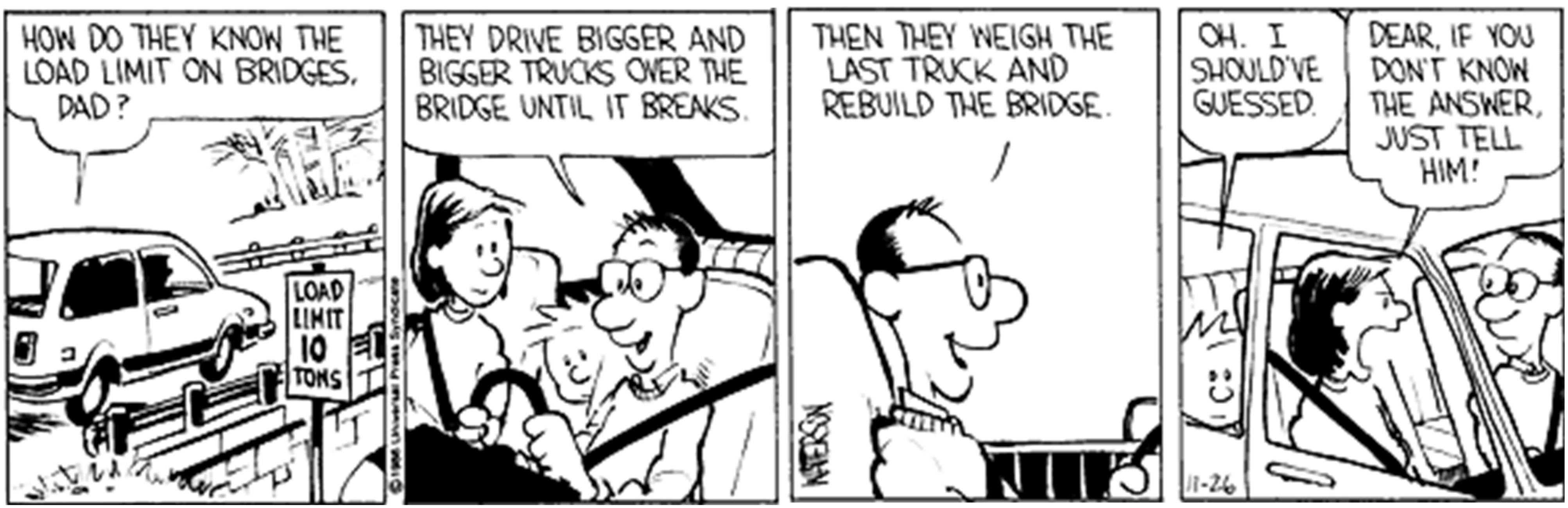
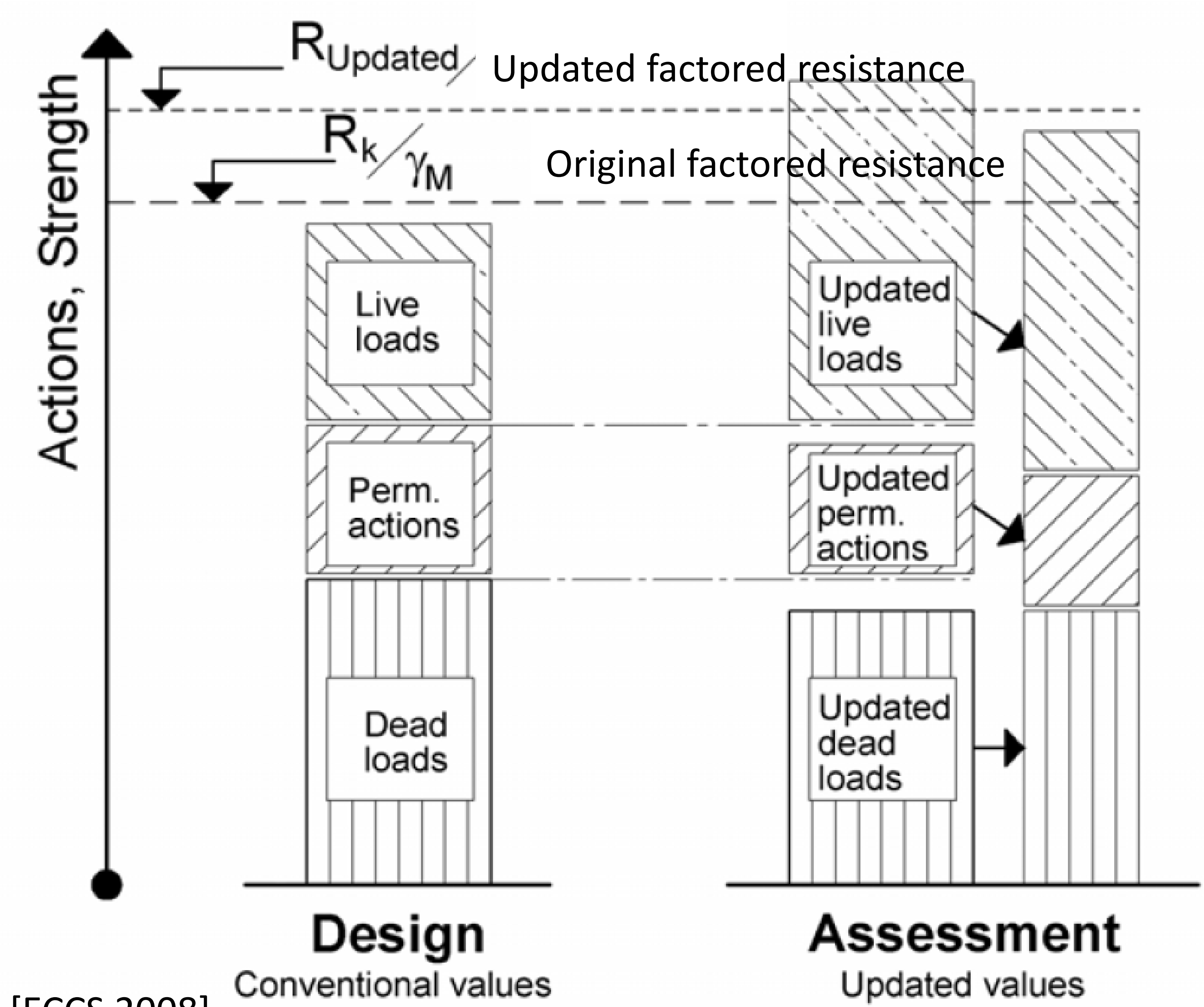
# Lecture 3A – Key Messages

