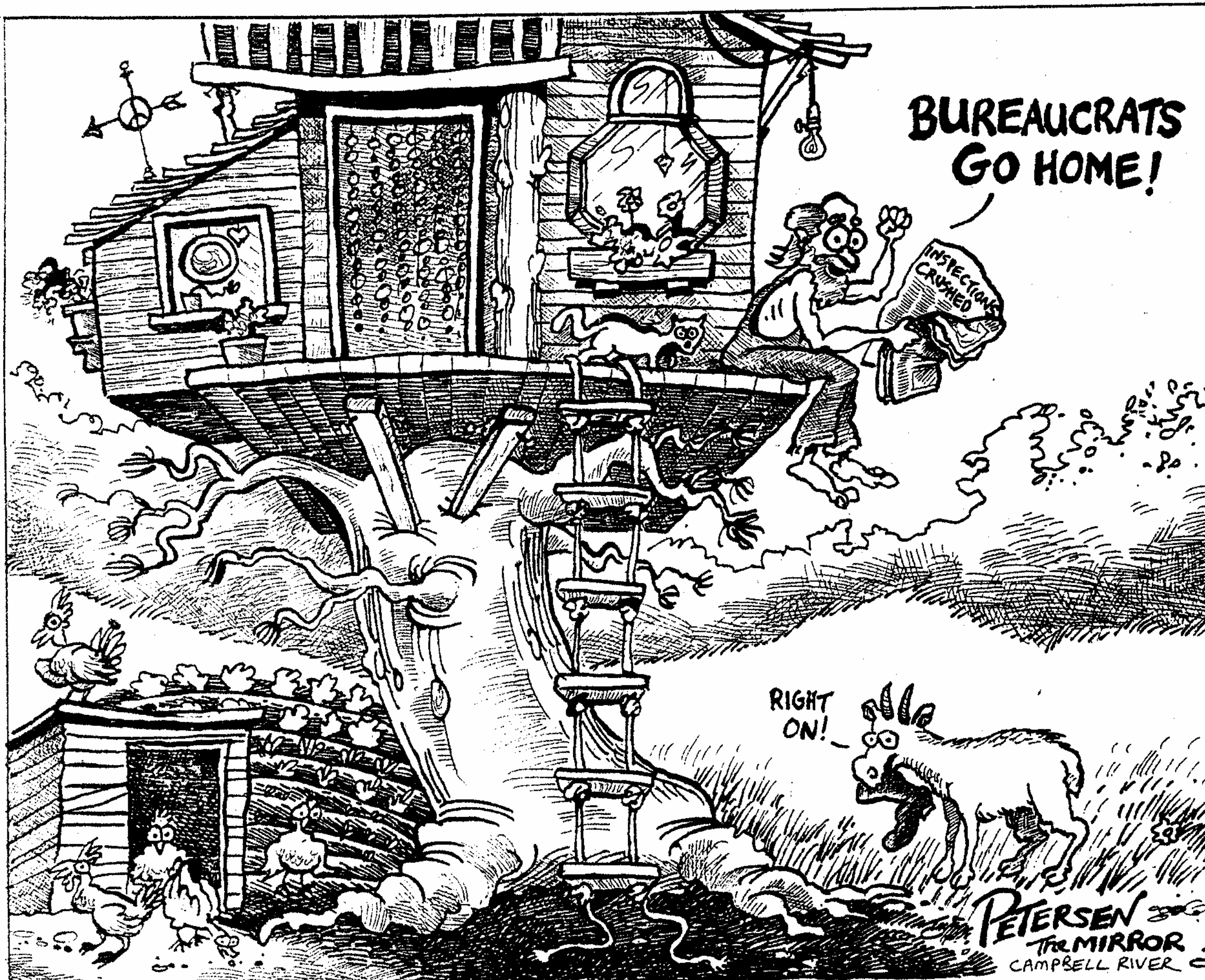

NEWS ITEM: QUADRA ISLANDERS VOTE 727–23 AGAINST BUILDING INSPECTIONS.

The new NBCC: Companion Loads, Wind/Snow Loading and Seismic

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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”*

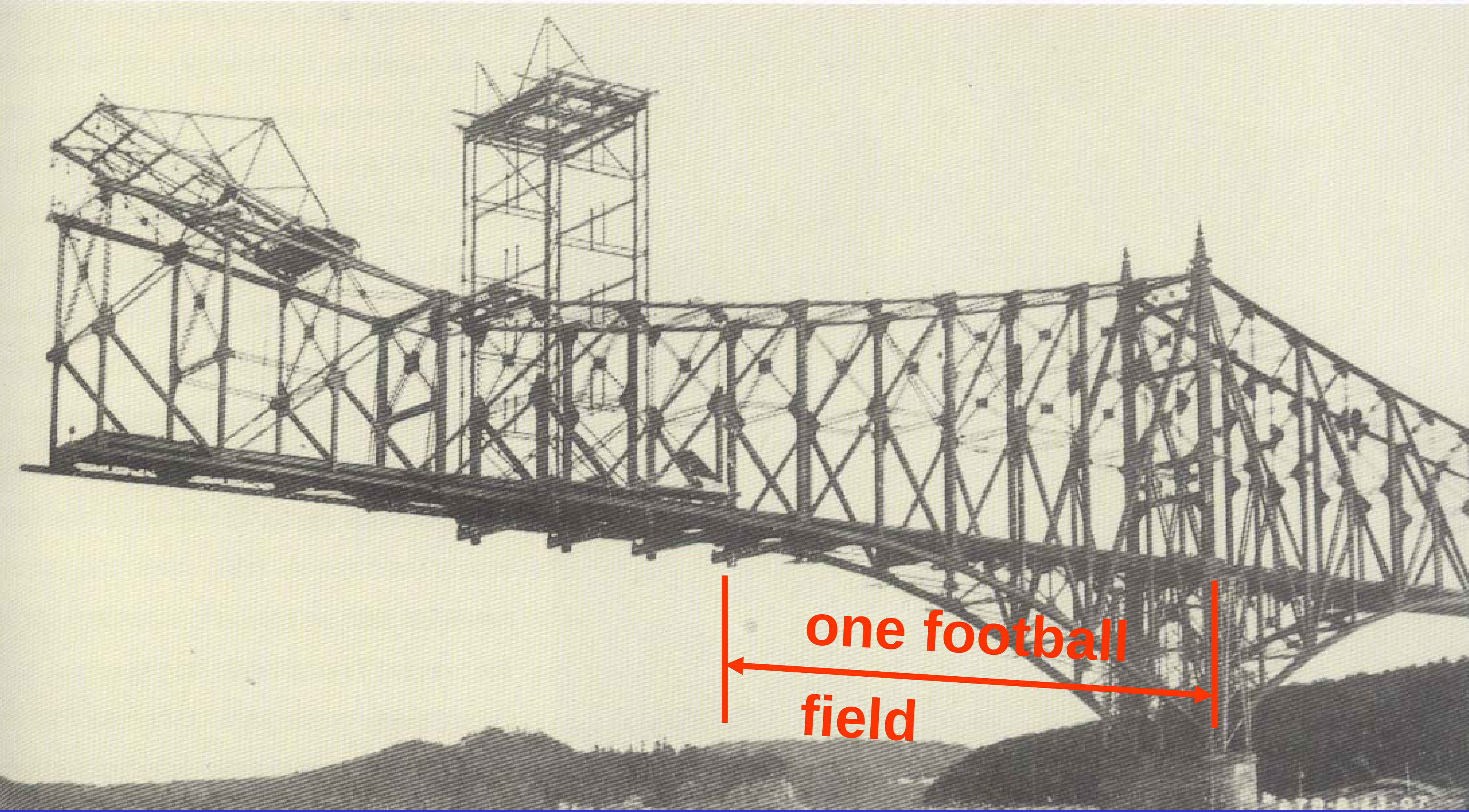
- This is equivalent to 72 days pay for a 44 m^2 house
  - (White Gergely & Sexsmith, 1972)

- say $40/s.f.

A Performance Code

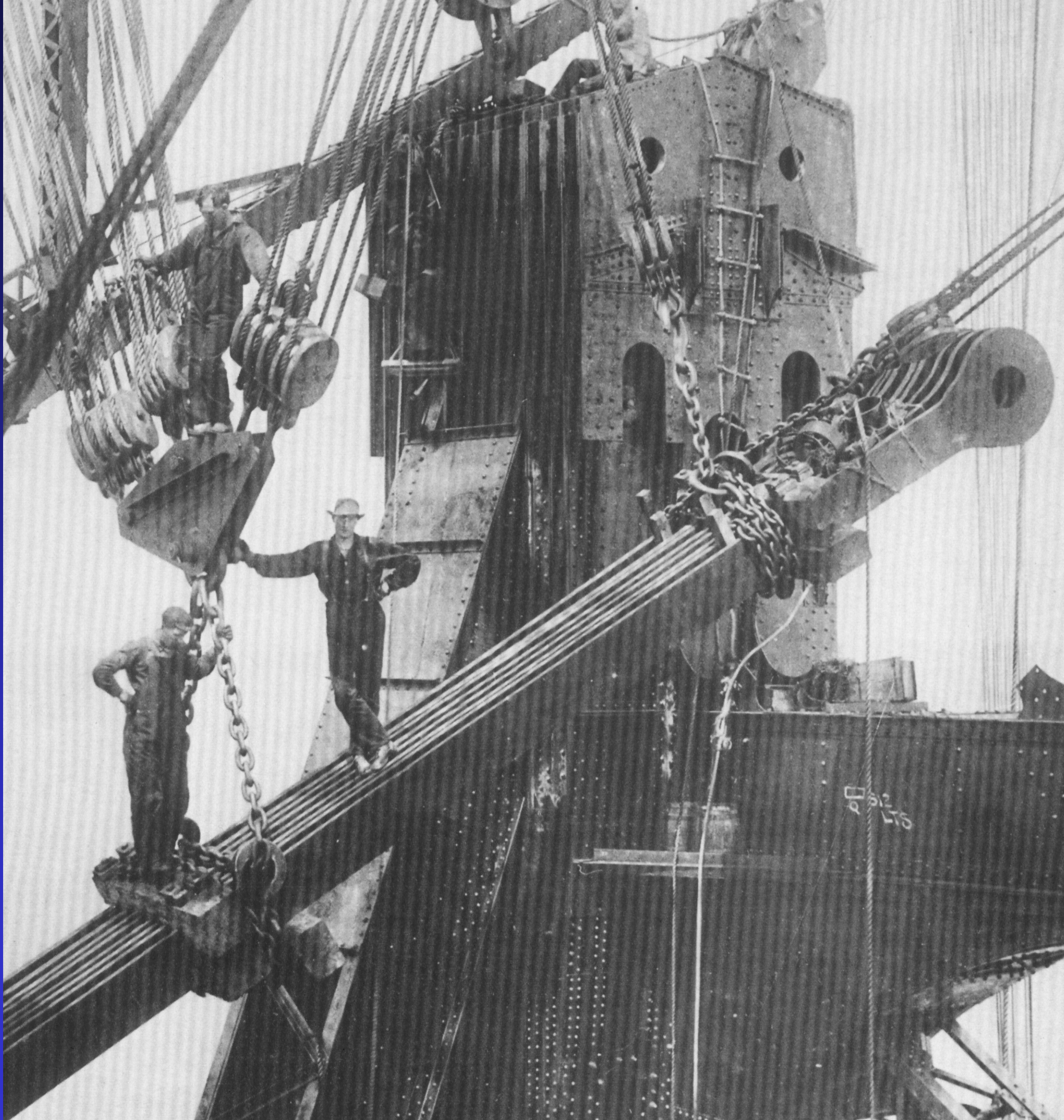
- ***"If a builder has made a house for a man and has not made his work sound, and the house which he had built has fallen down and so caused the death of the householder, that builder shall be put to death."***
- ***"if it causes the death of the householder's son, they shall put that builder's son to death"***
- ***"if the wall bulges, that builder shall put that wall into sound condition from his own silver"***

