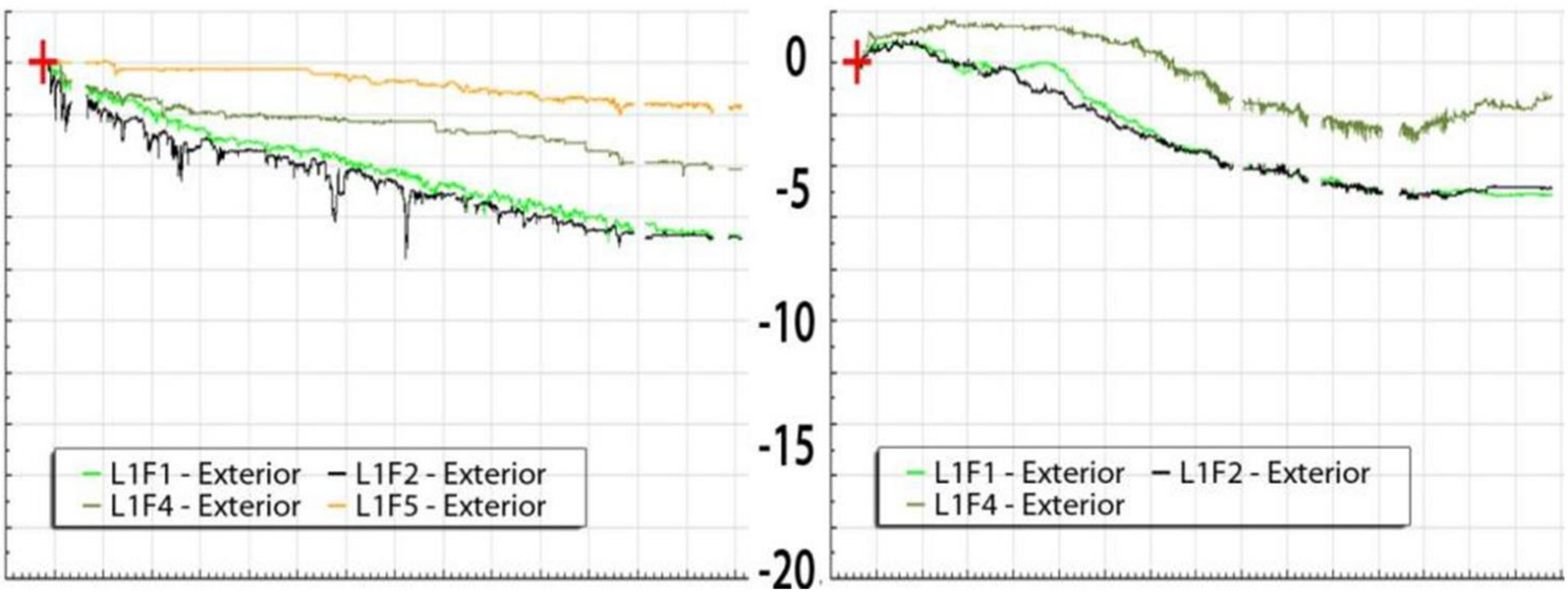


Exterior wall

Movement 34 mm from slab to roof

5-Storey Building: Exterior Wall

- Higher movement when framed in wet season



Wet season start (Phase A)