- CSA S6 – Section 14 is introduced.
- Various possibilities for estimating the material strength parameters required for bridge assessment are reviewed.



# Increasing Live Load Capacity




[ECCS 2008]

Basic idea: increase live load capacity by reducing dead load and resistance uncertainty.

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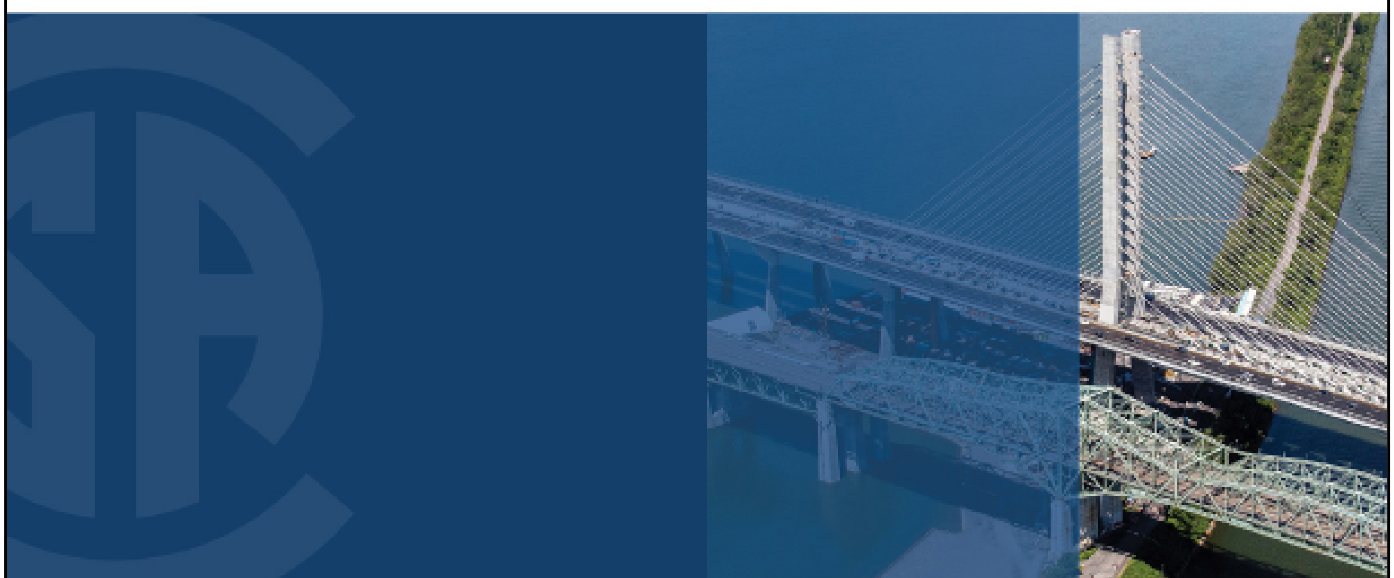
CSA S6:19