Canadian Code Development

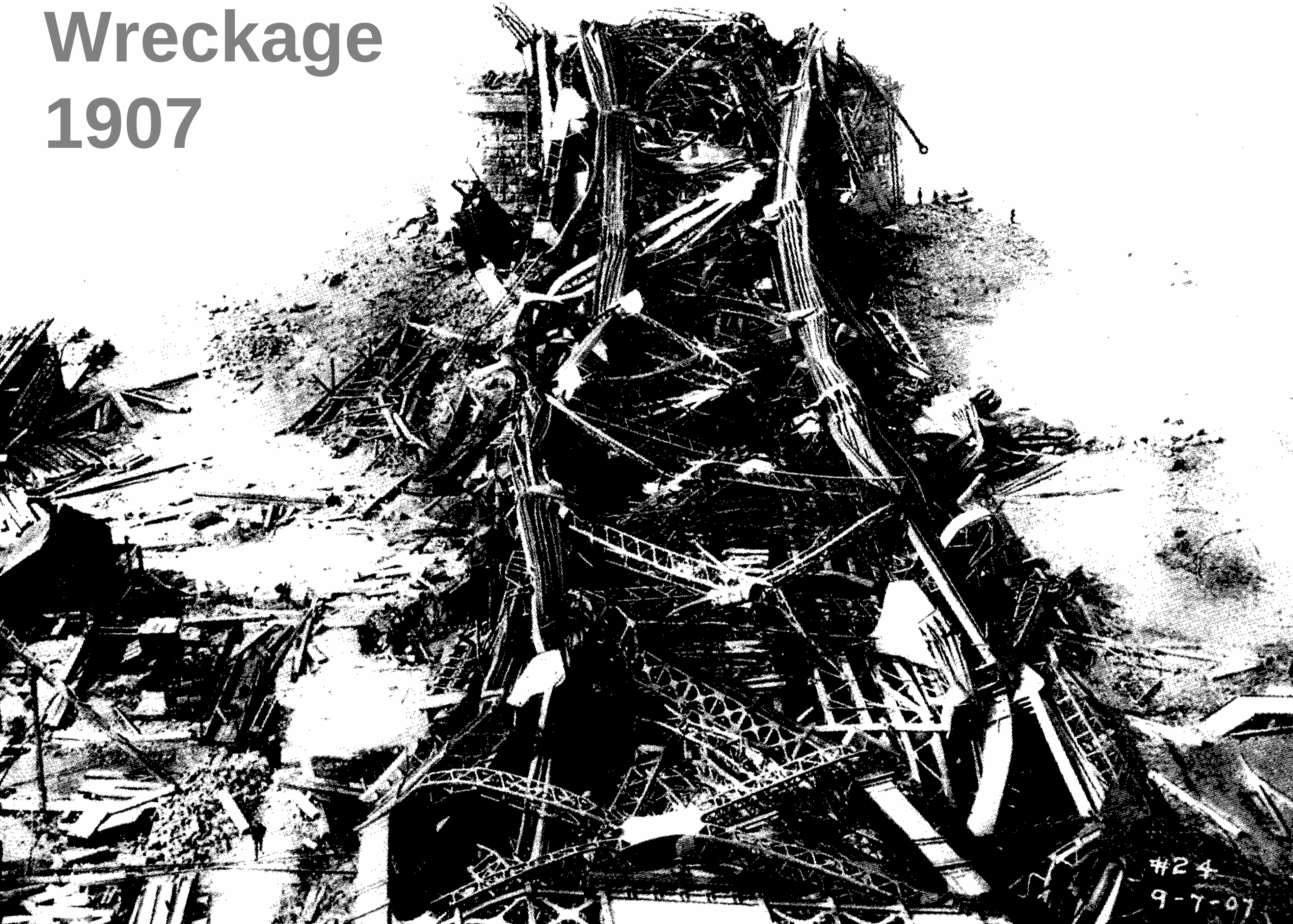


Quebec Bridge: Canada's longest cantilever

Quebec Bridge Workers, 1906

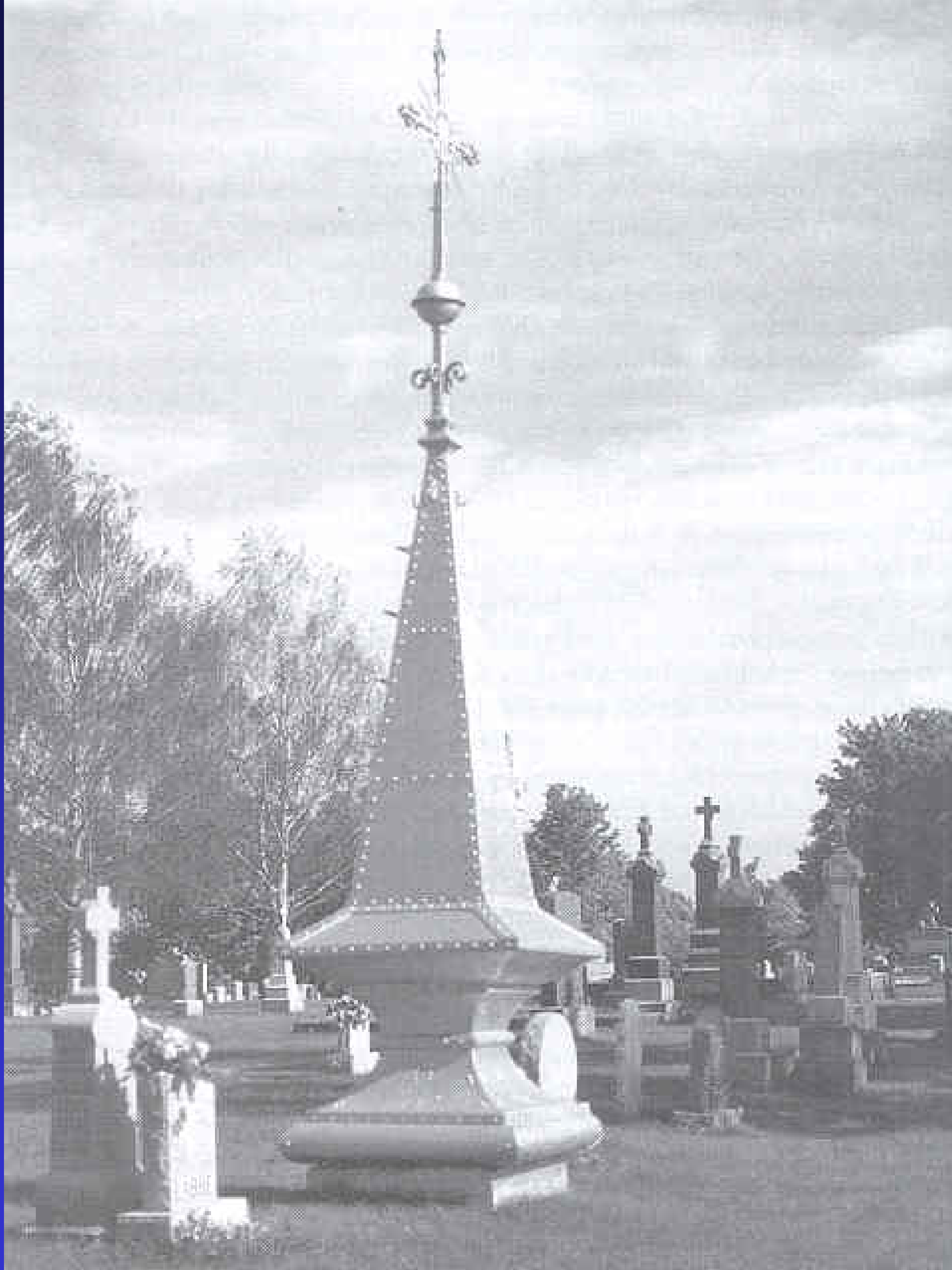


Wreckage 1907

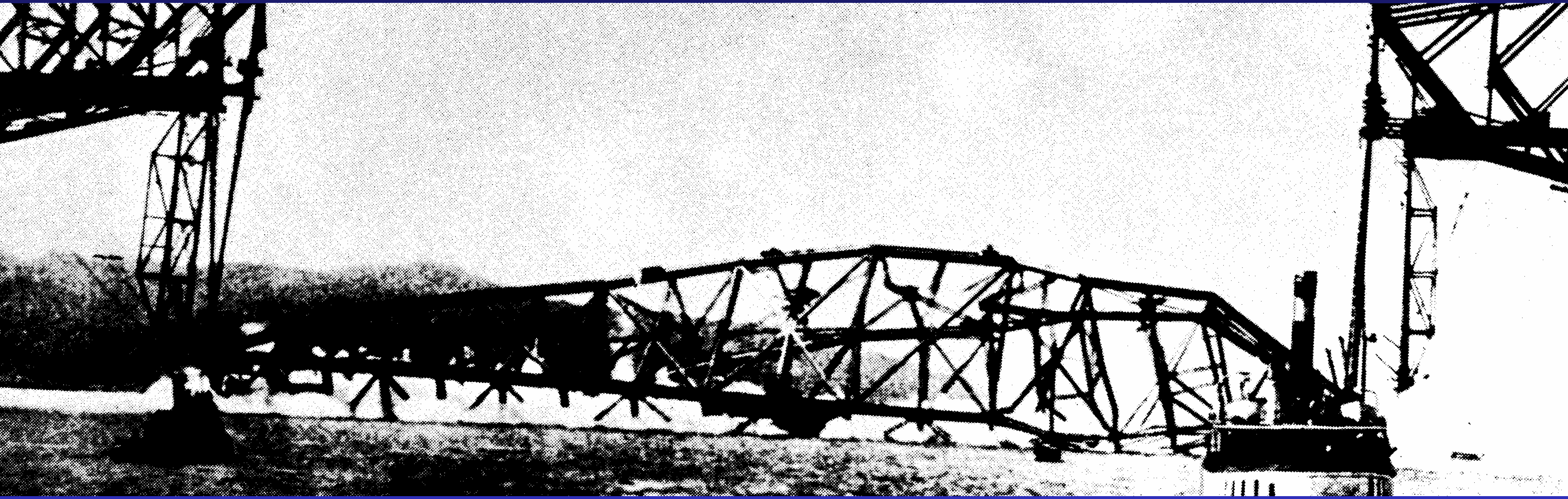


Finial as Grave Marker in St-Romuald Cemetary

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

ELASTIC ANALYSIS
Beam Selection Tables

G40.21 – 44W, 44T
$\phi = 0.90$

Shape	Properties						M_r' (Ft.-Kips)	
							Unbraced Length in Feet	
	J	C_w	L_u	V_r	I_x	M_r		
	In.^{4}	In.^{6}	Feet	Kips	In.^{4}	Ft.-Kips	16	18
WWF(M)47X326	60.1	1390000	27.4	602	40200	6138	....	....
WWF(M)43X307	58.6	1160000	28.0	461	32700	5445	....	....
WWF(M)47X270	27.5	1060000	26.0	602	32000	4950	....	....
WWF(M)39X300	58.4	954000	28.6	461	26600	4851	....	....
WWF(M)43X260	36.6	769000	24.7	461	27000	4488	....	....
WWF(M)47X244	21.3	745000	23.2	602	28000	4356	....	....
WWF(M)35X279	57.3	765000	29.6	284	20800	4191	....	....
WWF(M)39X253	36.4	631000	25.1	461	21900	4026	....	....
WWF(M)43X225	19.9	623000	23.8	461	22600	3795	....	....
WWF(M)35X233	35.2	507000	26.0	284	17000	3432	....	....
WWF(M)47X203	13.8	343000	17.6	602	21600	3432	....	3410
WWF(M)39X217	19.7	513000	24.2	461	18300	3366	....	....
WWF(M)43X195	16.4	320000	18.6	461	18700	3184	....	....
WWF(M)31X223	34.9	397000	26.8	235	13100	2963	....	....
WWF(M)35X197	18.5	413000	25.1	284	14200	2854	....	....
WWF(M)47X176	11.3	145000	12.6	602	17400	2841	2592	2423
WWF(M)39X188	16.1	263000	18.9	461	15100	2821	....	....
WWF(M)43X171	9.14	254000	17.8	461	15700	2696	....	2689
WWF(M)31X187	18.2	323000	25.7	235	10900	2455	....	....
WWF(M)39X163	8.92	209000	18.2	461	12600	2376	....	....
WWF(M)35X167	15.0	212000	19.7	284	11600	2363	....	....
WWF(M)43X147	7.44	107000	12.8	461	12600	2218	2036	1907
WWF(M)31X157	14.7	166000	20.3	235	8880	2020	....	....
WWF(M)35X142	7.73	168000	19.0	284	9580	1960	....	....
WWF(M)39X134	5.95	80800	12.8	461	9460	1835	1687	1581
WWF(M)35X128	8.42	80400	14.1	284	8290	1723	1653	1573
WWF(M)28X149	14.4	126000	20.9	190	6580	1703	....	....
WWF(M)31X133	7.43	132000	19.5	235	7300	1666	....	....
WWF(M)28X136	10.4	113000	20.5	190	6000	1551	....	....
WWF(M)35X113	4.76	65100	13.6	284	7030	1472	1389	1313
WWF(M)28X124	7.20	100000	20.1	190	5400	1396	....	....
WWF(M)31X109	5.72	55800	14.2	235	5700	1323	1274	1213
WWF(M)31X103	4.45	50900	14.0	235	5300	1234	1180	1120
WWF(M)28X110	7.89	47700	15.0	190	4630	1211	1189	1142
#W24X120	8.27	37400	15.0	353	3650	1115	1095	1053
WWF(M)28X101	5.50	42400	14.7	190	4180	1096	1068	1022

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 ψ = load combination factor

- NBCC 1995 load combinations:

