NEWS ITEM: QUADRA ISLANDERS VOTE 727-23 AGAINST BUILDING INSPECTIONS.
The new NBCC: Companion Loads, Wind/Snow Loading and Seismic

F. Michael Bartlett
F.CSCE, P. Eng.
University of Western Ontario
f.m.bartlett@uwo.ca
This Morning’s Agenda

- Divisions A and B of NBCC 2005
- Companion Action Load Combinations
- Importance Factors for Buildings
- Changes to Specified Loads
- Loose Ends
- Summary
NBCC 2005 is Objective-based

Division A (new!)
- 4 objective categories
- 46 functional statements

Division B (familiar)
- “Acceptable solutions”
- transition mechanism
Code of Hammurabi

Photo by C. R. Scollard
Not all that different..

• "a builder... [shall receive] ... 2 shekels of silver for every SAR of the house for his fee"

• This is equivalent to 72 days pay for a 44 m² house
  – (White Gergely & Sexsmith, 1972)

• say $40/s.f.
A Performance Code

- “If a builder has made a house for a man and has not made his work sound, and the house which he had built has fallen down and so caused the death of the householder, that builder shall be put to death.”

- “if it causes the death of the householder’s son, they shall put that builder’s son to death”

- “if the wall bulges, that builder shall put that wall into sound condition from his own silver”
Canadian Code Development

Quebec Bridge: Canada’s longest cantilever

one football field
Quebec Bridge Workers, 1906
Wreckage
1907
Finial as Grave Marker in St-Romuald Cemetery

17 Americans
58 Canadians
(33 Caughnawaga Iron Workers)
Drop-in Span Collapse
11 September 1916

Death toll: 75 (1907) + 11 (1916) = 86
Canadian Code Milestones

1922: CESA “Standard Specification for Steel Railway Bridges”

1924: CESA “Standard Specification for Steel Structures for Buildings”

1929: CESA “Standard Specification for Concrete and Reinforced Concrete”

1941: National Building Code of Canada
1974: Limit States Design

Key Players
- D. J. L. Kennedy
- J. G. MacGregor
- D. E. Allen

Others
- A. G. Davenport
- N. C. Lind
- D. A. Taylor
Safety Objectives in NBCC 05

OS 1: Fire Safety
OS 2: Structural Safety
OS 3: Safety in Use
OS 4: Resistance to Unwanted Entry
OS 5: Safety at Construction and Demolition Sites
Structural Safety Objective

“to limit the probability that a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to structural failure”
Structural Safety Sub-objectives

Prevent:

• loads exceeding capacity of building element or supporting medium
• Damage/deterioration of elements
• Vibration or deflection of elements
• Instability of building or part of building
• Collapse of excavations
Four Functional Statements

F20: To support and withstand expected loads and forces

F21: To limit or accommodate dimensional change

F22: To limit movement under expected loads and forces

F23: To maintain equipment in place during structural movement
Why this change?

“Codes freeze technology”
- Prof. Paul Gavreau, U of T

Shortcoming of Division A

Designer must define, for a particular structure constructed using particular materials, “unacceptable risk”.
Hence Division B “Acceptable Solutions”

• Designs in conformance with the prescriptive requirements of Division B are deemed to have met the Objectives of Division A.

• Division B still represents “the minimum a designer is legally allowed to get away with”.
Questions?
Moving along…

• Divisions A and B of NBCC 2005
• Companion Action Load Combinations
  – Rationale
  – Quantitative
  – Serviceability
• Importance Factors for Buildings
• Changes to Specified Loads
• Loose Ends
• Summary
NBCC 1995 Format

\[ \phi R > \alpha_D D + \psi \gamma \{ \alpha_L L + \alpha_Q Q + \alpha_T T \} \]

where \( \psi \) = load combination factor

- NBCC 1995 load combinations:
  1. \( 1.25 D + 1.5 L \)
  2. \( 1.25 D + 1.5 Q \) (wind)
  3. \( 1.25 D + 0.7 \{ 1.5 L + 1.5 Q \) (wind)\}
    \[
    = 1.25 D + 1.05 L + 1.05 Q \) (wind)\]
Time History of Loading

