Risk-Based Evaluation of Existing Highway Bridges: Past, Present and Future

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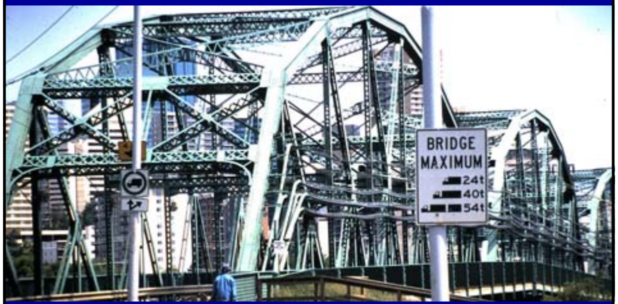
The Problem



Aging Bridge Inventory, Increasing Loads

The Solution: Rational Bridge Evaluation Criteria

Criteria Unchanged Since 1990

- Ontario Highway Bridge Design Code (3rd Ed.,1991) → *design* → CAN/CSA-S6-00 (CHBDC)
- CAN/CSA-S6, Design of Highway Bridges (8th Ed.,1988) → *evaluation* → CAN/CSA-S6-00 (CHBDC)
- *durability, truck model, fibre reinforced bridges, long spans, seismic* → CAN/CSA-S6-00 (CHBDC)

Presentation Objectives

- Existing Bridge Evaluation
  - Constant Risk Basis
- New Directions
  - Quantify Warning

Constant Risk – Life Safety

Risk = probability X consequences

$$P_f \, W \, \sqrt{n} = A \, K$$

- P_f: Probability of failure
- Consequences:
  - *W* – warning
  - *n* – number of people at risk
- $A\,K$: Constant

Factors that Provide Warning

- System Behaviour
  - S1 (Single Load Path), to
  - S3 (Multiple Load Path)
- Element Behaviour
  - E1 (Brittle), to
  - E3 (Ductile)
- Inspection Classification
  - INSP1 (Uninspectable), to
  - INSP 3 (Evaluator inspects deficient members)

Impact: Concrete Arch Bridge

Consider

- Top Chord
- Floor Beam

Umpqua River Bridge, Reedsport, Oregon

Top Chord (Compression)

- System: S1
  - single load path
- Element Behav.: E1
  - Brittle
- Inspection: INSP2
  - Routine
- Target β: 3.75

Floor Beam (Flexure)

- System: S2
  - Not SLP
- Element Behav.: E3
  - Ductile
- Inspection: INSP2
  - Routine
- Target β: 3.00

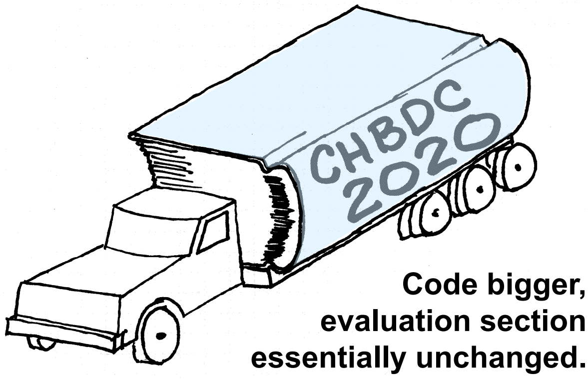
Impact on Rating

	Chord	Beam
Target β	3.75	3.00
Concrete DL	1.2 x 500	1.14 x 50
Asphalt DL	1.5 x 50	1.35 x 5
LL (incl DLA)	1.7 x 600	1.49 x 60
Factored Demand	1695	153
Factored Capacity	1550	155
Result	insufficient	ok

Economic Impact

- Short span elements including bridge floor systems susceptible to increased traffic loads.
- These elements tend to be ductile, readily inspected, and part of a multiple load path.
- Less stringent β allows them to be deemed adequate.
- Marked economic savings achieved.

Present: 2020 Design Truck?



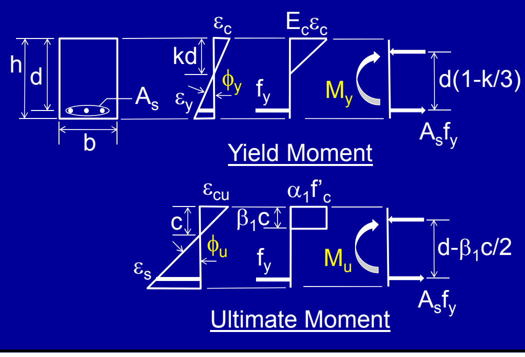
Future: Quantify Warning

1. Deflection as a metric of warning
2. Computing deflection at imminent failure, Δ_f:
   - Cross section response
   - Application of moment-area method
3. Computing warning factor, W, given Δ_f/L