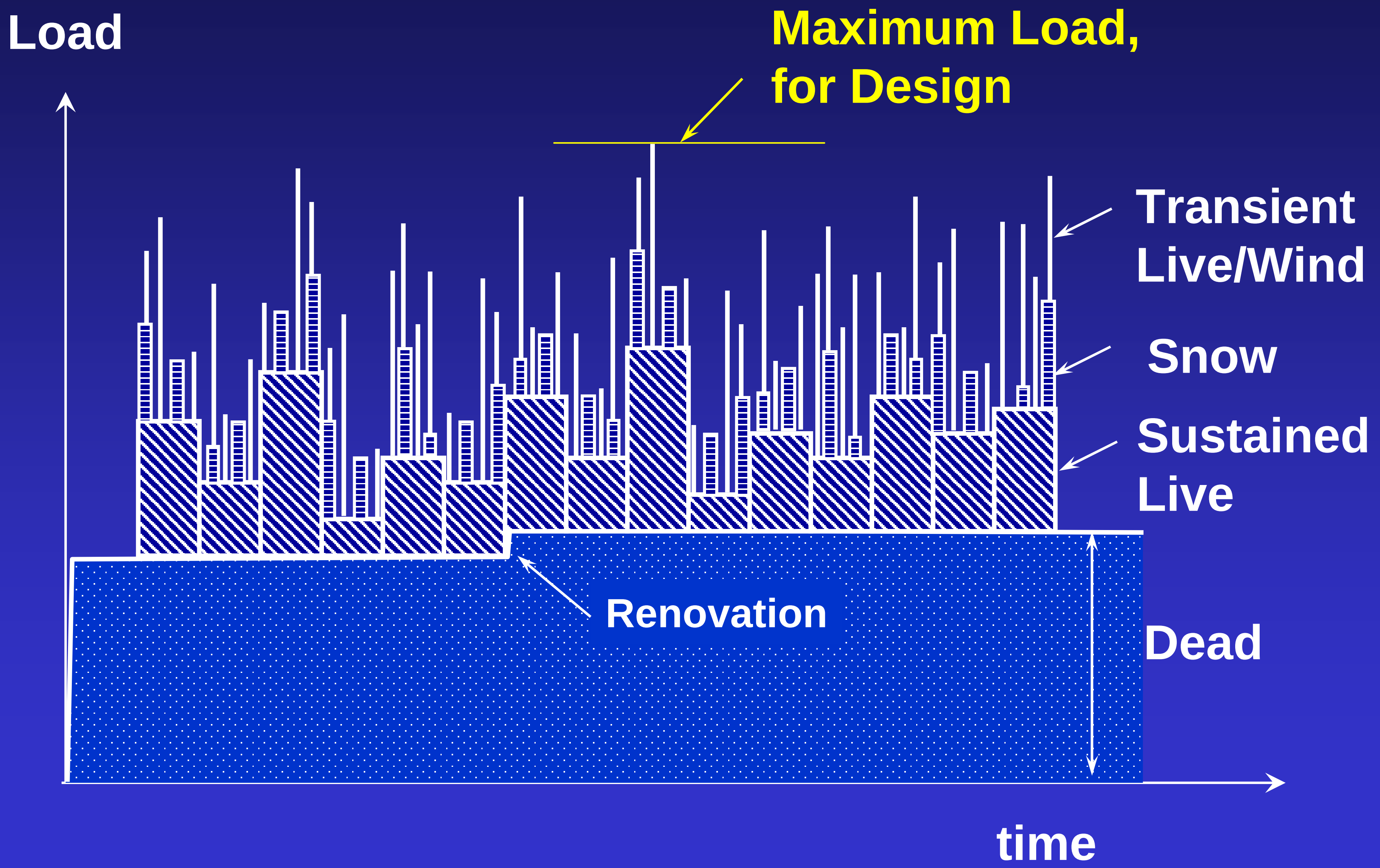
  1.25 D + 1.5 L

  1.25 D + 1.5 Q (wind)

  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



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

$\phi R > \alpha_D D + \alpha_i S_i + \Sigma \alpha_{ik} S_k$, $i \neq k$

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

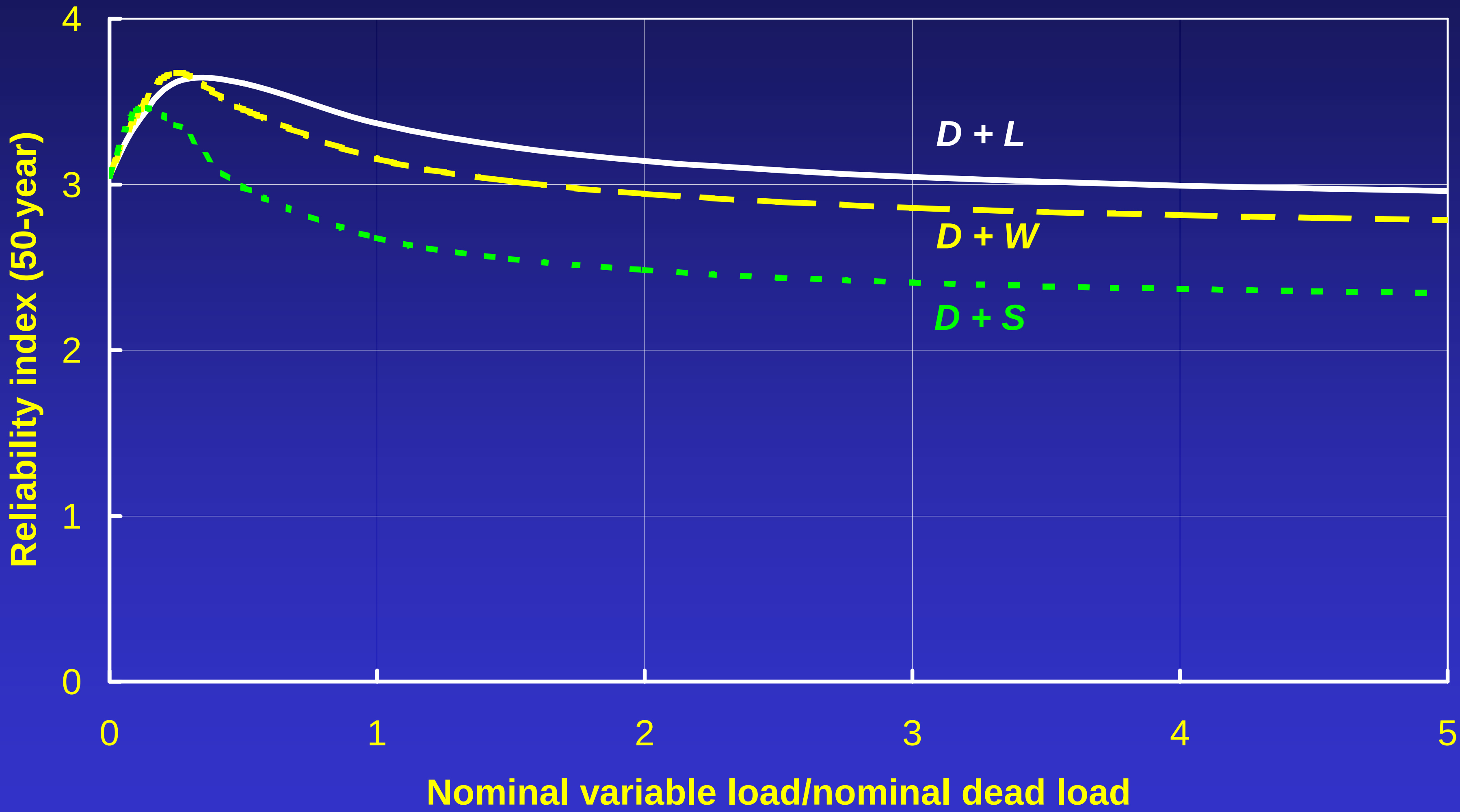
- Correlation of transient loads explicitly considered

- Can you imagine a structure where simultaneous maximum values of transient loads are:
  - unlikely?
  - expected?

Confederation Bridge: Wind + Live

Confederation Bridge: Wind + Ice

1995 NBCC Reliability Indices



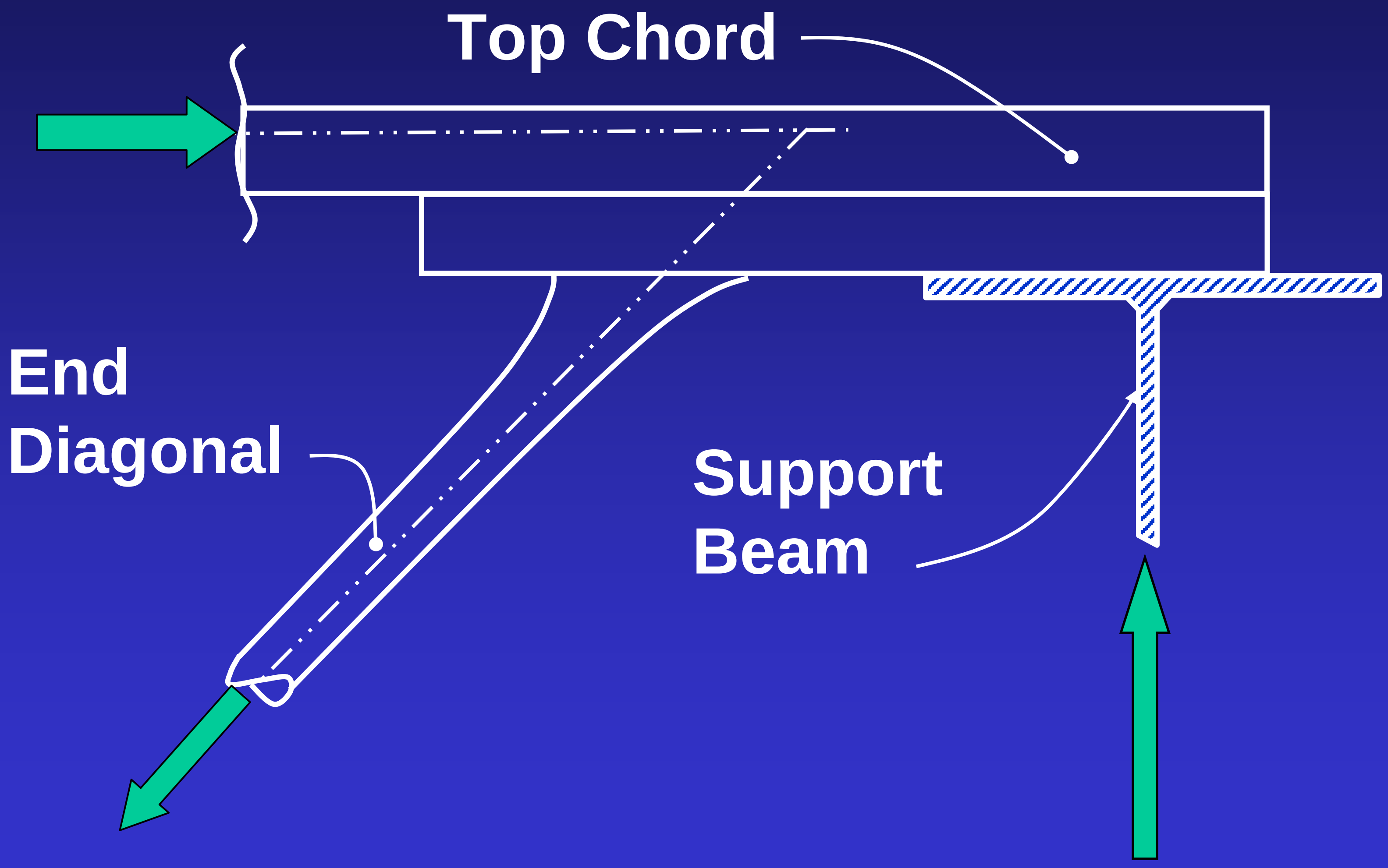
- reliability for snow load deficient?

2000/2001 Failures: Sarnia Mall

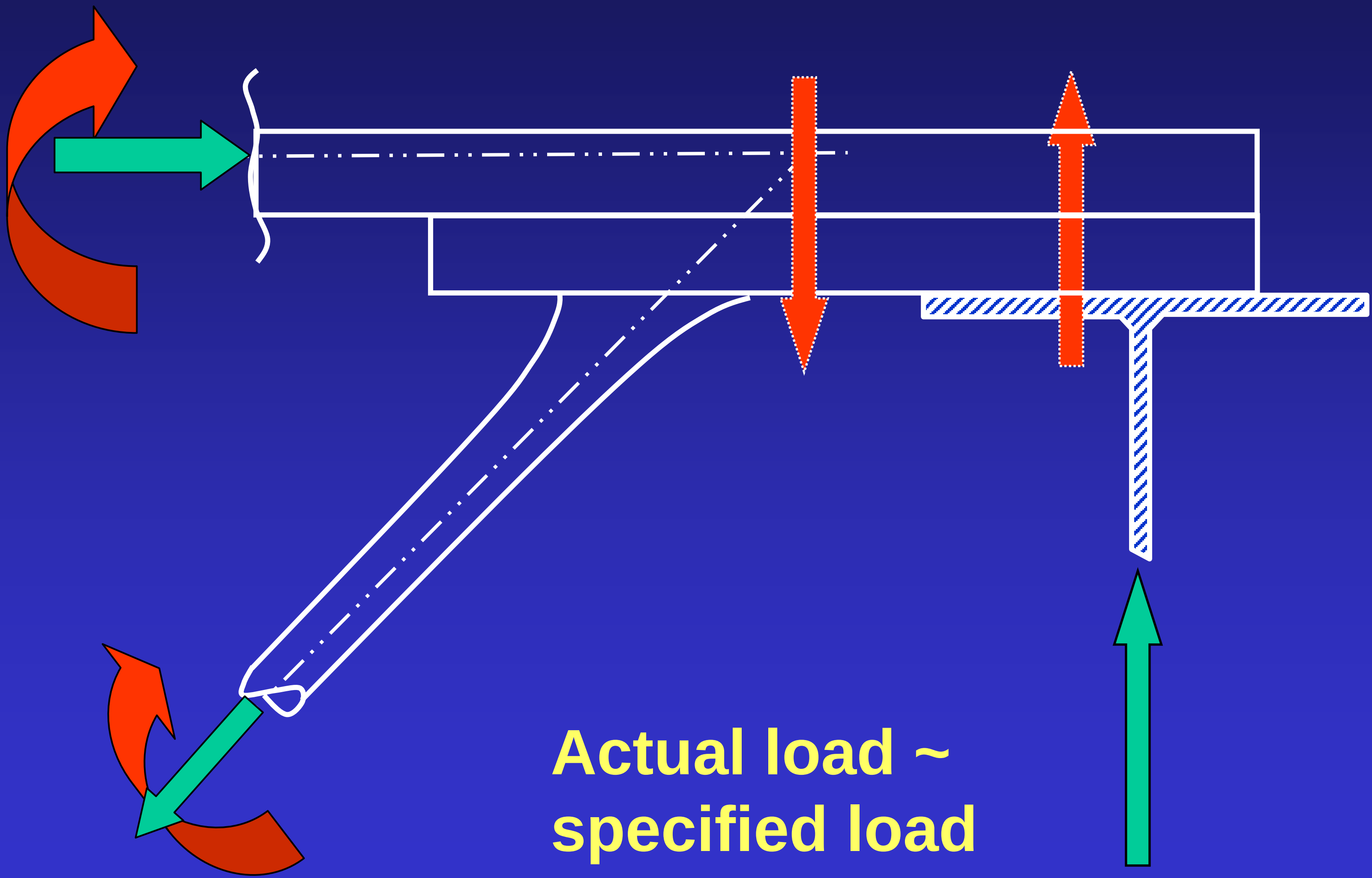
Collapse

Source: ***Globe and Mail*** **09 December 2000**

Snow Finds Weaknesses



Huge "Secondary" Bending



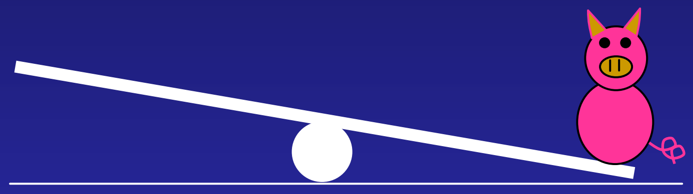
Actual load ~
specified load

NBCC 2005 Calibration Process

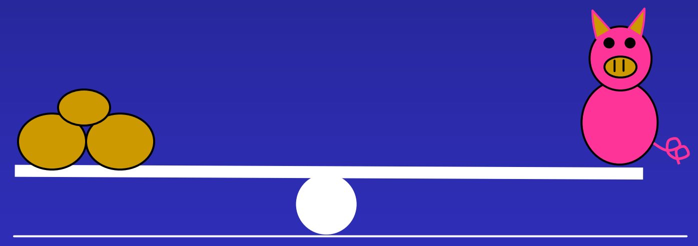
1. Reliability indices for 1995 NBCC
2. Preliminary load combinations for 50-yr, 500-yr loads by Bartlett, Hong & Zhou
   - review by Part 4 Task Group on Snow & Wind Loads
   - review by Part 4 Standing Committee
3. Revised load combinations, 50-yr loads
   - review by Task Group and Part 4 cttee
   - 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)