Maximum Load, for Design

Load

Transient Live/Wind
Snow
Sustained Live
Renovation

Dead

Dead

time
Turkstra’s Rule (early ’80s)

Worst case of combined transient loads occurs when:

• one load, the principal action, is its extreme value
• other loads, the companion actions, are the largest that would be expected while the principal action has its extreme value
Companion Action Format

\[ \phi R > \alpha_D D + \alpha_i S_i + \sum \alpha_{ik} S_k, i \neq k \]

where \( S_i = \) principal action
\( S_k = \) companion actions

Typical Load Combinations:
1.25 D + 1.5 L + 0.5 W (wind)
1.25 D + 1.5 W (wind) + 0.5 L
Designer can **Envisage** Hazards

- Correlation of transient loads explicitly considered

- Can you imagine a structure where simultaneous maximum values of transient loads are:
  - unlikely?
  - expected?
Confederation Bridge: Wind + Live
1995 NBCC Reliability Indices

Reliability index (50-year)

Nominal variable load/nominal dead load

- D + W
- D + L
- D + S

• reliability for snow load deficient?
2000/2001 Failures: Sarnia Mall

Source: *Globe and Mail* 09 December 2000
Snow Finds Weaknesses

Top Chord

End Diagonal

Support Beam
Huge “Secondary” Bending

Actual load ~ specified load
NBCC 2005 Calibration Process

1. Reliability indices for 1995 NBCC

2. Preliminary load combinations for 50-yr, 500-yr loads by Bartlett, Hong & Zhou
   • review by Part 4 Task Group on Snow & Wind Loads
   • review by Part 4 Standing Committee

3. Revised load combinations, 50-yr loads
   • review by Task Group and Part 4 cttee
   • public review
Calibration: Alberta Farmer Weighs Pig (MacGregor)

Step 1:
Put pig on plank

Step 2:
Add rocks until plank level

Step 3:
Guess weight of rocks
2005 NBCC Combinations

1.4 D
1.25 D + 1.5 L + (0.4 W or 0.5 S)
1.25 D + 1.4 W + (0.5 L or 0.5 S)
1.25 D + 1.5 S + (0.5 L or 0.4 W)
0.9 D + (1.5 L or 1.4 W or 1.5 S)

Add to all combinations:

P = prestress
H = horizontal earth pressures
T = restrained deformations (safety)
Impact: Single Transient Load

Proposed/NBCC 1995

D+W

D+S

D+L

Transient-to-dead load ratio
Impact: D+L+S

Proposed/1995 NBCC

S/D = 0.25
0.5
1.0
2.0
4.0

Live-to-dead load ratio, L/D

Proposed/1995 NBCC

S/D = 0.25
0.5
1.0
2.0
4.0

0 1 2 3 4 5
Impact: D+L+W

Proposed/1995 NBCC

$W/D = 4.0$

Live-to-dead load ratio, $L/D$
Impact: D+W+S

Snow-to-dead load ratio

Proposed/1995 NBCC

W/D = 4.0
Serviceability Limit States

• Intention is not to greatly change serviceability design criteria.

• Consequence: specified snow load increases but for SLS check apply a SLS load factor of 0.9.

• Simplification: eliminate 1-in-10 yr specified wind load for SLS check but apply a SLS load factor of 0.75 to the specified (1-in-50 yr) wind load.
Table A-4 in Commentary A:

“Loads & Load Combinations for Serviceability”

Limit States: Vibration serviceability
- Operation of moving equipment
- Damage to non-structural comp.
- Damage to structural components

Give:
- Structural parameters to consider (stresses, accelerations, crack widths, deflections)
- Loads + load combinations
- References
<table>
<thead>
<tr>
<th>Category</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential</td>
<td>(D + H + \alpha_L \cdot L + \alpha_S \cdot S)</td>
</tr>
<tr>
<td>Settlement</td>
<td></td>
</tr>
<tr>
<td>Long Term</td>
<td>(D + H + T_P + P + \alpha_L \cdot L + \alpha_S \cdot S)</td>
</tr>
<tr>
<td>Deflection</td>
<td></td>
</tr>
<tr>
<td>Short Term</td>
<td>((L + \alpha_S \cdot S) \text{ or } (S + \alpha_L \cdot L))</td>
</tr>
<tr>
<td>Deflection</td>
<td>\text{ or } W \text{ or } E</td>
</tr>
</tbody>
</table>
Drainage

Water runs down surface

Water drips away from surface
Questions?