Higher initial MC of wood

Movement 27 mm from slab to roof

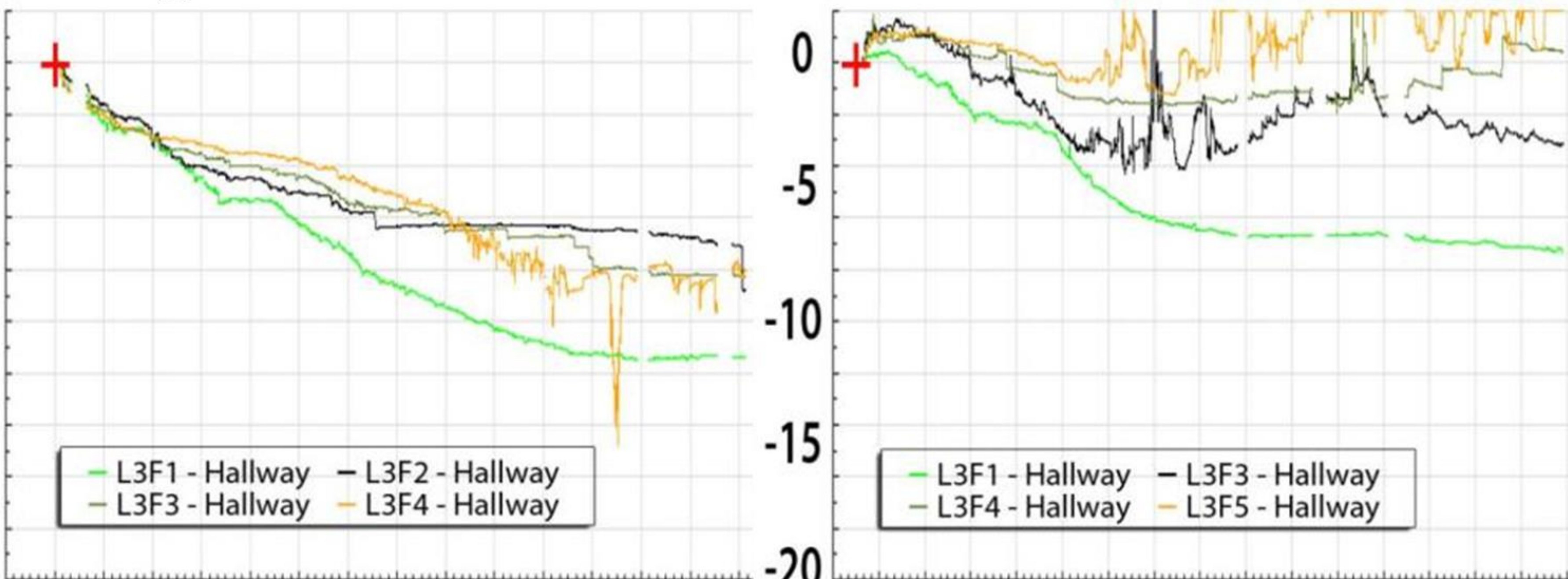
Dry season start (Phase B)

Lower initial MC (expanded at first)

Movement 17 mm from slab to roof

5-Storey Building: Hallway Wall

- Higher movement when framed in wet season
- Higher movement amount in interior walls