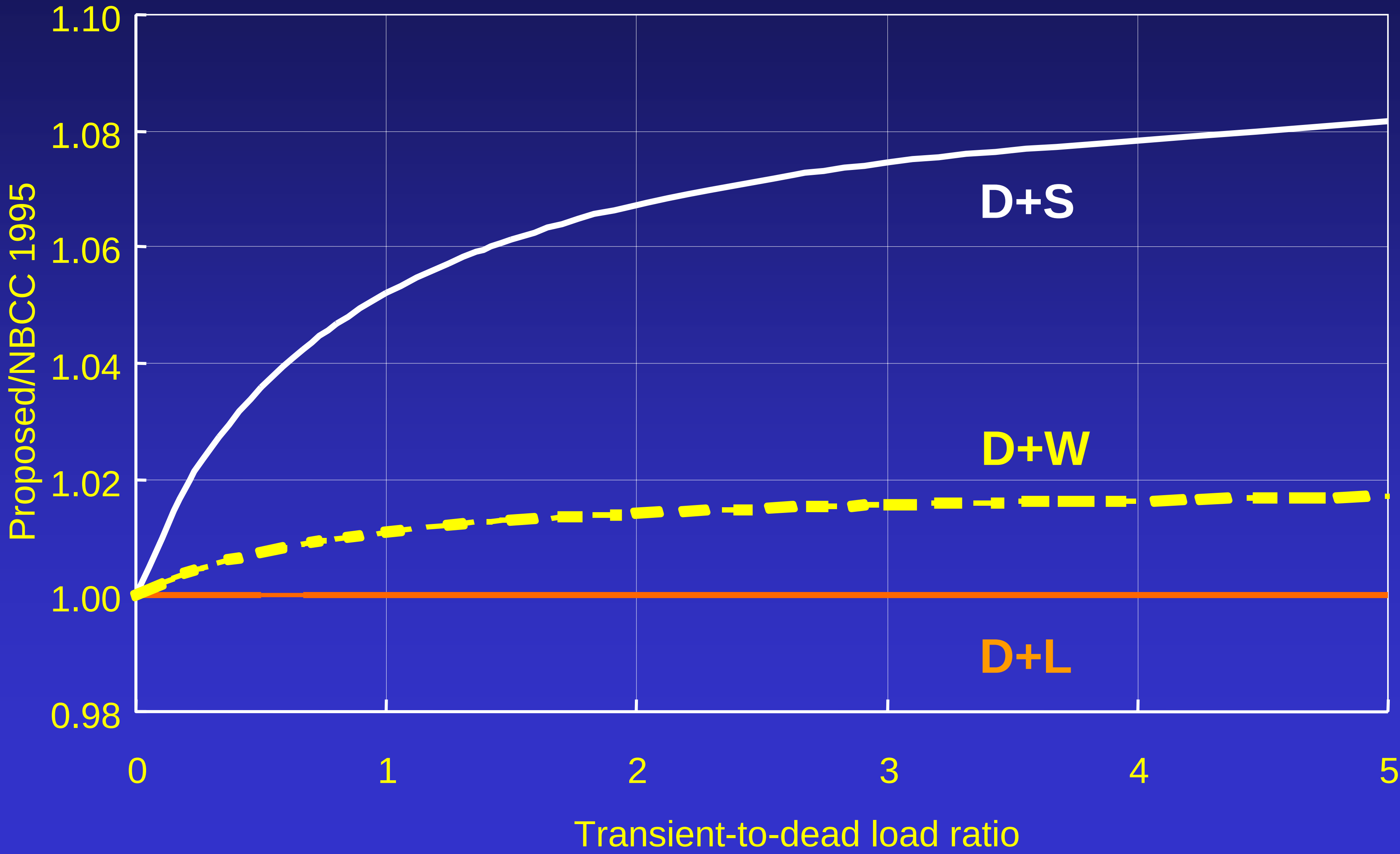
Add to all combinations:

P = prestress

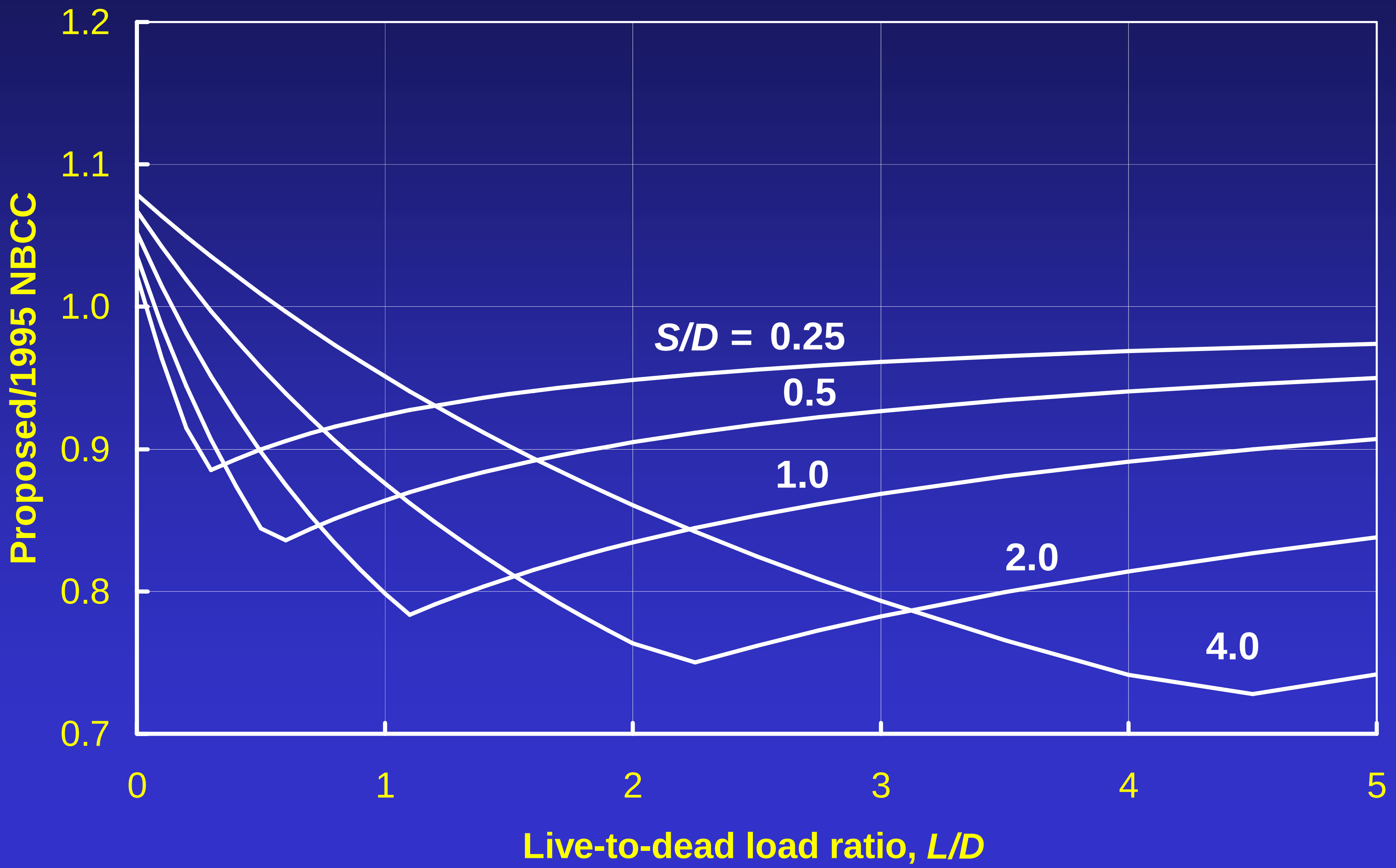
H = horizontal earth pressures

T = restrained deformations (safety)

Impact: Single Transient Load

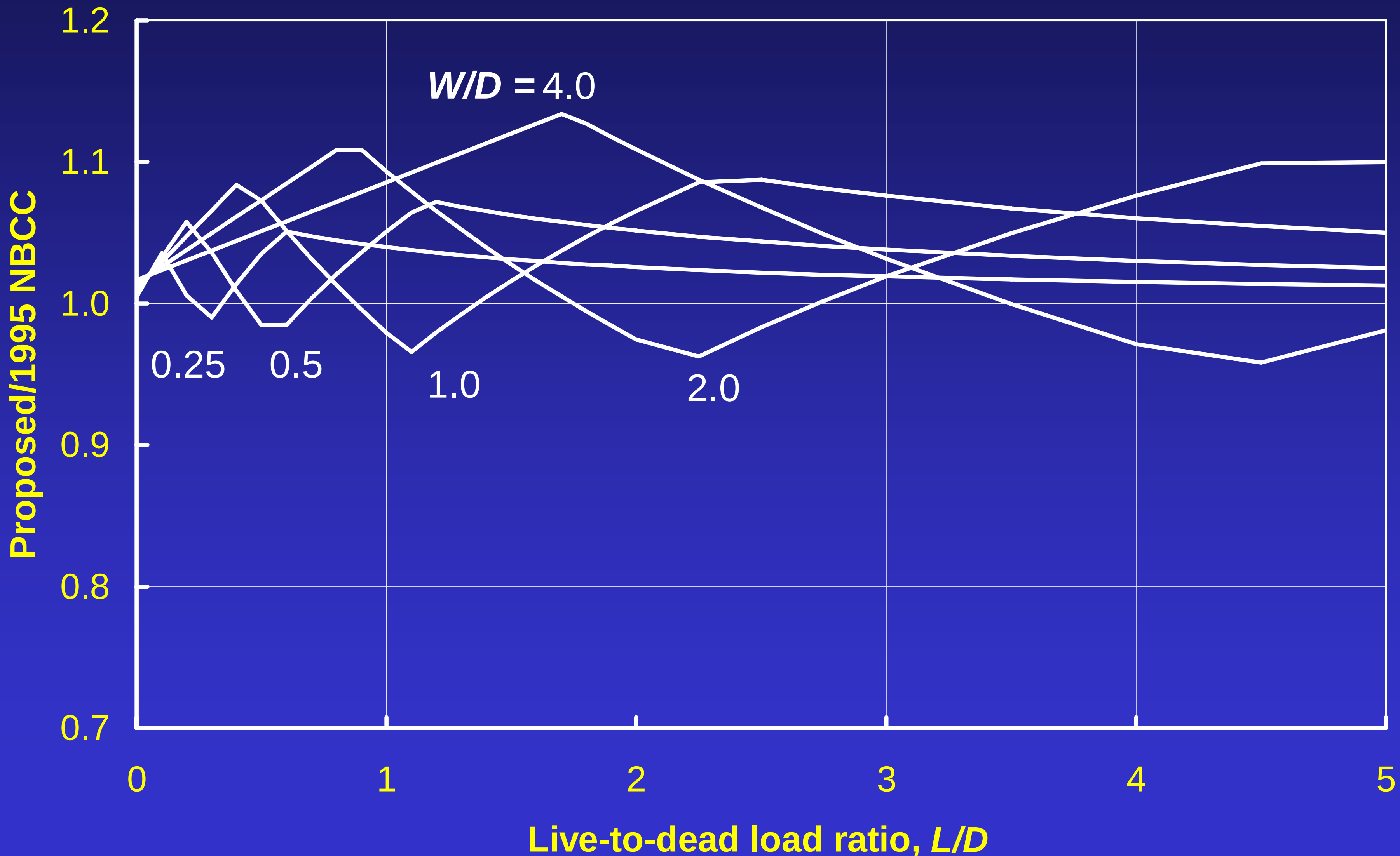


Impact: D+L+S



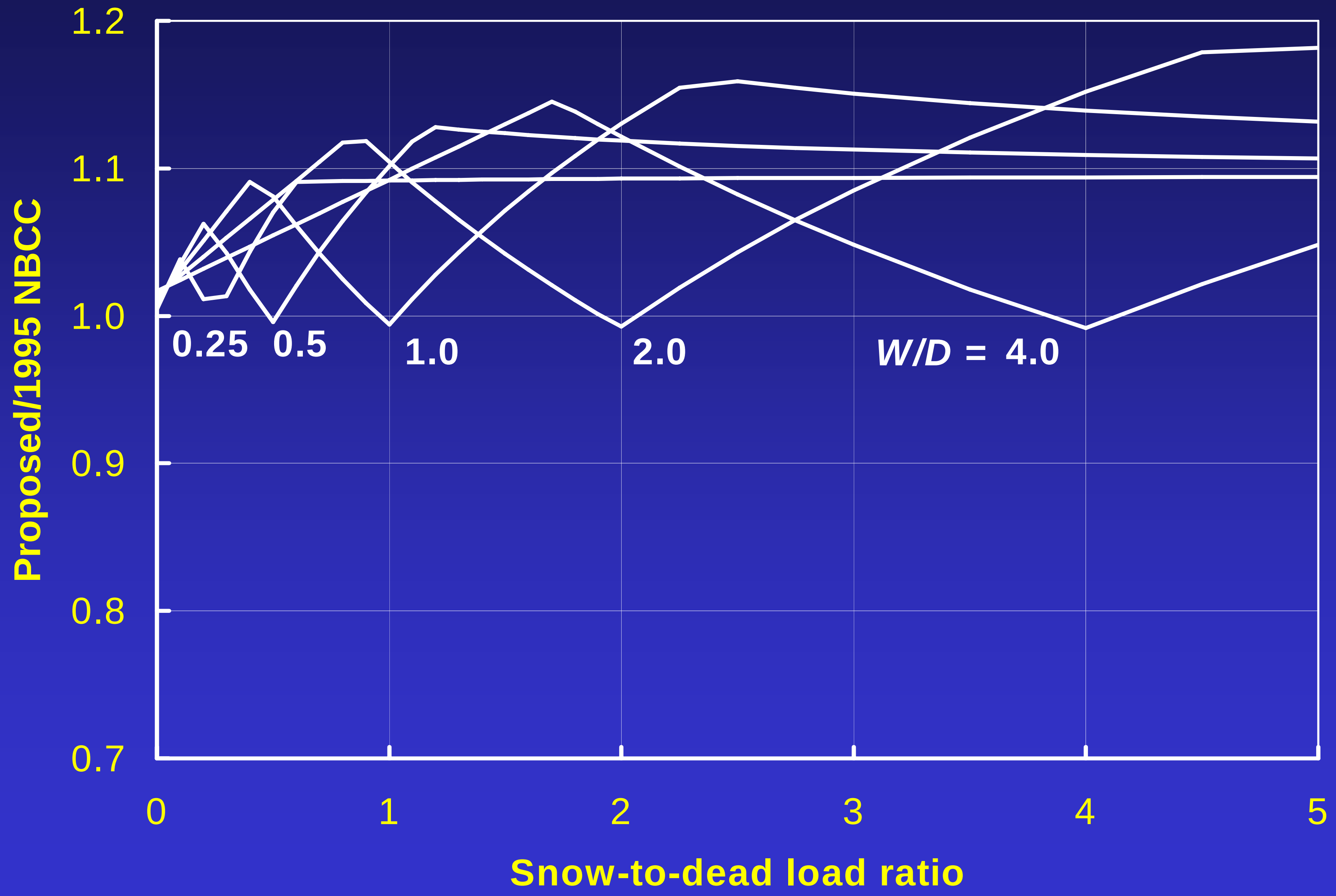
1.2
1.1
1.0
0.9
0.8
0.7
Proposed/1995 NBCC
S/D = 0.25
0.5
1.0
2.0
4.0
0
1
2
3
4
5
Live-to-dead load ratio, *L/D*