# Canadian Highway Bridge Design Code



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[CSA S6]

# CSA S6 – Section 14

- specifies methods of evaluating existing bridges
- Clause 14.6 – inspection
- Clause 14.7 – material strengths
- Clauses 14.8-14.10 – loads
- Clauses 14.11 – lateral load distribution factors
- Clause 14.12 – target reliability index, $\beta$
- Clause 14.13 – load factors
- Clause 14.14 – resistance calculation
- Clause 14.15 – live load capacity factor, $F$
- Clause 14.16, 14.17 – load testing, posting



[CSA S6]

# CSA S6 – Section 14

*"The cost of upgrading or replacing a bridge may be great; Section 14 offers a method of evaluation by setting safety levels that are consistent and appropriate for the bridge or bridge component being evaluated. The intention is to avoid some of the conservatism that, in the interests of simplicity, may have been incorporated into the design provisions. Section 14 is not to be used for design."*



[CSA S6]

# CSA S6 – Section 14

The need for evaluation may be created by:

- observed defects, deterioration, or damage
- an anticipated increase in traffic loading
- a change in road classification
- a review of an existing load limit posting
- any alteration to a bridge
- a heavy vehicle permit application
- serviceability or fatigue performance issues

# Clause 14.7 – Material Strengths

- The strengths of materials that do not have visible signs of deterioration shall be determined using one of the following methods:
  a) review of Plans, etc. (Clause 14.7.2)
  b) analysis of tests of samples obtained from the bridge or from specific bridge components (Clause 14.7.3)
  c) estimation by considering the date of bridge construction (Clause 14.7.4); or
  d) an Approved method.

[CSA S6]

# Clause 14.7 – Material Strengths

- “Nominal” material strengths can be determined by testing samples obtained from bridge.
- Samples should not be taken from locations that may compromise bridge integrity.
- Record sample location and orientation.
- Test results should not be used directly – rather, they should be converted into nominal strengths, using Annex A14.1 or an Approved method.

[CSA S6]