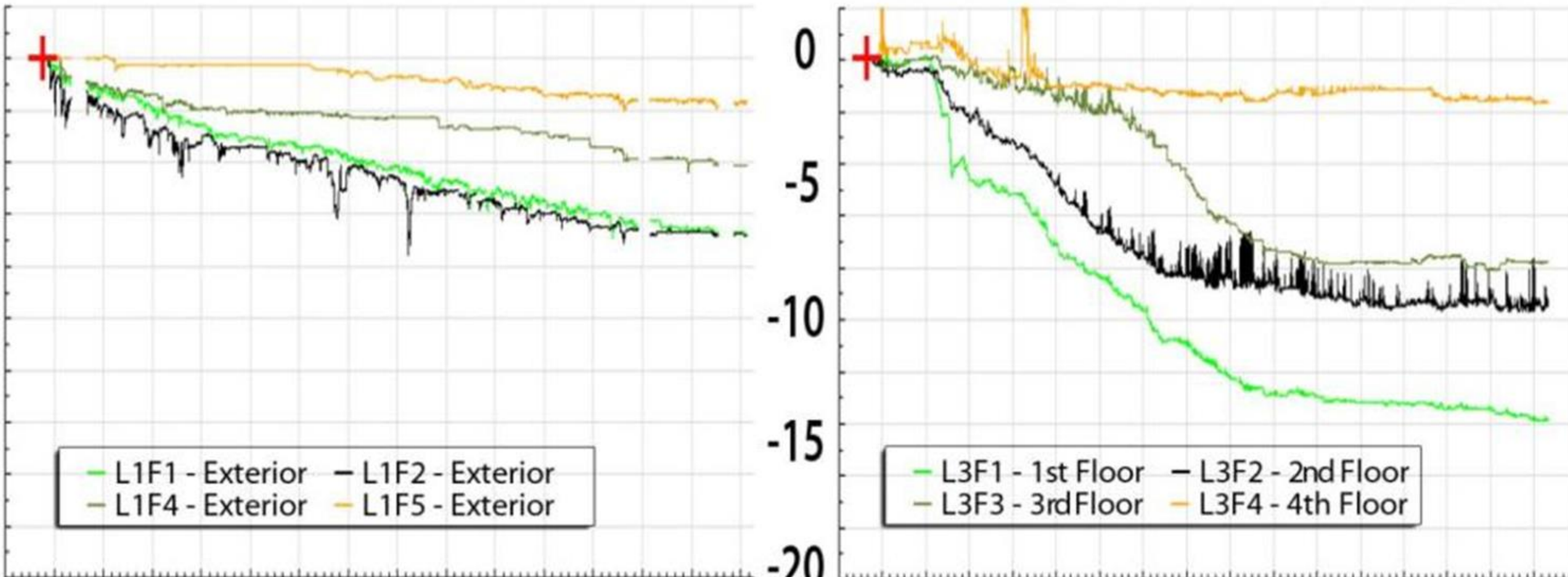


Wet season start (Phase A)
Higher initial MC
Movement 36 mm from slab to roof

Dry season start (Phase B)
Lower initial MC (expanded at first)
Movement 20 mm from slab to roof