Impact: D+L+W



1.2
1.1
1.0
0.9
0.8
0.7
Proposed/1995 NBCC
W/D = 4.0
0.25
0.5
1.0
2.0
0
1
2
3
4
5
Live-to-dead load ratio, L/D

Impact: D+W+S


1.2
1.1
1.0
0.9
0.8
0.7
Proposed/1995 NBCC
0.25
0.5
1.0
2.0
W/D = 4.0
0
1
2
3
4
5
Snow-to-dead load ratio

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:

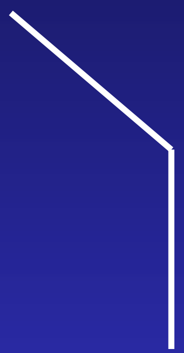
- Structural parameters to consider (stresses, accelerations, crack widths, deflections)
- Loads + load combinations
- References

Table A-5 in Commentary A

"Load Combinations for Deflection Limit States"

Differential Settlement	$D + H + \alpha_L L + \alpha_S S$
Long Term Deflection	$D + H + T_P + P + \alpha_L L + \alpha_S S$
Short Term Deflection	$(L + \alpha_S S)$ *or* $(S + \alpha_L L)$ *or* W *or* E

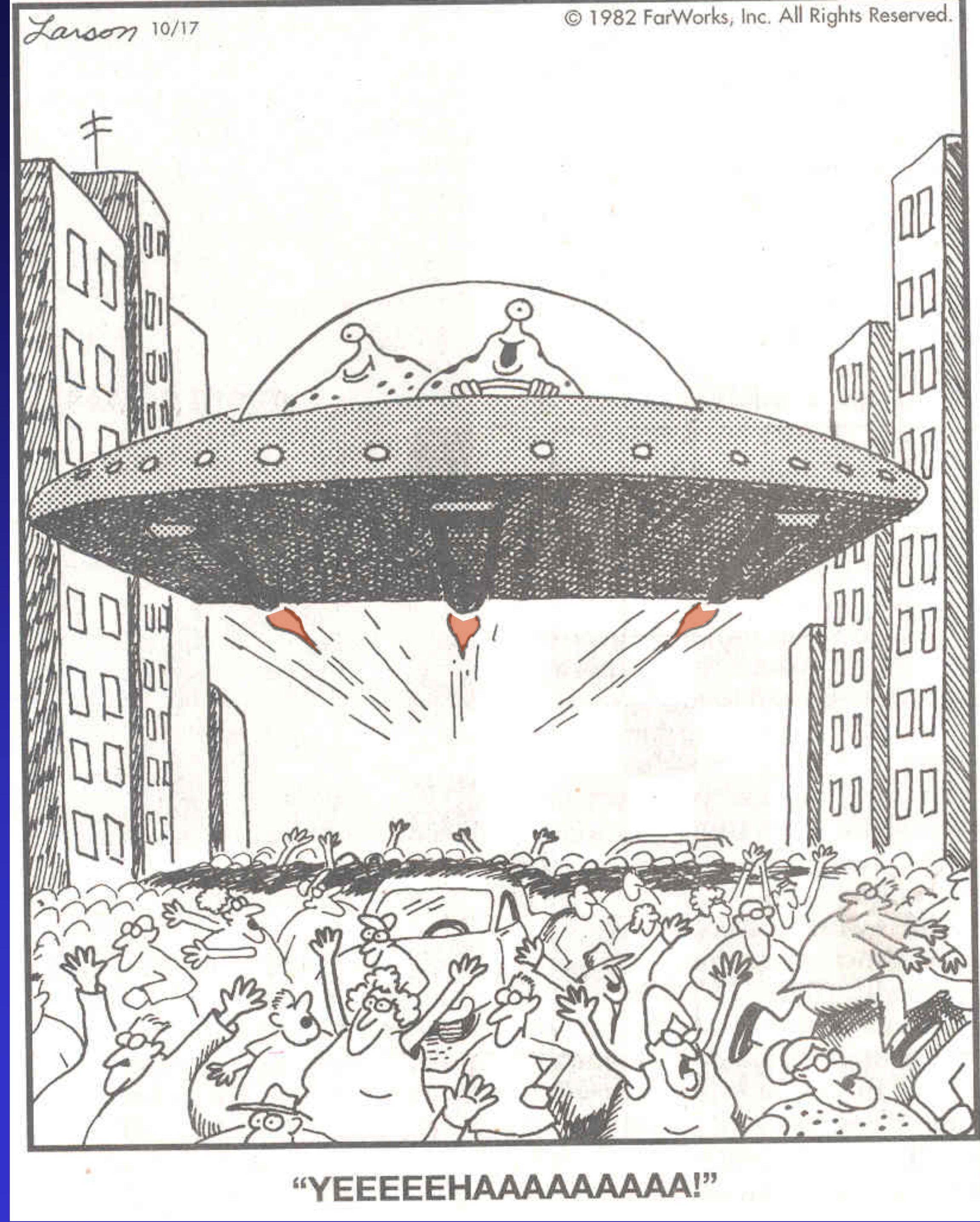
Drainage



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
- Loose Ends
- Summary

Table 4.1.2.1 “Importance Categories for Buildings”

Low: low direct or indirect hazard to human life.

Normal: the kitchen-sink category.

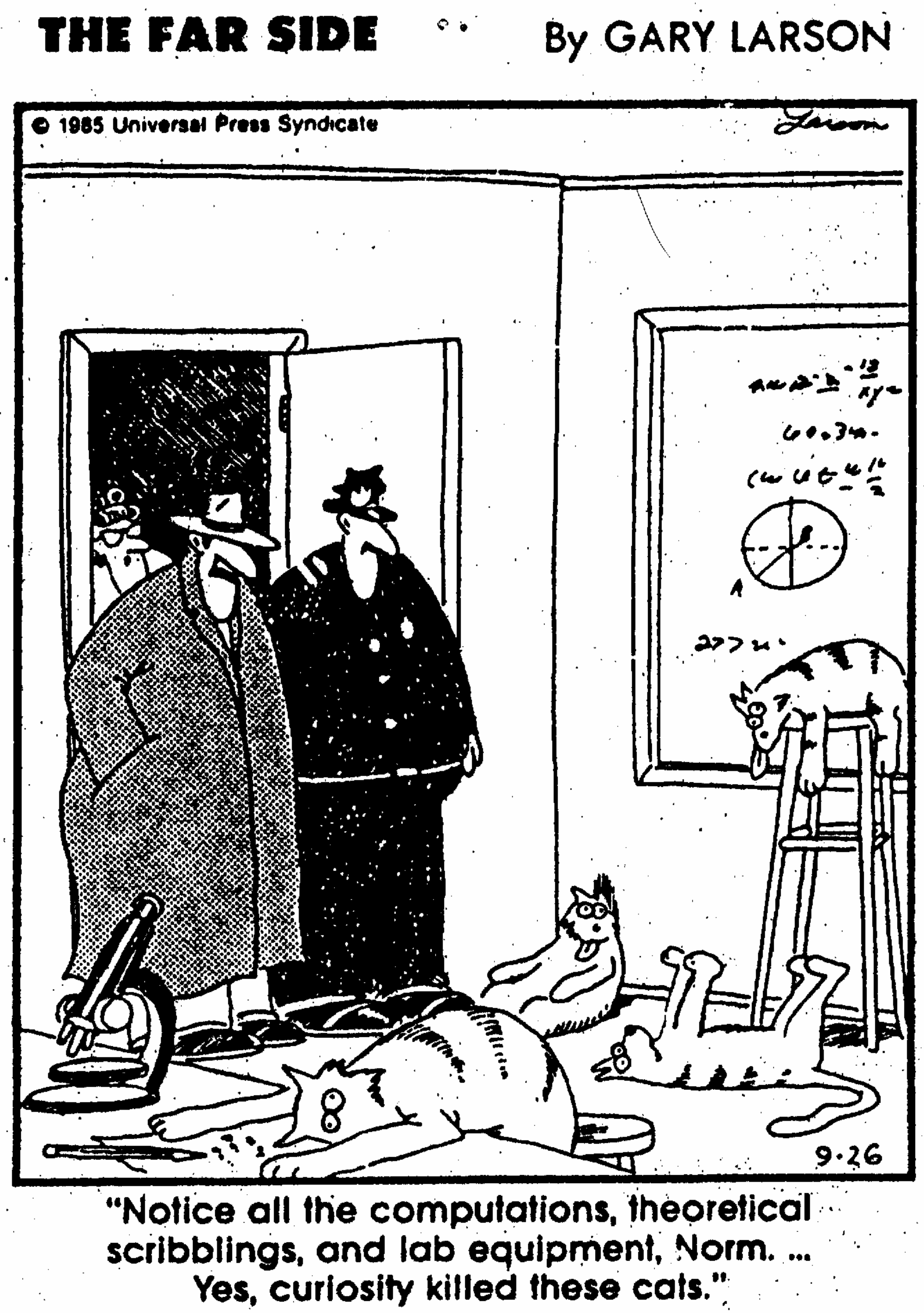
High: likely to be used as post-disaster shelters or contain hazardous substances.

Post-Disaster: essential to the provision of services after a disaster.

Importance Factors for S, W

Importance Category	Ultimate (Snow or Wind)	Serviceability Snow	Serviceability Wind
Low	0.8	0.9	0.75
Normal	1.0	|	|
High	1.15	|	|
Post Disaster	1.25	0.9	0.75

Questions?



THE FAR SIDE
By GARY LARSON
© 1985 Universal Press Syndicate
Larson
9-26
"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.
- <u>Consequence:</u> 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)


4. 6. 2001

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:

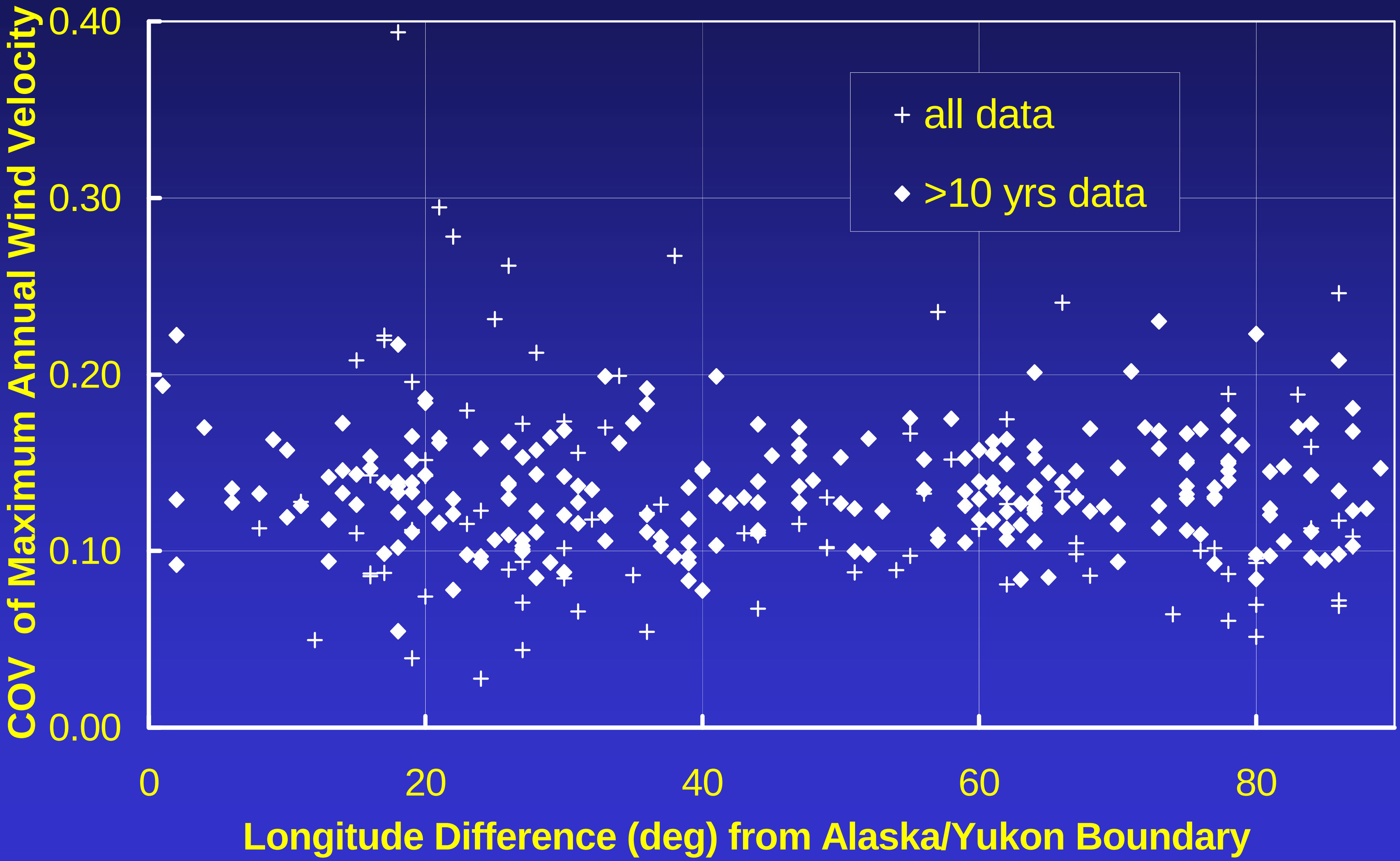
"These are use and occupancy loads, intended to provide for maintenance loadings, workmen, and so forth."