- Far Side
  G. Larsen
Moving along…

- Divisions A and B of NBCC 2005
- Companion Action Load Combinations
- Importance Factors for Buildings
- Changes to Specified Loads
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Table 4.1.2.1 “Importance Categories for Buildings”

**Low:** low direct or indirect hazard to human life.

**Normal:** the kitchen-sink category.

**High:** likely to be used as post-disaster shelters or contain hazardous substances.

**Post-Disaster:** essential to the provision of services after a disaster.
### Importance Factors for S, W

<table>
<thead>
<tr>
<th>Importance Category</th>
<th>Ultimate (Snow or Wind)</th>
<th>Serviceability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Snow</td>
</tr>
<tr>
<td>Low</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Normal</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>Post Disaster</td>
<td>1.25</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Questions?

“Notice all the computations, theoretical scribblings, and lab equipment, Norm. ... Yes, curiosity killed these cats.”
Moving along…

- Divisions A and B of NBCC 2005
- Companion Action Load Combinations
- Importance Factors for Buildings
- Changes to Specified Loads
  - Uncouple L from S
  - 50 year return periods for W, S
- Loose Ends
- Summary
Uncoupling Snow & Live

• Logical consequence of considering Live and Snow as independent.

• Similar format adopted in ASCE-7 based on load combinations derived in 1980.

• **Consequence:** Members resisting low D, high L (use + occupancy), high S require less resistance.
Is there a structure down there?

Clearing Trans Canada Highway in Newfoundland (G. Jin, photo)
Live Loads on Roofs

- Table 4.1.5.3 specifies 1.0 kPa
- Table 4.1.5.10 specifies 1.3 kN

Commentary G “Snow Loads” paragraph 51 states:

“These are use and occupancy loads, intended to provide for maintenance loadings, workmen, and so forth.”

“They are **not** reduced as a function of area or roof slope”
Return Period for Environmental Loads

• NBCC 1995 specified:
  – 30 years for specified Snow, Wind
  – 10 years for Wind for deflections
  – 100 years for wind on Important Structures

• Use 50 year or 500 year return periods (only) for 2005 NBCC?

• Ratio n-yr/30-yr depends coefficient of variation of annual maximum load
Wind Speed Data

COV of Maximum Annual Wind Velocity

Longitude Difference (deg) from Alaska/Yukon Boundary

+ all data

>10 yrs data
Specified Load Return Period

- 1-in-500
- 1-in-100
- 1-in-50
- 1-in-10

90% of values in this range

COV of Maximum Annual Wind Velocity

90% of values in this range
50-yr Wind & Snow Specified

• typically ~10% greater than 30-yr values

• snow load factor initially 1.7, implies a 25% increase in factored load, deemed too big.

• factored wind load unchanged, factored snow slightly greater

• reduce for SLS checks
”Ha ha ha, Biff. Guess what? After we go to the drugstore and the post office, I’m going to the vet’s to get tutored.”
Moving along…

- Divisions A and B of NBCC 2005
- Companion Action Load Combinations
- Importance Factors for Buildings
- Changes to Specified Loads
- Loose Ends
  - Dead load factors
  - Rain and ponding
  - Other examples
- Summary
Proposed 1.2 D criticized

- **History:** 1.3 proposed for 1975 NBCC. Reduced to 1.25 to maintain same ratio of dead/live load factor as in ACI 318-71.
- Proposed 1.2 D + 1.6 L not accepted
- Specific concerns:
  - floor thickness variability
  - dead load of soil & landscaping
  - tributary area computation
2000 Survey: Concrete Floor Thickness

• Marked variability for
  – Cast-in-place toppings on precast
  – Cover slabs in unshored composite construction (tolerances?)