Floor Comparison: Exterior Wall

- Lumber joists result in higher movement

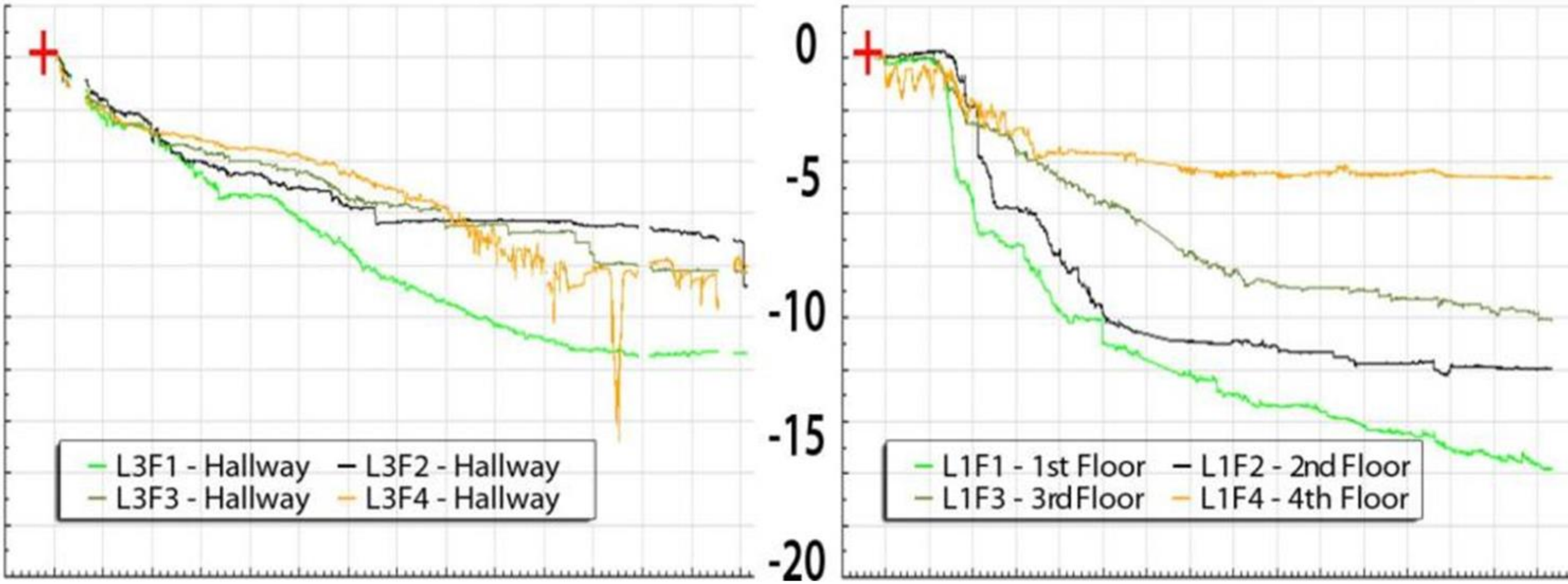


5-storey, engineered floor joists
Wet season start (Phase A)
Initial MC about 20%
Movement 27 mm from slab to roof

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

Floor Comparison: Hallway Wall

- Lumber joists result in higher movement



5-storey, engineered floor joists

Wet season start (Phase A)