"They are not reduced as a function of area or roof slope"

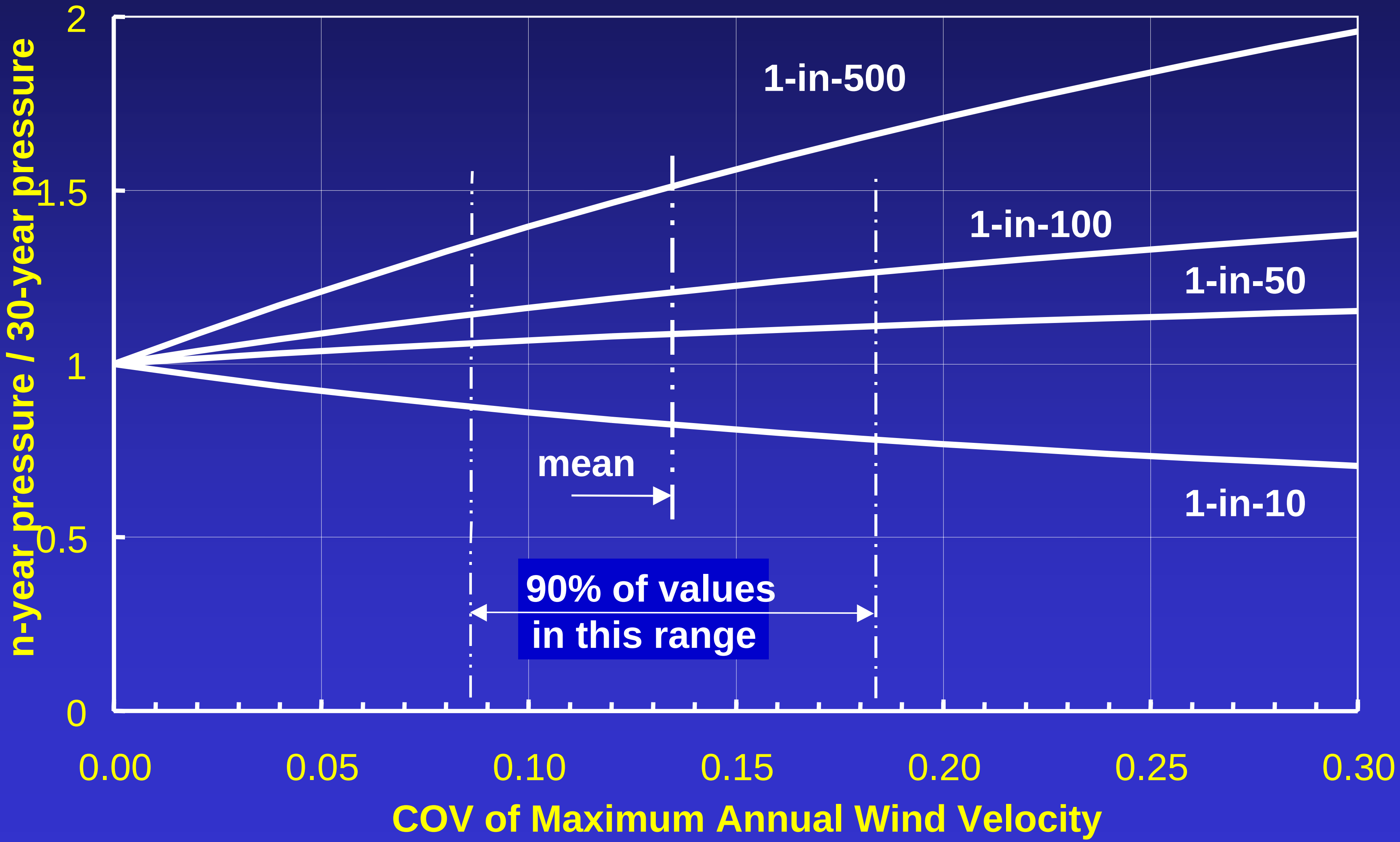
Return Period for Environmental Loads

- 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



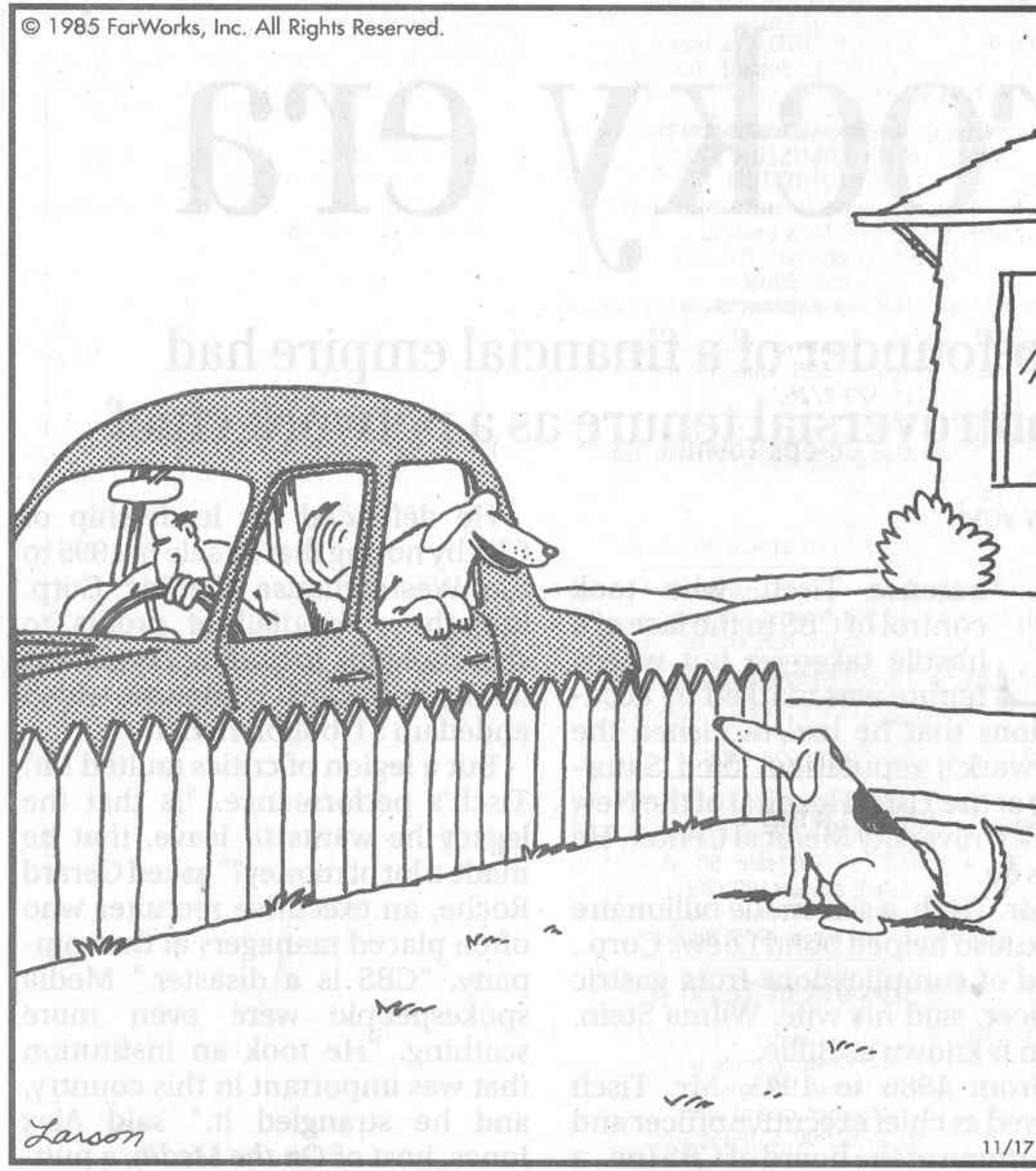
Specified Load Return Period



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

Questions?



"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."

Far Side

G. Larson

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

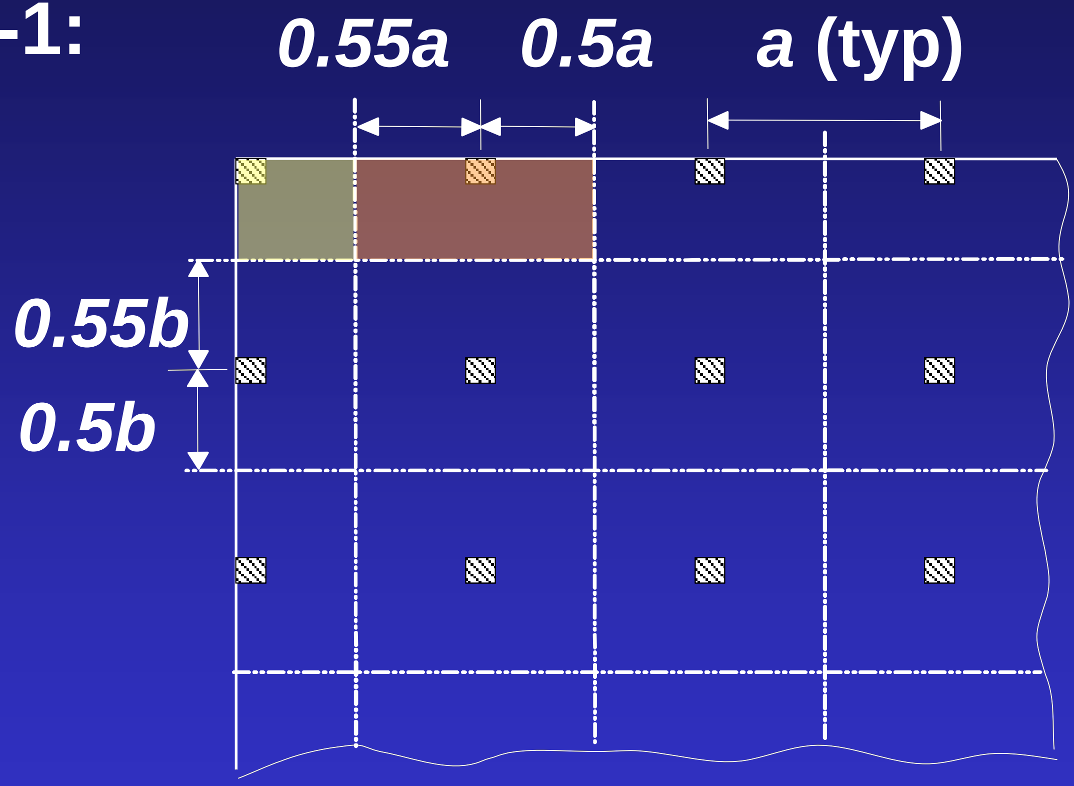
2000 Survey: Concrete Floor Thickness

- 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 1st 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

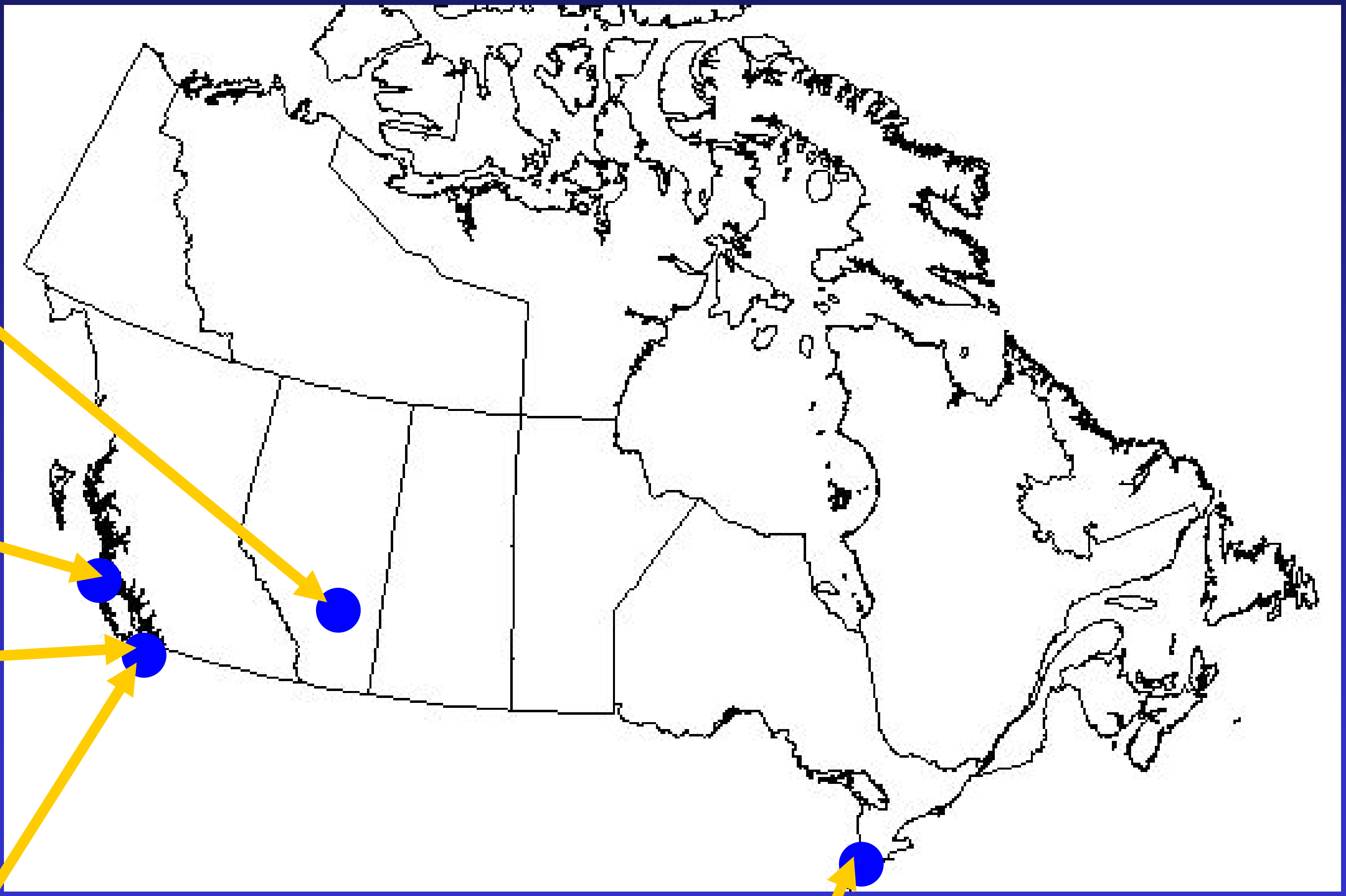
Regions where 1-day rain exceeds snow load on flat roof