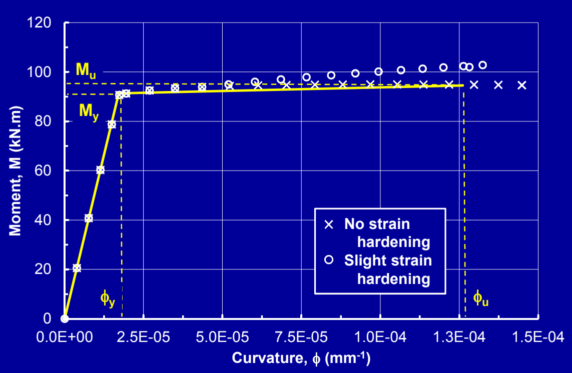
Deflection = Warning

Bridge over Schubenacadie River near Truro, NS

Conventional Flexural Analysis



Bilinear Idealization



Shape Factor

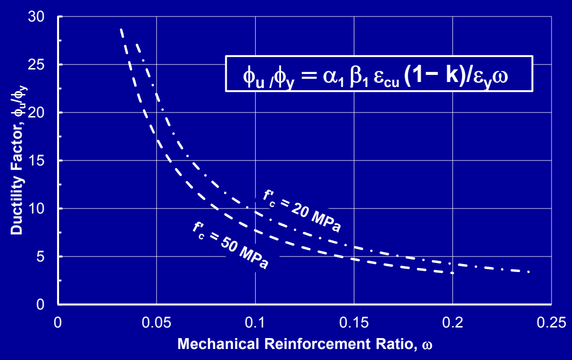
- Shape Factor $f = M_u/M_y$

  $$f = (1 - \omega/2\alpha_1) / (1 - k/3)$$

  where w, the mechanical reinforcing ratio, $= A_s f_y / (b\ d\ f'_c)$

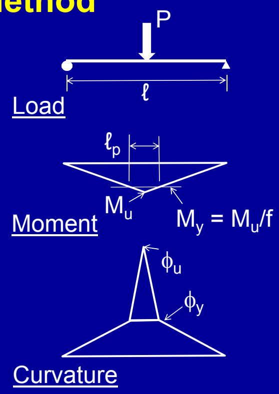
- Typically $1.01 < f < 1.05$ for $\omega < 0.3$

Curvature Ductility Factor, ϕ_u/ϕ_y



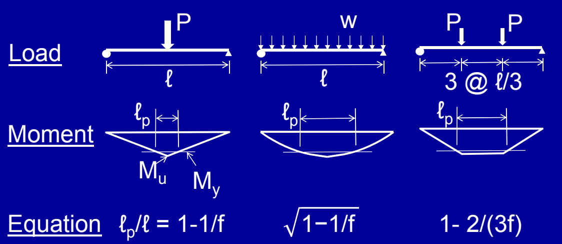
Moment Area Method

- Integrate curvature diagram accounting for plastic hinging
- Get Δ_t: deflection at incipient failure

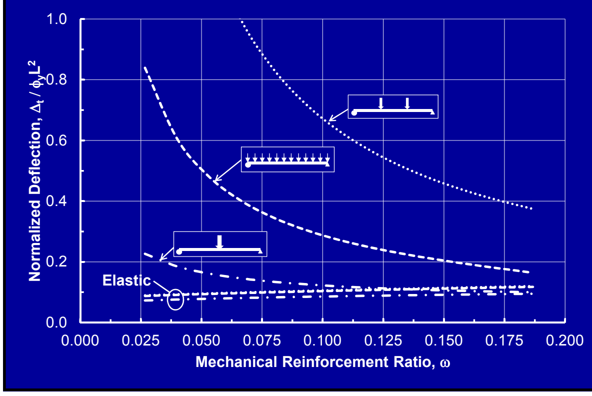


Plastic Hinge Length Varies

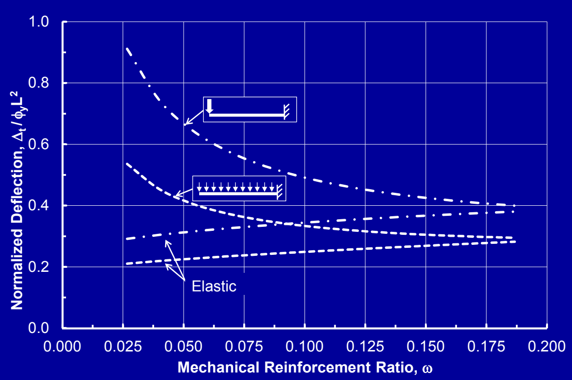
- Function of shear force in plastic hinge region – and Shape Factor f