# Annex 14.1 – Material Strengths

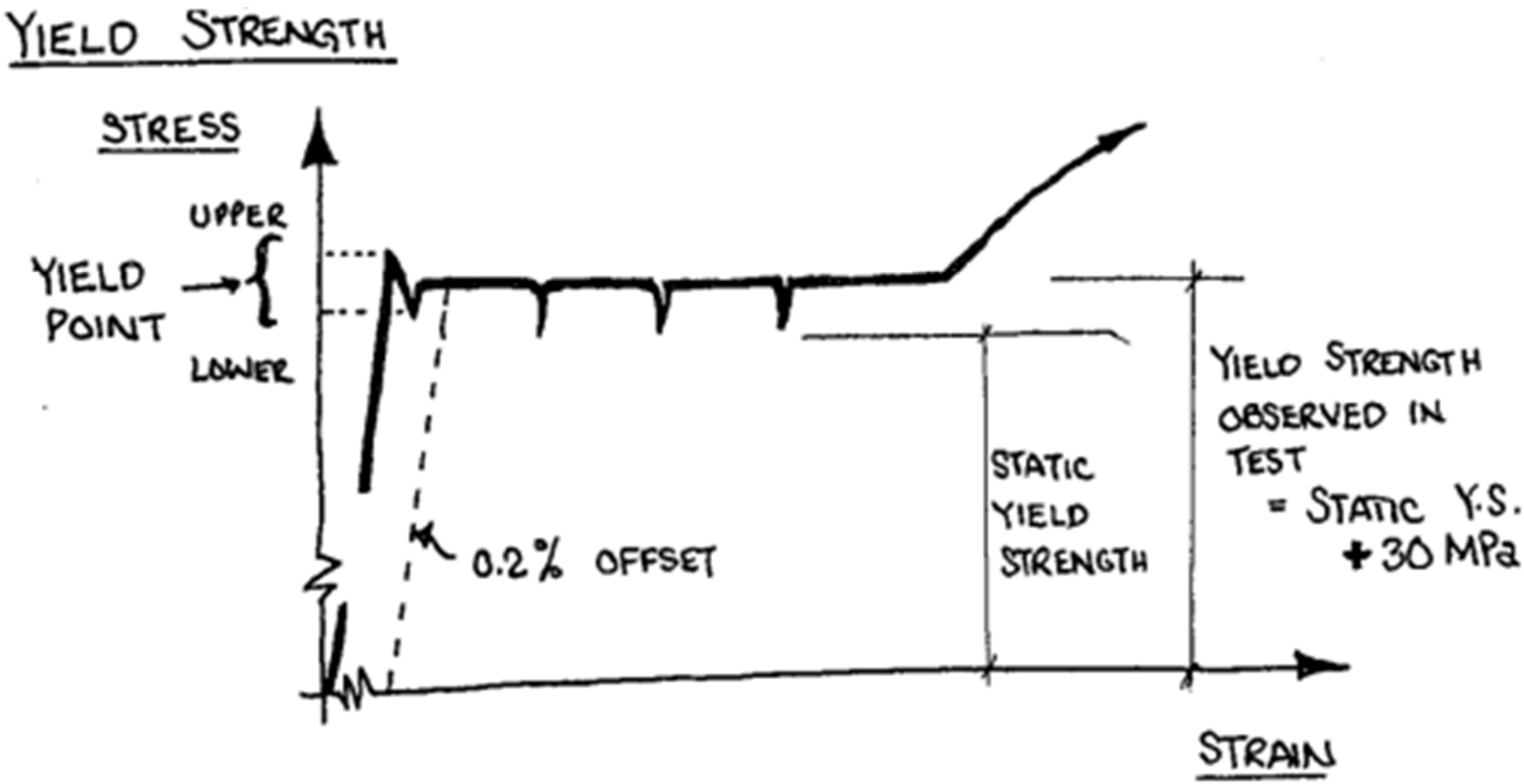
- Structural steel:
  - Difference between the coupon test and actual yield strength is 28 MPa. Additional factor for difference between web and flange yield strength.
  - Uncertainty of standard deviation due to sample size considered.
  - 10% characteristic strength with 95% confidence (and $k_s$ reduced by a constant factor so $k_s$ = 1.0 for $n$ = 30 samples).

| $n$ | $k_s$ |
|---|---|
| 3 | 3.46 |
| 4 | 2.34 |
| 5 | 1.92 |
| 6 | 1.69 |
| 8 | 1.45 |
| 10 | 1.32 |
| 12 | 1.24 |
| 16 | 1.14 |
| 20 | 1.08 |
| 25 | 1.03 |
| 30 or more | 1.00 |

$$\boxed{f_y = \left(\bar{f}_y - 28\right)\exp\left(-1.3 k_s V\right)}$$

[CSA S6]

# Annex 14.1 – Material Strengths




[Bartlett 2018]

# Annex 14.1 – Material Strengths

Factors for one-sided tolerance limits for normal distributions:

| | $\gamma = 0.95$ | | | | | $\gamma = 0.99$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $n$ \ $P$ | 0.75 | 0.90 | 0.95 | 0.99 | 0.999 | 0.75 | 0.90 | 0.95 | 0.99 | 0.999 |
| 3 | 3.804 | 6.158 | 7.655 | 10.552 | 13.857 | — | — | — | — | — |
| 4 | 2.619 | 4.163 | 5.145 | 7.042 | 9.215 | — | — | — | — | — |
| 5 | 2.149 | 3.407 | 4.202 | 5.741 | 7.501 | — | — | — | — | — |
| 6 | 1.895 | 3.006 | 3.707 | 5.062 | 6.612 | 2.849 | 4.408 | 5.409 | 7.334 | 9.540 |
| 7 | 1.732 | 2.755 | 3.399 | 4.641 | 6.061 | 2.490 | 3.856 | 4.730 | 6.411 | 8.348 |
| 8 | 1.617 | 2.582 | 3.188 | 4.353 | 5.686 | 2.252 | 3.496 | 4.287 | 5.811 | 7.566 |
| 9 | 1.532 | 2.454 | 3.031 | 4.143 | 5.414 | 2.085 | 3.242 | 3.971 | 5.389 | 7.014 |
| 10 | 1.465 | 2.355 | 2.911 | 3.981 | 5.203 | 1.954 | 3.048 | 3.739 | 5.075 | 6.603 |
| 11 | 1.411 | 2.275 | 2.815 | 3.852 | 5.036 | 1.854 | 2.897 | 3.557 | 4.828 | 6.284 |
| 12 | 1.366 | 2.210 | 2.736 | 3.747 | 4.900 | 1.771 | 2.773 | 3.410 | 4.633 | 6.032 |
| 13 | 1.329 | 2.155 | 2.670 | 3.659 | 4.787 | 1.702 | 2.677 | 3.290 | 4.472 | 5.826 |
| 14 | 1.296 | 2.108 | 2.614 | 3.585 | 4.690 | 1.645 | 2.592 | 3.189 | 4.336 | 5.651 |
| 15 | 1.268 | 2.068 | 2.566 | 3.520 | 4.607 | 1.596 | 2.521 | 3.102 | 4.224 | 5.507 |
| 16 | 1.242 | 2.032 | 2.523 | 3.463 | 4.534 | 1.553 | 2.458 | 3.028 | 4.124 | 5.374 |
| 17 | 1.220 | 2.001 | 2.486 | 3.415 | 4.471 | 1.514 | 2.405 | 2.962 | 4.038 | 5.268 |
| 18 | 1.200 | 1.974 | 2.453 | 3.370 | 4.415 | 1.481 | 2.357 | 2.906 | 3.961 | 5.167 |
| 19 | 1.183 | 1.949 | 2.423 | 3.331 | 4.364 | 1.450 | 2.315 | 2.855 | 3.893 | 5.078 |
| 20 | 1.167 | 1.926 | 2.396 | 3.295 | 4.319 | 1.424 | 2.275 | 2.807 | 3.832 | 5.003 |
| 21 | 1.152 | 1.905 | 2.371 | 3.262 | 4.276 | 1.397 | 2.241 | 2.768 | 3.776 | 4.932 |
| 22 | 1.138 | 1.887 | 2.350 | 3.233 | 4.238 | 1.376 | 2.208 | 2.729 | 3.727 | 4.866 |
| 23 | 1.126 | 1.869 | 2.329 | 3.206 | 4.204 | 1.355 | 2.179 | 2.693 | 3.680 | 4.806 |
| 24 | 1.114 | 1.853 | 2.309 | 3.181 | 4.171 | 1.336 | 2.154 | 2.663 | 3.638 | 4.755 |
| 25 | 1.103 | 1.838 | 2.292 | 3.158 | 4.143 | 1.319 | 2.129 | 2.632 | 3.601 | 4.706 |
| 30 | 1.059 | 1.778 | 2.220 | 3.064 | 4.022 | 1.249 | 2.029 | 2.516 | 3.446 | 4.508 |
| 35 | 1.025 | 1.732 | 2.166 | 2.994 | 3.934 | 1.195 | 1.957 | 2.431 | 3.334 | 4.364 |
| 40 | 0.999 | 1.697 | 2.126 | 2.941 | 3.866 | 1.154 | 1.902 | 2.365 | 3.250 | 4.255 |
| 45 | 0.978 | 1.669 | 2.092 | 2.897 | 3.811 | 1.122 | 1.857 | 2.313 | 3.181 | 4.168 |
| 50 | 0.961 | 1.646 | 2.065 | 2.863 | 3.766 | 1.096 | 1.821 | 2.296 | 3.124 | 4.096 |