Initial MC about 20%

Movement 36 mm from slab to roof

4-storey, lumber floor joists

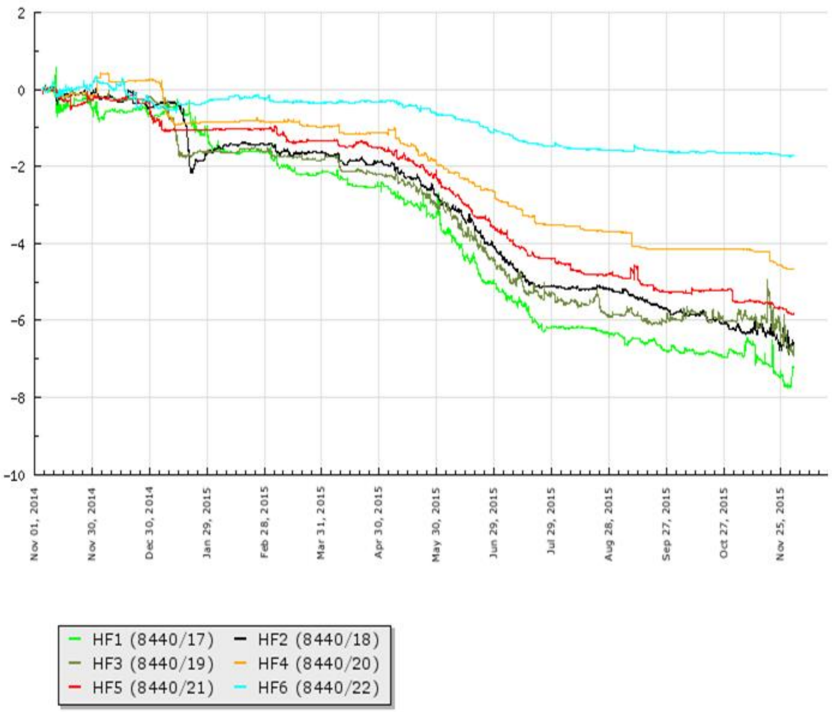
Wet season start

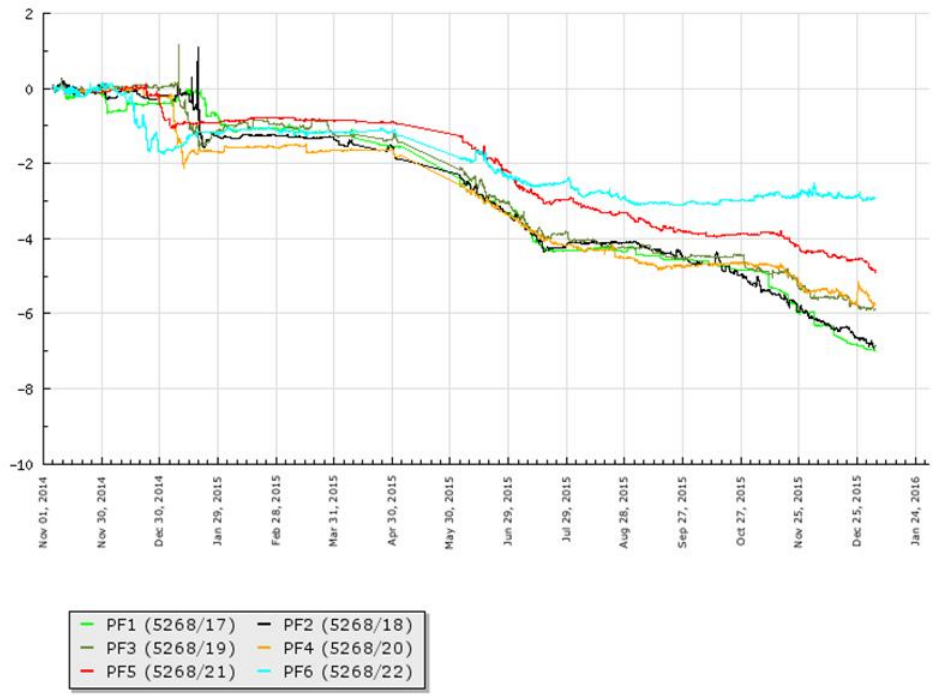
Initial MC about 20%

Movement 46 mm from slab to roof

6-Storey: Hallway Wall and Party Wall

- Hallway wall has slightly higher movement





Hallway wall

Movement 36 mm from slab to roof, 14 months

Party wall

Movement 34 mm from slab to roof, 14 months

Prediction of Vertical Movement

Building height	Construction season	Floor material	Shrinkage predicted (mm)	Total movement predicted (mm)	Measurement (mm)	Measurement /Shrinkage predicted
4-storey	Wet	Dimension lumber	40	44	46 (20 months)	**1.15**
5-storey	Wet	Engineered wood	28	34	36 (20 months)	**1.28**
5-storey	Dry	Engineered wood	18	24	20 (higher fluctuations)	**1.11**
6-storey	Relatively dry	Engineered wood	22	27	36 (14 months)	**1.64**

All hallway walls; "Wet" initial MC: 19%; "Dry" initial MC: 15%; in-service MC: 8%; engineered wood joists initial and final MC: 8%

Prediction of Vertical Movement

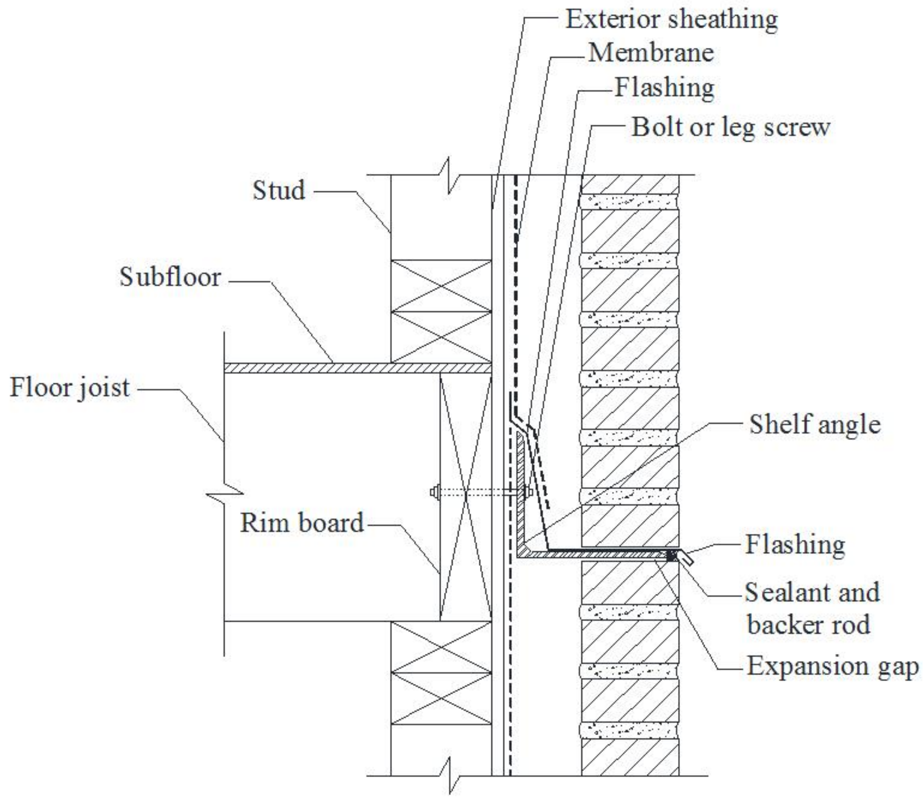
- Prediction should consider material used, realistic moisture content change, and load
- Prediction can be accurate
- Margin of safety should be added to the predicted wood shrinkage amount