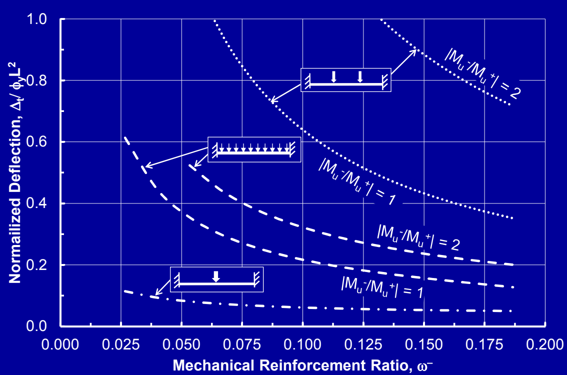
Simply Supported Beams



Cantilevers



Fixed-ended Beams



Express Δ_t as Δ_t/L

- Common practical measure
- Can show $\Delta_t/L = \alpha\, \Delta_t/(\phi_y L^2)$

where $$\alpha = \frac{\varepsilon_y}{(1-k)}\left(\frac{h}{d}\right)\frac{L}{h}$$

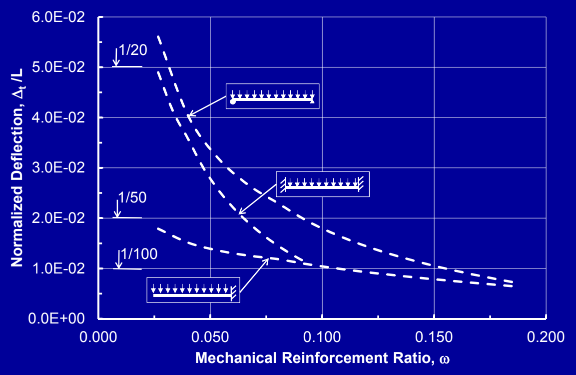
say (h/d) ~ 1/0.85 for a thin slab to
~ 1/0.95 for a deep beam

(L/h) from Deflection Control Limits

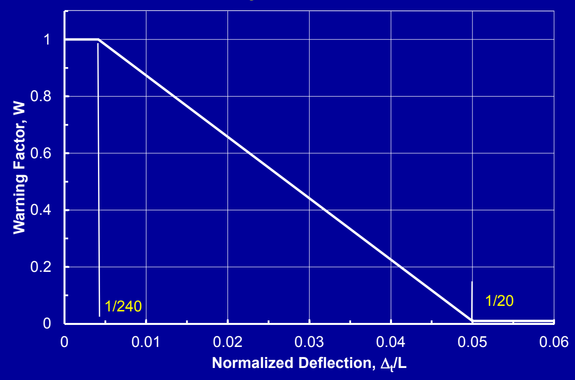
- ACI 318 & A23.3 provide maximum L/h limits that, if satisfied, do not require deflections to be checked.

Beam end restraints	Span-to-depth ratio, L/h		Avg.
	1-way Slab	Beam	α
Simple support	20	16	0.054
Cantilever	10	8	0.027
Fixed ends	28	21	0.073

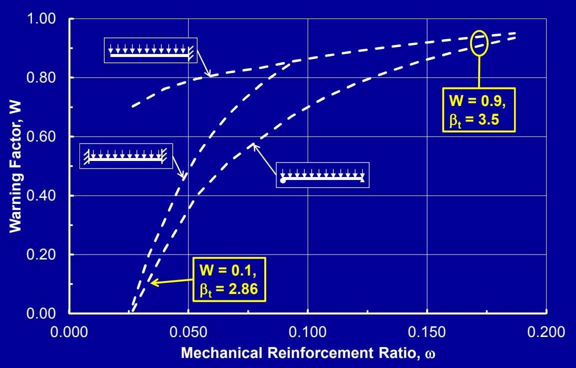
Beams with UDLs



Relate W to Δ_t/L



W Variation with ω



Conclusions

1. Constant risk criteria in CHBDC require more safety for members with severe consequences of failure.
2. Bridge members that are sensitive to higher modern traffic loadings get a break.
3. Significant economies are achieved.

4. Deflection at imminent failure captures warning of failure.
5. Increased deflections for:
   - Ductile cross sections
   - Long plastic hinge lengths (load configurations matter!)
6. Redundancy is an inconsistent indicator of warning of failure.
7. Can rationally quantify warning factor as a continuous variable.

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