• “Uncertain D” with load factor of 1.5 not adopted

• Make allowances for extra dead load

• Consider deflections of supporting members
Tributary Areas in NBCC

Commentary Fig F-1:
lines of zero shear halfway between column lines

- Safe for corners
- Unsafe for 1\textsuperscript{st} interior columns

Para 6: “For continuous construction, structural analysis is required to find the lines of zero shear.”
Rain Loads and Ponding

• Flat roofs deflect, intensifying load in worst place

• Essential design consideration for Calgary and southern Alberta

• NBCC Commentary H gives guidance
  – One-day rain load?
  – Residual stresses?
  – Multiple-span cases?

• Western M.E.Sc. thesis by Praught
Regions where 1-day rain exceeds snow load on flat roof

- Calgary (103%)
- Port Hardy (131%)
- Tofino (147%)
- Ucluelet (132%)
- Leamington (107%)
1-d rain and 24-hr rain

- 1-d rain recorded 12:00 to 12:00
- 24-hr rain in any 24-hr period

- 24-hr rain/1-d rain $\sim 1.23$
Regions where 24-hour rain exceeds snow load

- Similar to Nixon’s (1979) “Ponding Map of Canada”
NBCC ignores residual stresses

Moment

Curvature

Initial EI

Secant EI at given M

Underestimates ponding deflections
Animation by Schouten Engineering Consultants, NL
Stepwise Analysis

1. Load joists
2. Calculate joist deflections, reactions
3. Apply reactions to beams
4. Calculate beam moments, deflections
5. Calculate total deflected shape
6. Do deflections converge?
   NO: recompute load and repeat analysis
   YES: stop, check capacities not exceeded
Gerber Beam Example Calculation

• Joists at 1.5m span 10.5m between beams
• W530x66 cantilever/anchor beam
• W460x52 drop-in beam
• Design for Calgary snow load, check for 1-day (not 24-hr, not factored) rain
Deflected shape after 1st iteration
Beam Moments

Final (after 6\textsuperscript{th} iteration)

+26%

-20%

-26%

Volume of water on drop-in & cantilever spans reduces 46%
Deflections

\[ C_L \text{ sym} \]
Questions?
1. Composite prestressed concrete members will have stress limits based on dead, live and environmental loads. In the past I have used working stress load combinations to verify the stresses. How is this handled now?
2. Why use different load factors for wind loads than for occupancy loads? This does not follow the ISO standards recommendations and does not follow the trend being followed in Europe (EuroCode 1990) and the US (ASCE-7-02 LRFD).
3. In the US, ASCE-7-05 uses a return period of 50 years but the $C_b$ set at 0.70 versus 0.80 in the National Building Code of Canada. Why are we increasing the snow load relative to the US?
A Loaded Question?

4. What loads are temporary structures to be designed for in the new building code? Are the structures to be designed for the same likelihood of failure in an annual period or are they to be designed for the same likelihood of failure over the service life of the structure?
Questions?
Summary

1. Companion action load combination format proposed for NBCC 2005:
   • more realistic representation
   • permits logical decisions for unusual cases
   • little difference for many members
   • consistent with other international standards (ACI 318, AISC LRFD, etc.)
2. Dead loads:
   • make allowance for extra thickness of thin toppings
   • tributary areas for first interior columns

3. Snow loads are no longer classified with live loads due to use and occupancy.
   • less resistance needed for members carrying snow and live loads
4. Only 50-year environmental loads specified:
   • increases specified loads by ~ 10%
   • additional increases for important and post-disaster buildings
   • load factors less than 1.0 reduce specified loads for serviceability checks.

5. New load combinations give similar demands to NBCC 1995:
   • less demand due to snow & live loads
   • more demand due to snow only
6. Watch out for ponding of rainwater on flat roofs:
   • 24-hr rain $\approx 1.23 \times$ 1-day rain
   • residual stresses reduce stiffness
   • multi-span members can share water between spans

7. The National Building Code remains a minimum standard:
   • consult with owner to confirm what really is necessary
“More than ever before, the challenge to the profession is to develop designers who have sufficient intuition to stand up to, and reject or modify, the results of a computer-aided analysis or design.”

--- J. G. MacGregor, Professor Emeritus, University of Alberta
Additional References

- More information: f.m.bartlett@uwo.ca
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