Calgary (103%)

Port Hardy (131%)

Tofino (147%)

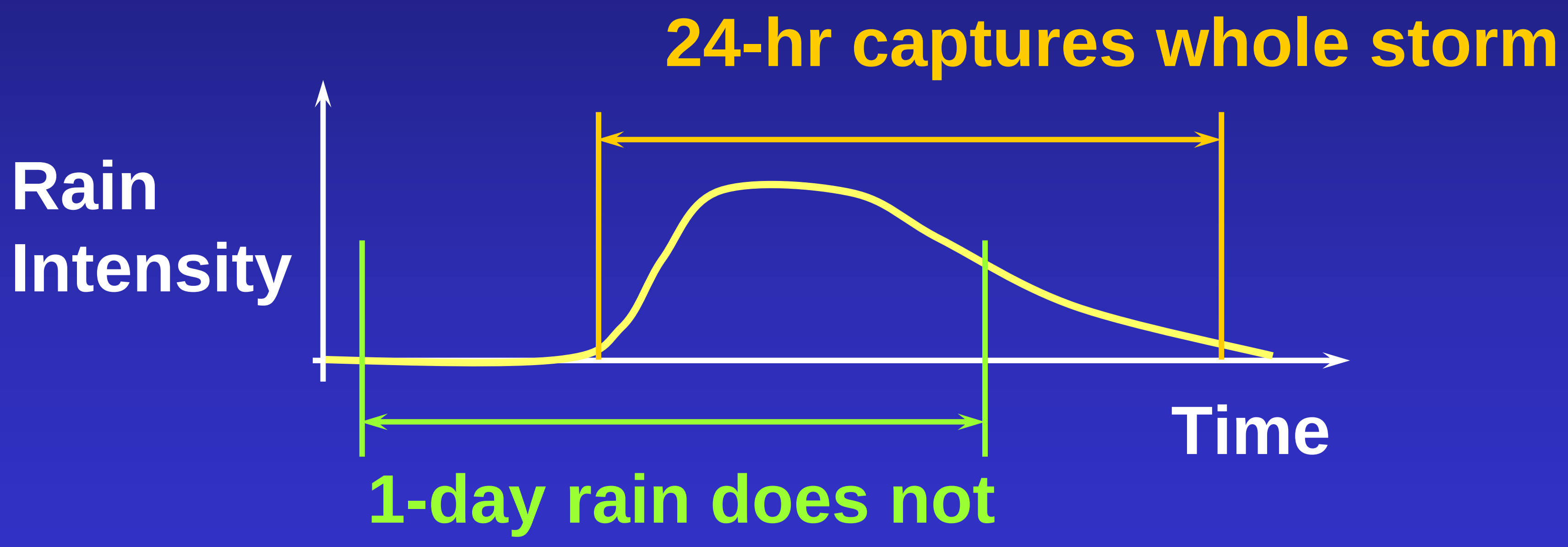
Ucluelet (132%)



Leamington (107%)

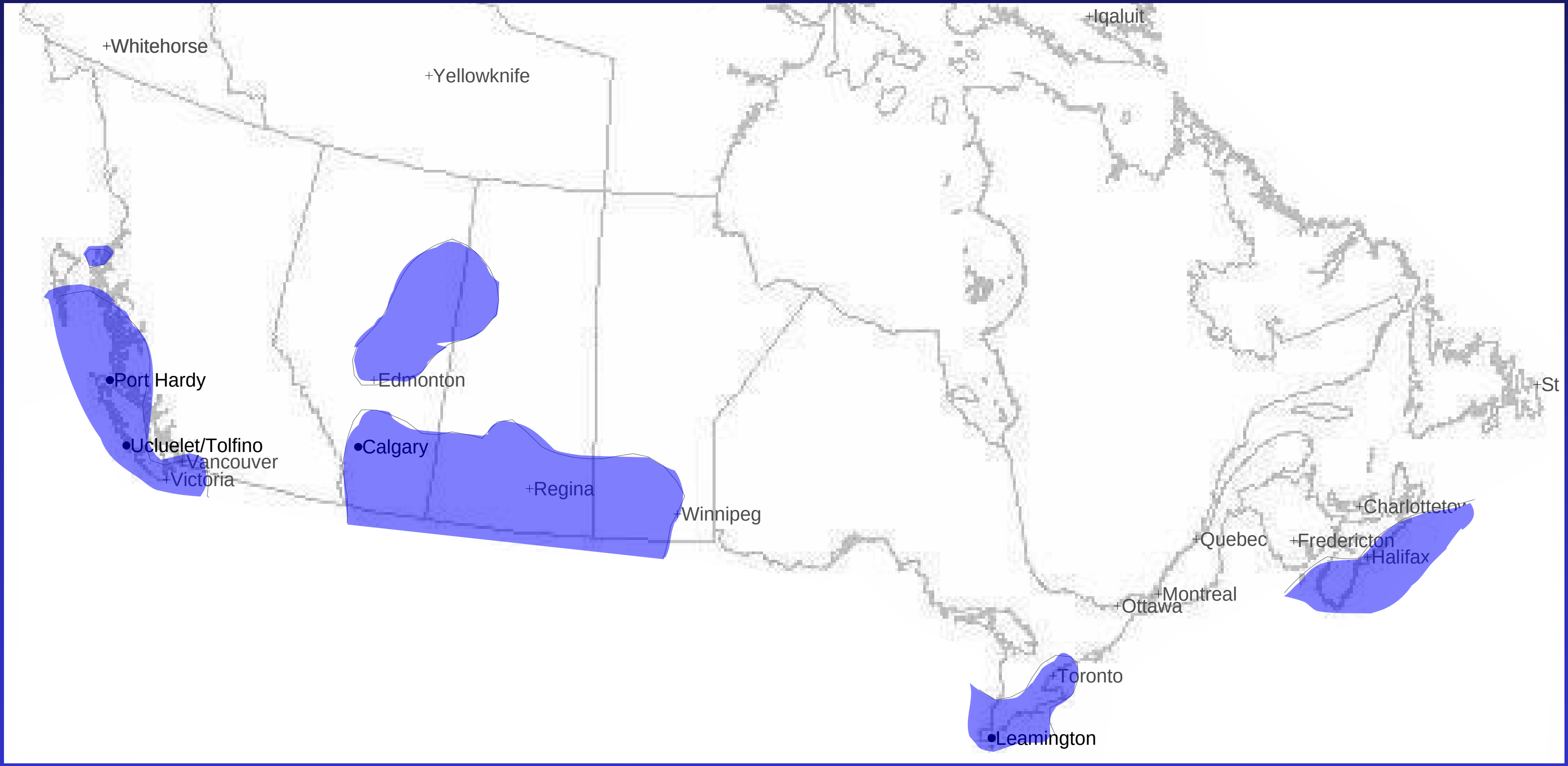
1-d rain and 24-hr rain

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



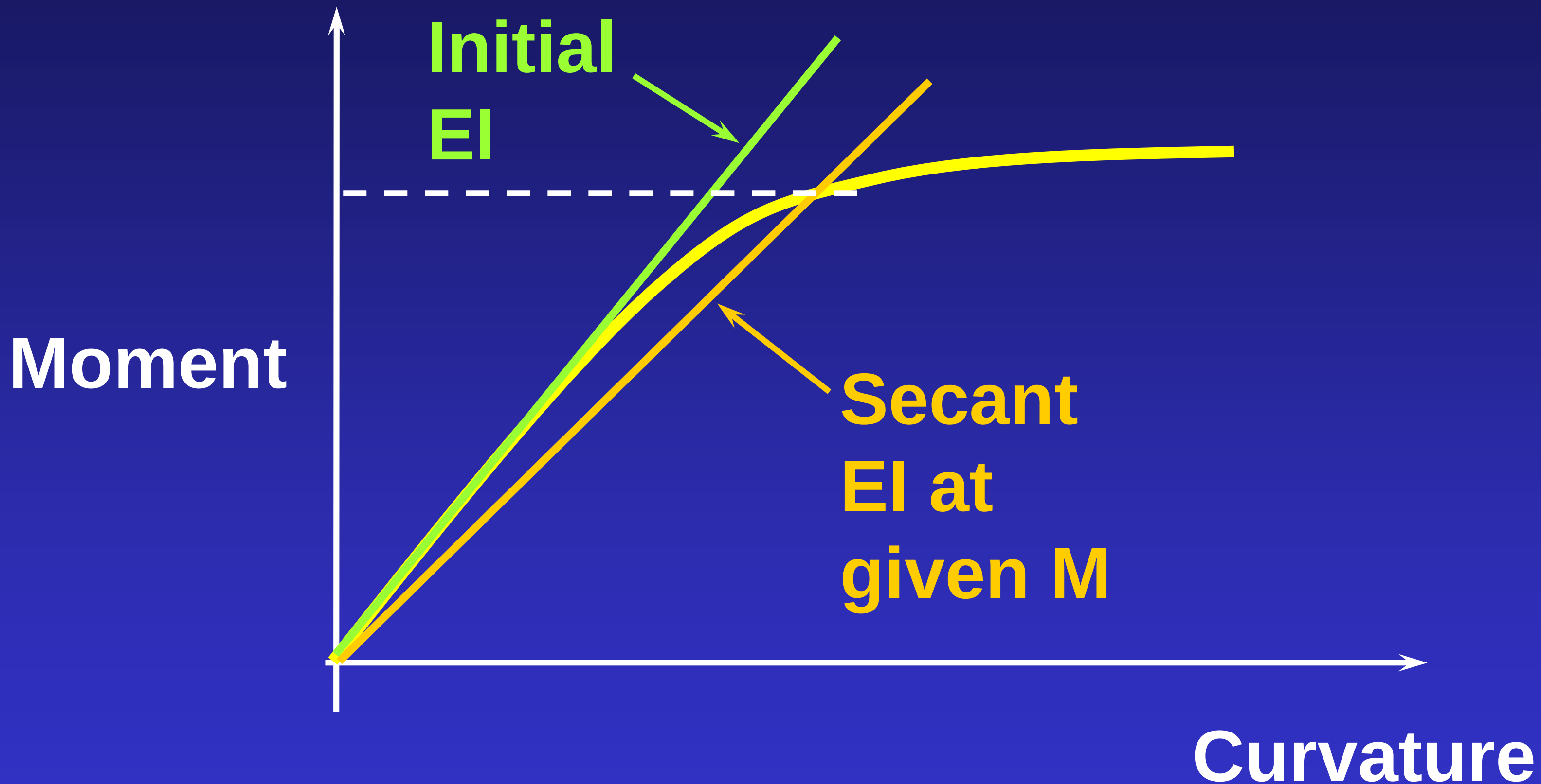
- 24-hr rain/1-d rain ~ 1.23

Regions where 24-hour rain exceeds snow load



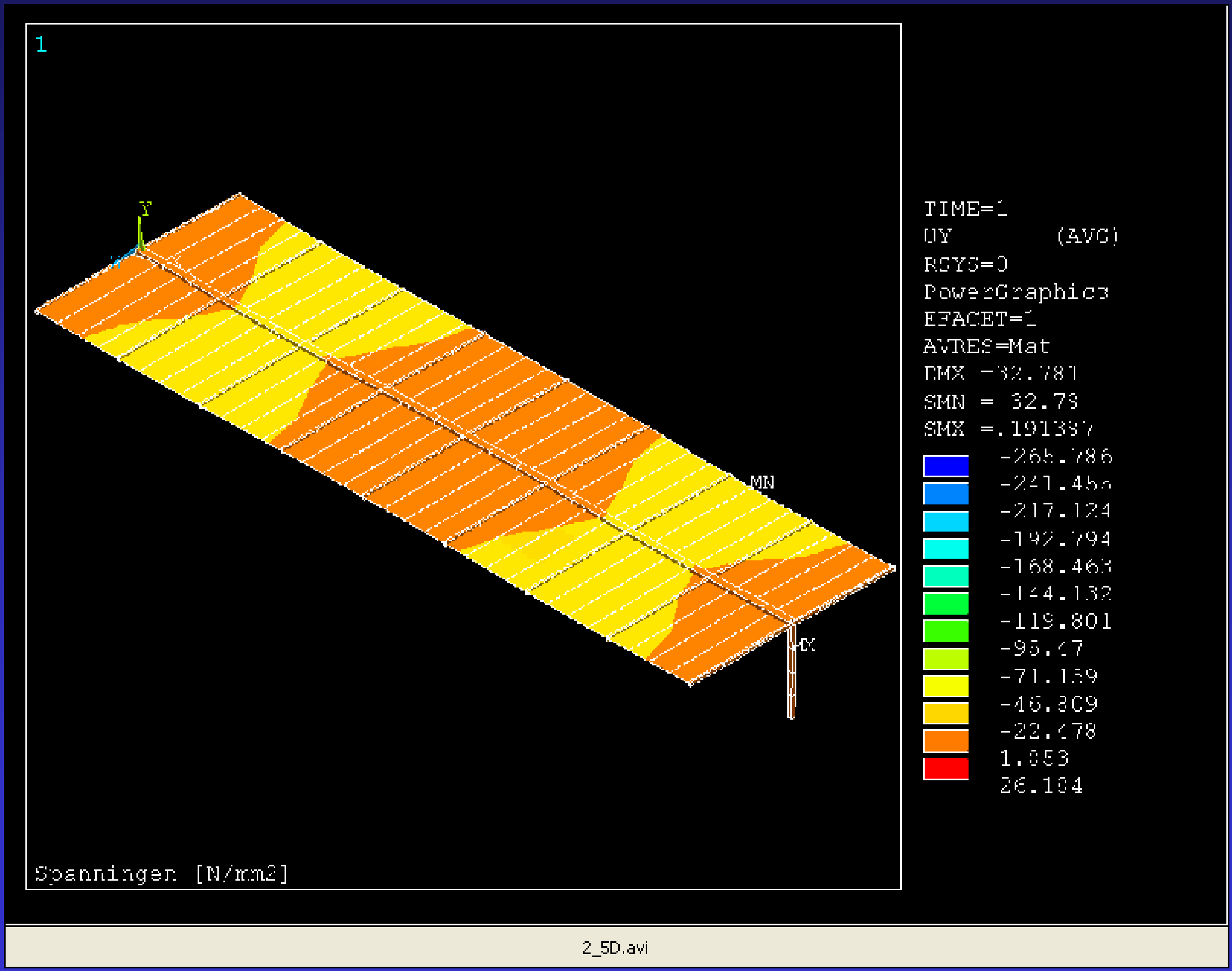
- Similar to Nixon's (1979) "Ponding Map of Canada"

