Ministry Contract No. EN1128A003

Reliability evaluation of existing timber bridge deck systems in BC
Phase 2

Dr. R. Foschi, P. Eng
L. Quiroz, UBC

March 30, 2011

PROBLEM

Many bridges used in forestry roads of British Columbia consist of two main steel girders and a timber deck.

The design falls under the Canadian Highway Bridge Code S6.

S6 Code load and resistance factors for timber deck design were calibrated using conditions for Quebec and Ontario, and uncertain timber strengths.

Code provisions in S6 contradict, in some cases, the good performance of the bridges built in BC for many years. Causes: Poor S6 calibration? Other problems?

Typical S6 design equation format:

$$\alpha_d D_N + \alpha_L L_N f = R_N S / \gamma$$

D_N, L_N, R_N are "characteristic" values; f is an impact coefficient

Load factors α and resistance factor γ must be calibrated so that the calculated section property S meets a target reliability level.

Problems: 1) Calculation of L_N , D_N (structural model)
2) Strength values for characteristic resistance R_N
3) Calibration procedure, calibration configurations

APPROACH FOLLOWED IN THIS EVALUATION

To estimate the reliability levels corresponding to existing bridge configurations, to see if those levels are consistent with the aims of S6.

Based on the results, recommend a re-calibration of S6 using BC data?

REQUIREMENTS FOR THIS APPROACH

- Configuration and statistics for gross truck weights of BC vehicles

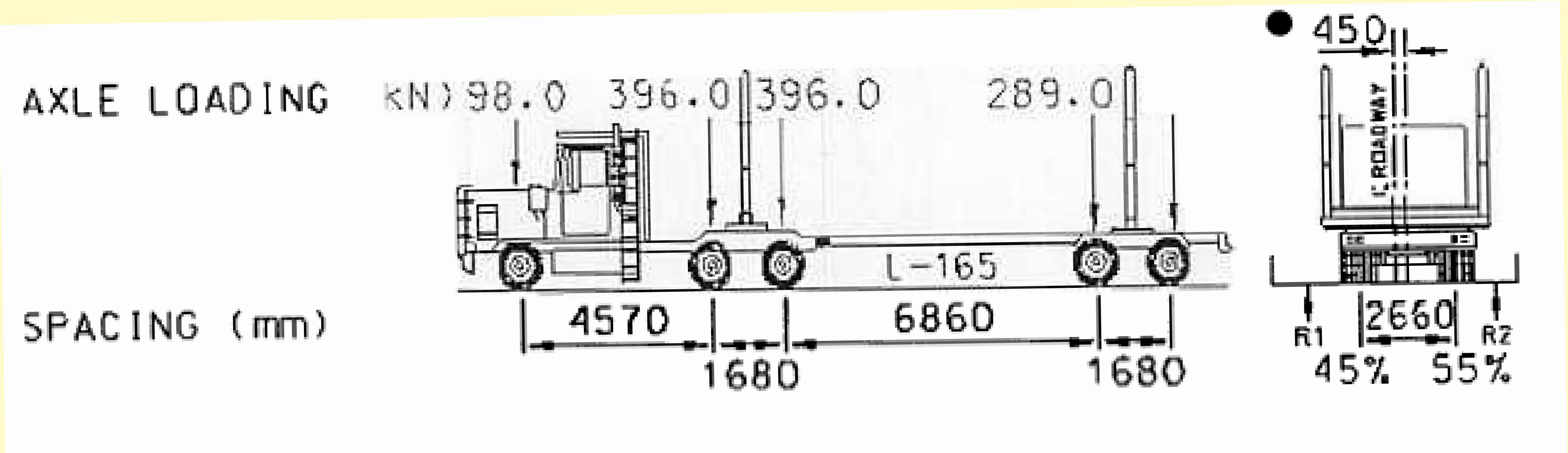
- Mechanical properties and grades (quality) of the timbers used in the decks

- A structural analysis model of the deck system (considering load sharing between ties, mechanical non rigid fasteners, and uncertainty in truck position

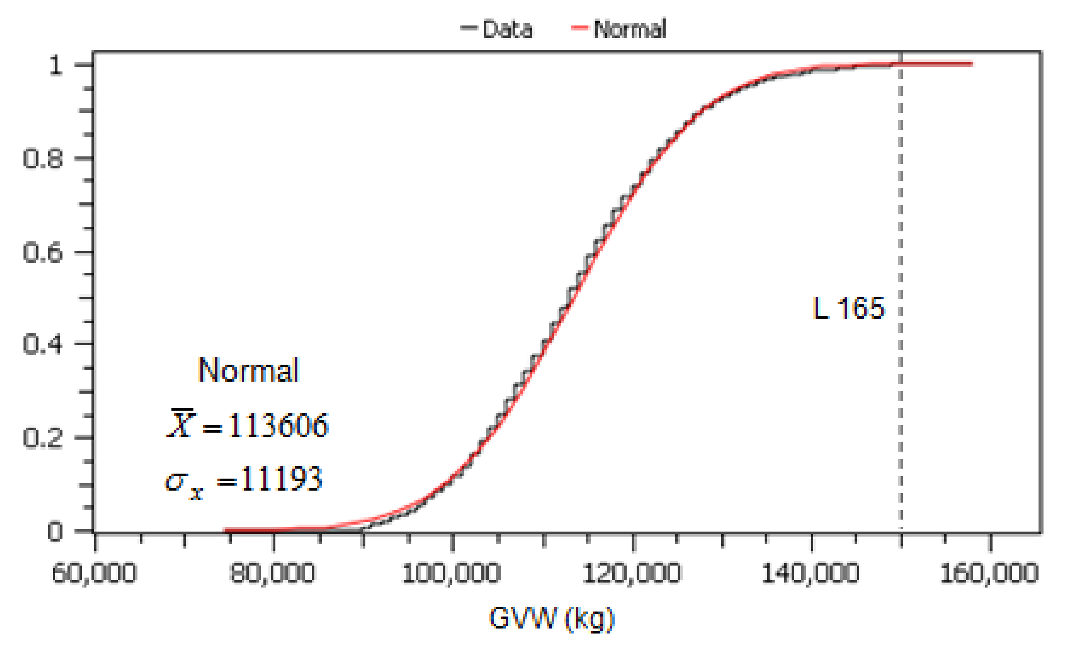
- A definition of performance criteria for bending, shear and compression perpendicular to the grain of the wood