6.158 / 1.778 = 3.46

[Natrella 1963]

$$\boxed{f_y = \left(\bar{f}_y - 28\right)\exp\left(-1.3 k_s V\right)}$$

Example

318 MPa
331
346
327
380

N = 5

results from 5 tests on Steel

$k_s = \underline{1.92}$

$\downarrow$

$\boxed{f_y = 261.8 \text{ MPa}}$

$\Sigma = 1702 \div 5 = \underline{340.5 \text{ MPa}} = \bar{f}_y$

$\sigma = \sqrt{\dfrac{\Sigma (x_i - \bar{x})^2}{N-1}} = 24.1 \text{ MPa}$

$\text{COV} = \dfrac{\sigma}{\bar{x}} = \dfrac{24.1}{340.5} = \underline{0.071} \rightarrow V$

# Annex 14.1 – Material Strengths

- Concrete:
  - *"The equivalent specified strength obtained using this procedure is an estimate of the 13% fractile of in-place concrete strength. This fractile is consistent with statistical description of the concrete strength for $f'_c$ and can be used with customary resistance factors. The method is based on the approach proposed by Bartlett and MacGregor (1995)."*

| $n$ | $k_c$ |
|---|---|
| 2 | 2.40 |
| 3 | 1.47 |
| 4 | 1.28 |
| 5 | 1.20 |
| 6 | 1.15 |
| 8 | 1.10 |
| 10 | 1.08 |
| 12 | 1.06 |
| 16 | 1.05 |
| 20 | 1.03 |
| 25 or more | 1.02 |

$$f'_c = 0.9\bar{f}_c\left[1 - 1.28\left[(k_c V)^2 / n + 0.0015\right]^{0.5}\right]$$

[CSA S6]

# Annex 14.1 – Material Strengths

- Reinforcing Steel
  - *"The procedure for calculating the yield strength for evaluation gives the 10% characteristic value of the static yield strength, which is slightly conservative with respect to the values assumed in setting the resistance factors (Mirza and MacGregor 1982). It is assumed that the difference between the yield strength from a coupon test and the static yield is 24 MPa."*

| $n$ | $k_s$ |
|---|---|
| 3 | 3.46 |
| 4 | 2.34 |
| 5 | 1.92 |
| 6 | 1.69 |
| 8 | 1.45 |
| 10 | 1.32 |
| 12 | 1.24 |
| 16 | 1.14 |
| 20 | 1.08 |
| 25 | 1.03 |
| 30 or more | 1.00 |

$$f_y = \left(\overline{f}_y - 24\right)\exp\left(-1.3k_sV\right)$$

[CSA S6]

# Clause 14.7 – Material Strengths

### 14.7.4.2 Structural steel

If plans and mill certificates are not available, and coupons have not been taken for testing, the values specified in Table 14.1 shall be used for structural steel.

**Table 14.1**
**Properties of structural steel**
(See Clause 14.7.4.2.)

| Date of bridge construction | Specified $F_y$, MPa | Specified $F_u$, MPa |
|---|---|---|
| Before 1905 | 180 | 360 |
| 1905–1932 | 210 | 420 |
| 1933–1975 | 230 | 420 |
| 1976–1997 | 300 | 450 |
| After 1997 (plates) | 350 | 450 |
| After 1997 (remainder) | 300 | 450 |
| Weathering steel (any date) | 350 | 450 |

### 14.7.4.3 Concrete

If plans and specifications are not available and cores have not been obtained, the compressive strength of concrete with no visible signs of deterioration shall be taken as 15 MPa for the substructure, 20 MPa for the superstructure, and 25 MPa for prestressed concrete components.

[CSA S6]

# Clause 14.7 – Material Strengths

**Table 14.2**
**Minimum yield strengths of reinforcing steel, MPa**
(See Clause 14.7.4.4.)

| Date of bridge construction | Grade: Structural | Medium or intermediate | Hard | Unknown |
|---|---|---|---|---|
| Before 1914 | — | — | — | 210 |
| 1914–1972 | 230 | 275 | 345 | 230 |
| 1973–1978 | 275 | 345 | 415 | 275 |
| 1979–1991 | 300 | 350 | 400 | 300 |
| After 1991 (stirrups and ties) | 300 | 350 | 400 | 300 |
| After 1991 (remainder) | 300 | — | 400 | 300 |

[CSA S6]