NBCC ignores residual stresses



Underestimates ponding deflections

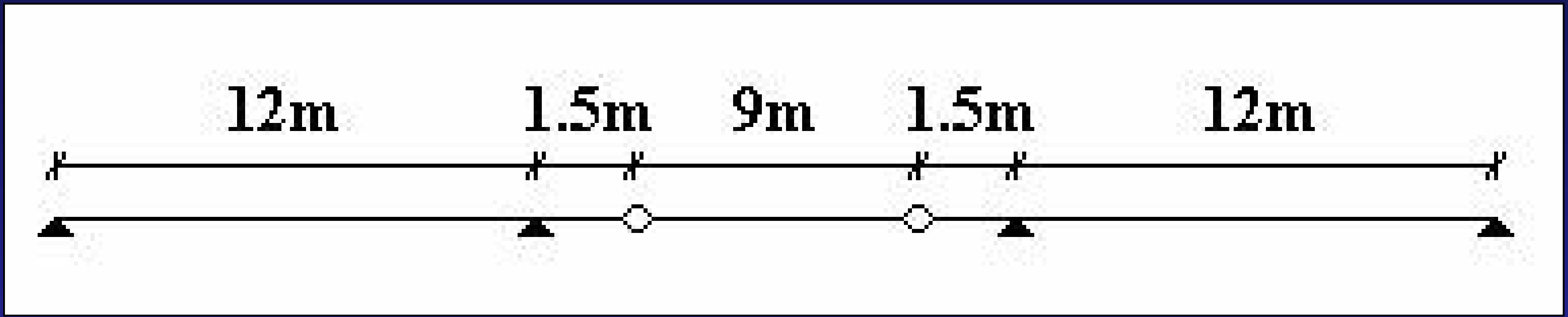
Animation by Schouten Engineering Consultants, NL



Stepwise Analysis

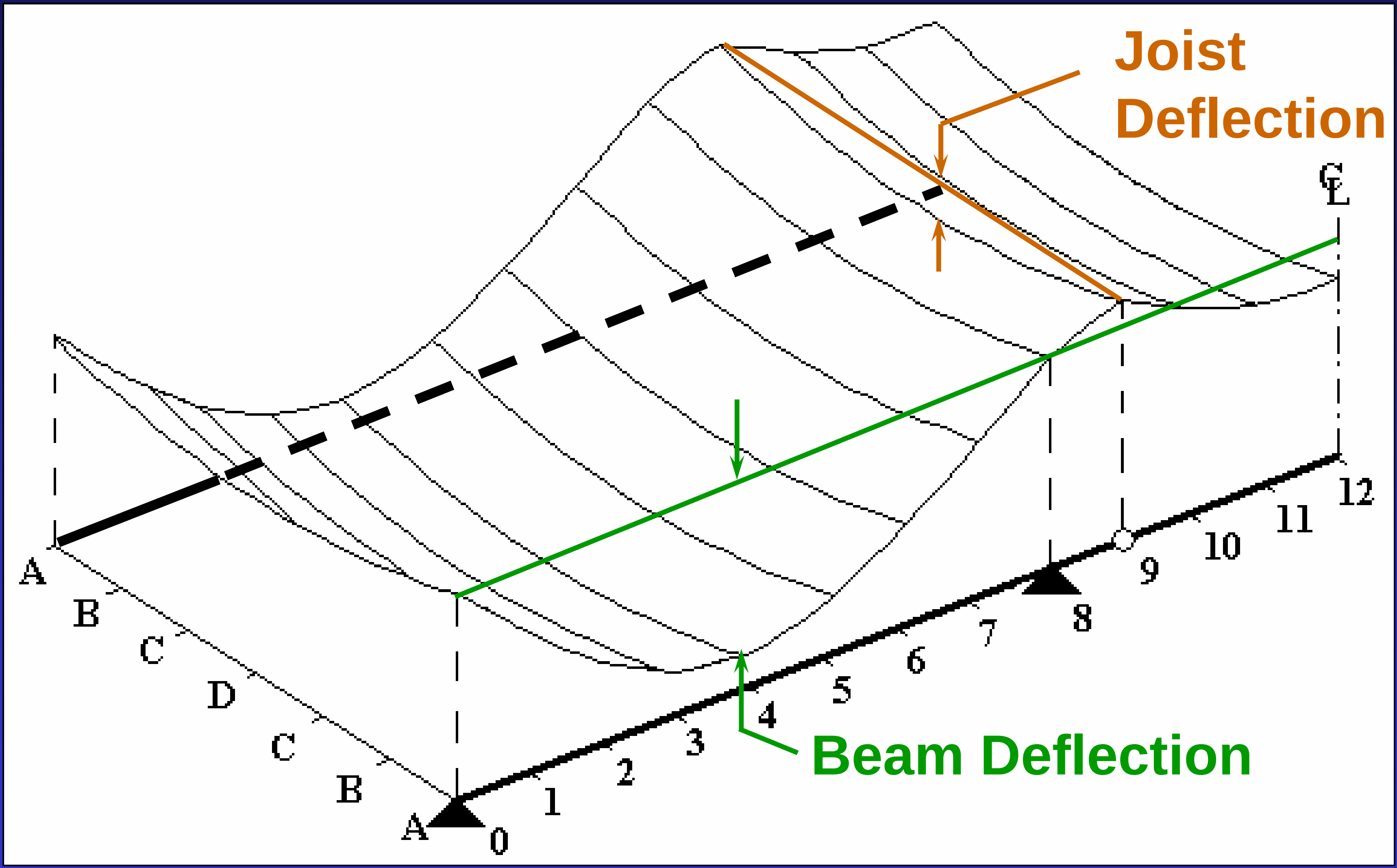
1. Load joists
2. Calculate joist deflections, reactions
3. Apply reactions to beams
4. Calculate beam moments, deflections
5. Calculate total deflected shape
6. Do deflections converge?
   NO: recompute load and repeat analysis
   YES: stop, check capacities not exceeded

Gerber Beam Example Calculation

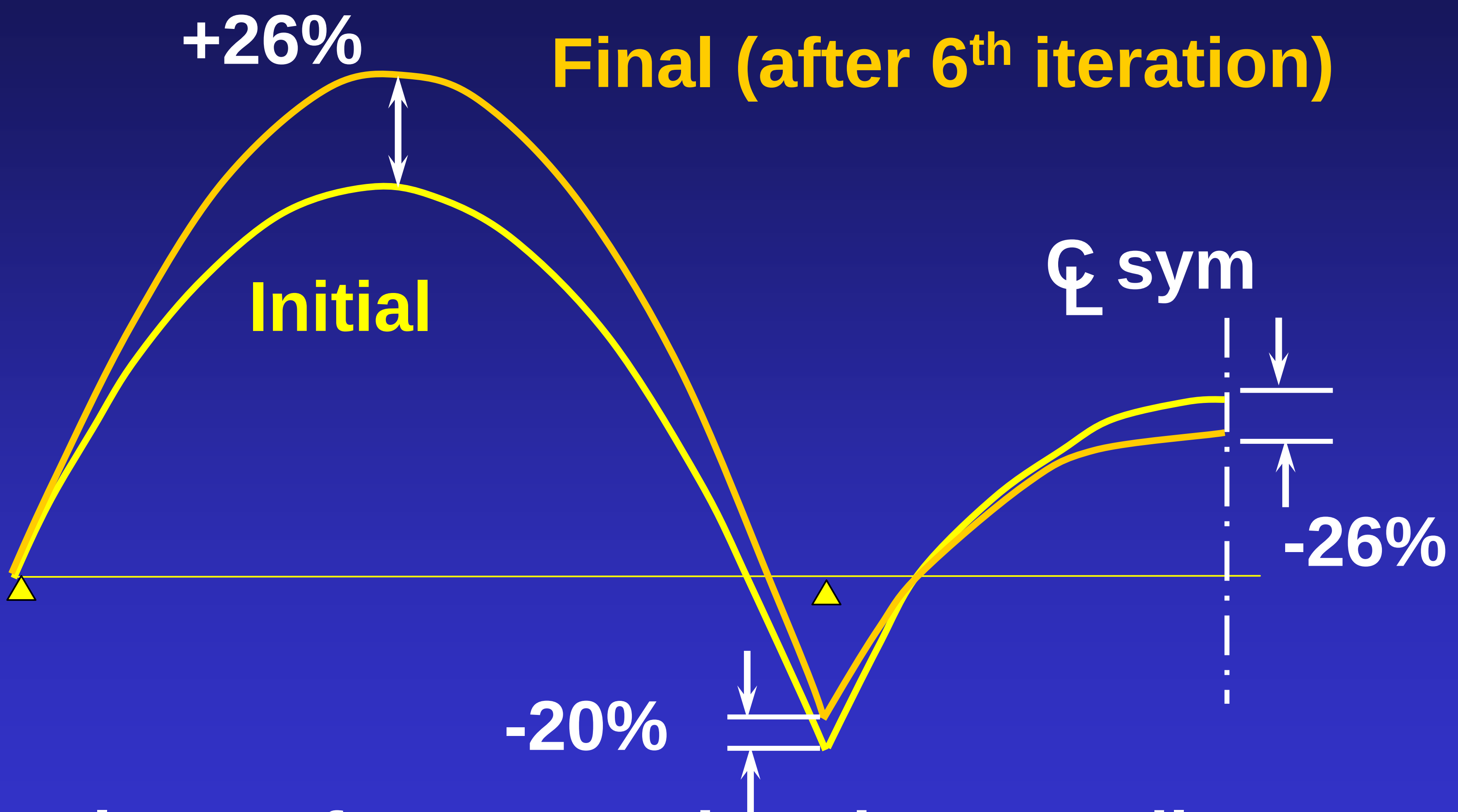


- Joists at 1.5m span 10.5m between beams
- W530x66 cantilever/anchor beam
- W460x52 drop-in beam
- Design for Calgary snow load, check for 1-day (not 24-hr, not factored) rain

Deflected shape after 1st iteration

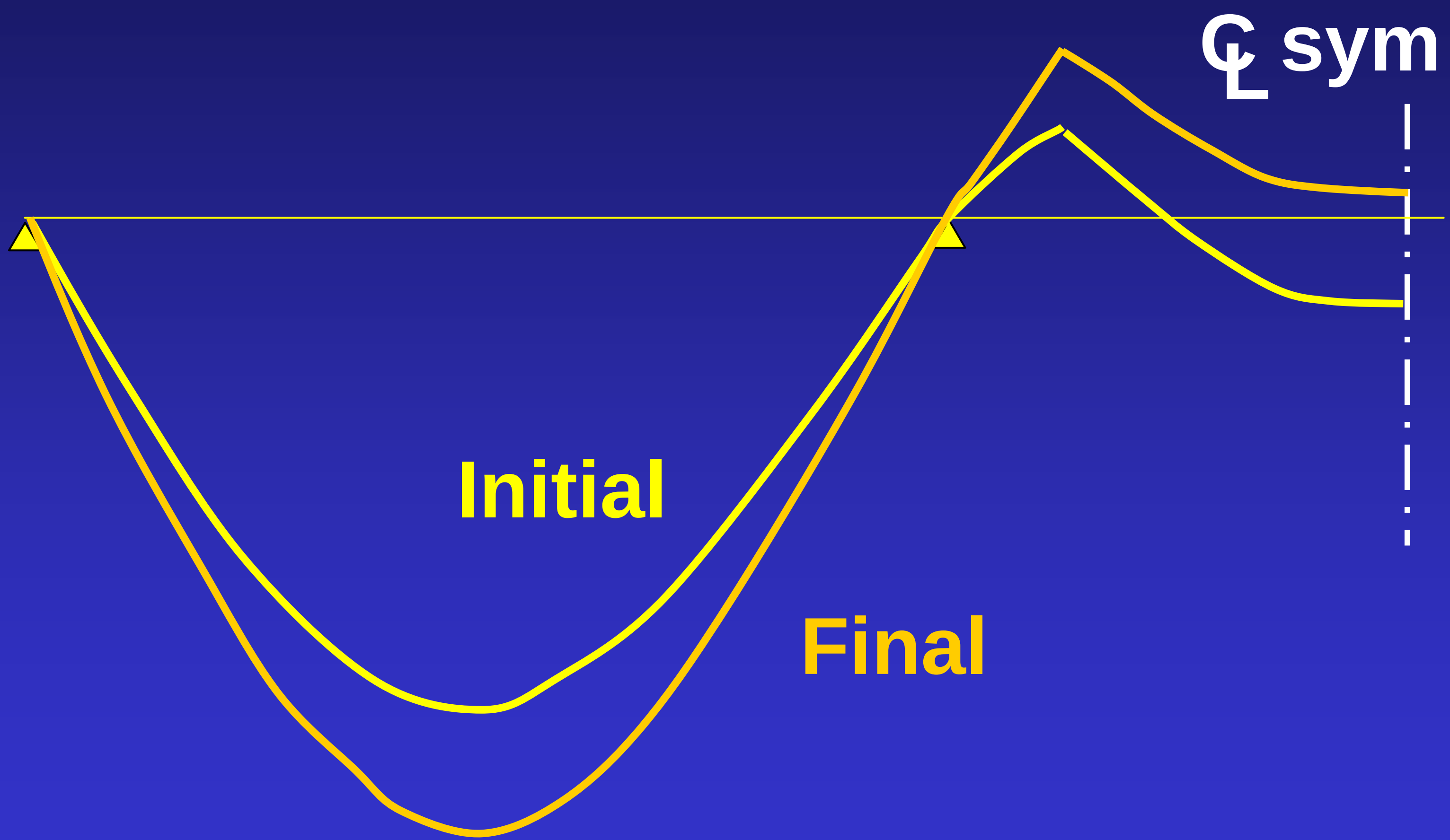


Beam Moments



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

Deflections




Questions?

David's 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?

More Questions!

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).

More Questions!

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 ~1.23 x 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

- Two papers by Bartlett, Hong & Zhou, *Canadian Journal of Civil Engineering*, April 2003.
- Paper by Praught & Bartlett in 2005 CSCE Annual Conference, Toronto.
- More information: f.m.bartlett@uwo.ca

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