Critical Locations for Detailing

- Detailing at:
  - Masonry cladding
  - Windows
  - Balconies and roof decks
  - Connections to firewalls, stairwells, elevator shafts, rigid pipes etc.
  - Uneven movement at ends of roof/floor joists
  - Connected parts under different service environments
- For building envelope design, key is to maintain a good slope for drainage
  - Flashing, balconies, roof decks

Critical Locations for Detailing

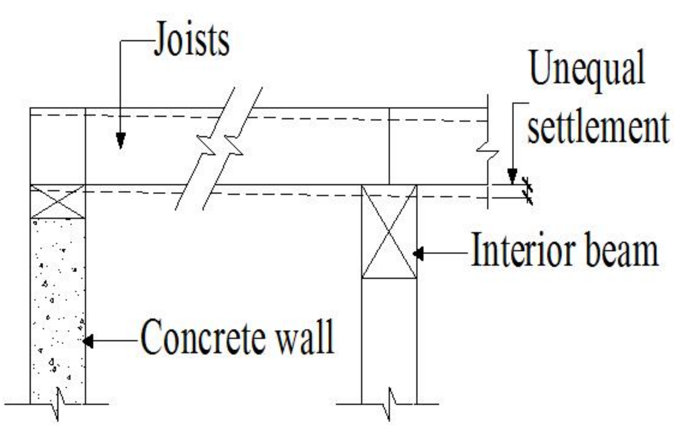
- When masonry cladding is used
  - Shelf angles recommended for each floor to compartmentalize cladding
  - A 12 mm joint under shelf angle to accommodate differential movement

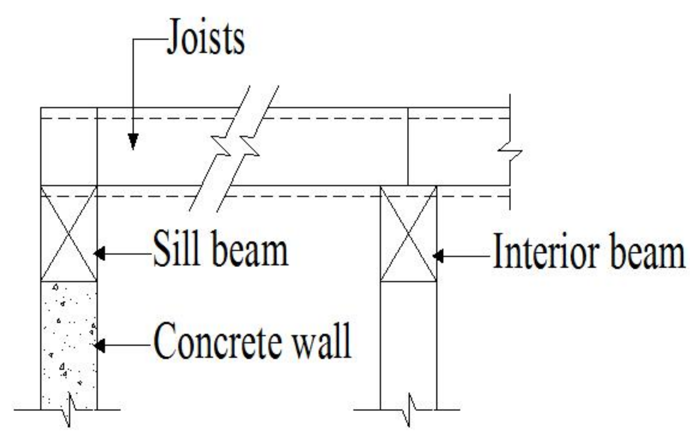


In consultation with Masonry Institute of British Columbia, Bill McEwen

Critical Locations for Detailing

- Solutions for uneven shrinkage at ends of joists
  - e.g., a sill beam can be installed to equalize shrinkage at the two ends





Summary: How to Reduce Movement

- Use and maintain drier wood in construction
  - Reduce both shrinkage and deformation
  - Adjust construction in a wet season
    - Increase on-site moisture protection
    - Use space heating etc. to accelerate drying

Summary: How to Reduce Movement

- Use engineered wood (e.g., floor joists)
  - Rain protection may be more important than solid wood
  - A Guide for On-site Moisture Management of Wood Construction recently developed

Summary: 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

- Funding partners:
  - Natural Resources Canada
  - Homeowner Protection Office, Branch of BC Housing
- Developers, construction companies, engineers involved
- SMT Research

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