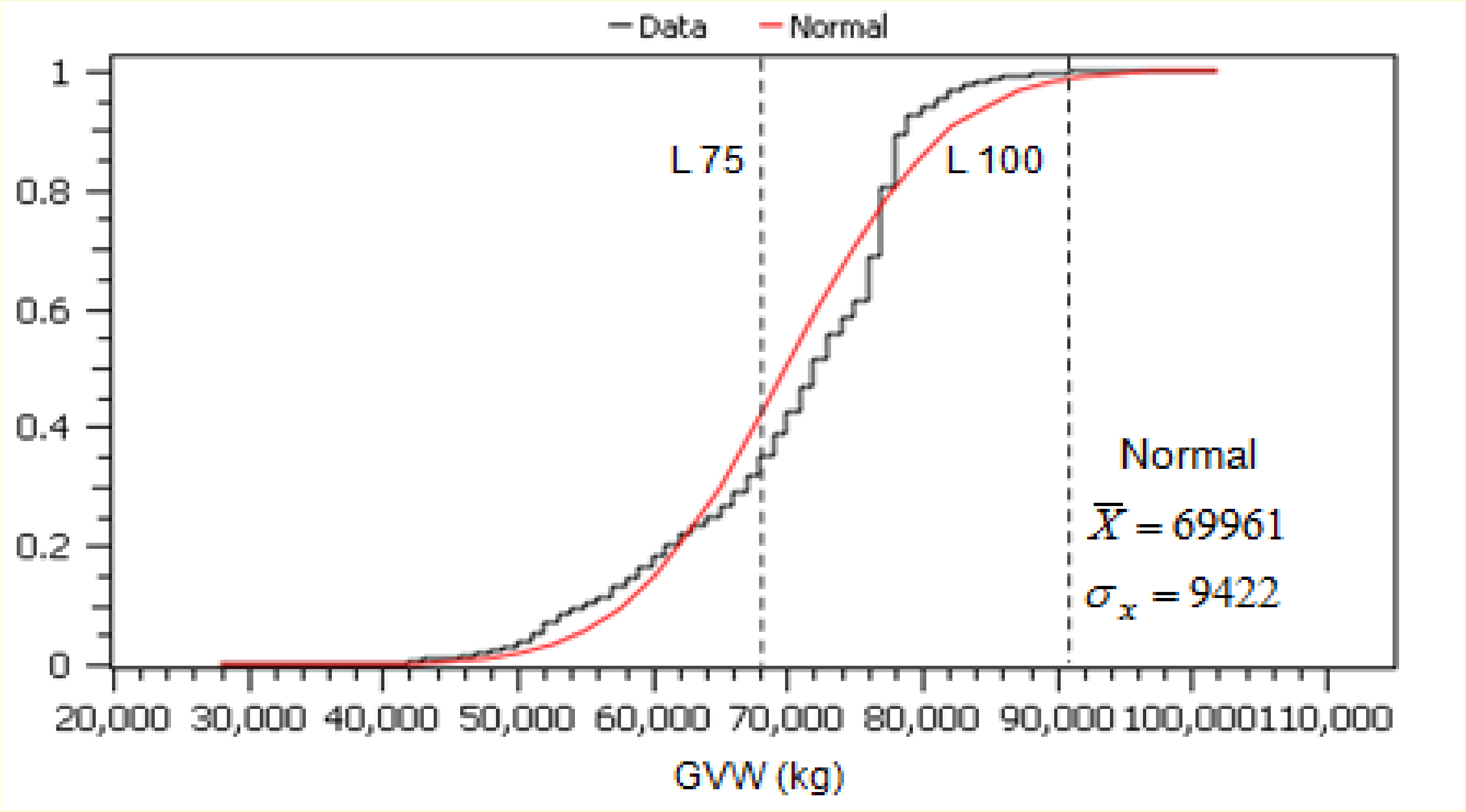
- Calculation of the reliability levels for each performance criteria, considering different scenarios of timber quality and type of trucks.

SURVEY DATA FOR BC TRUCK WEIGHTS (GVW)

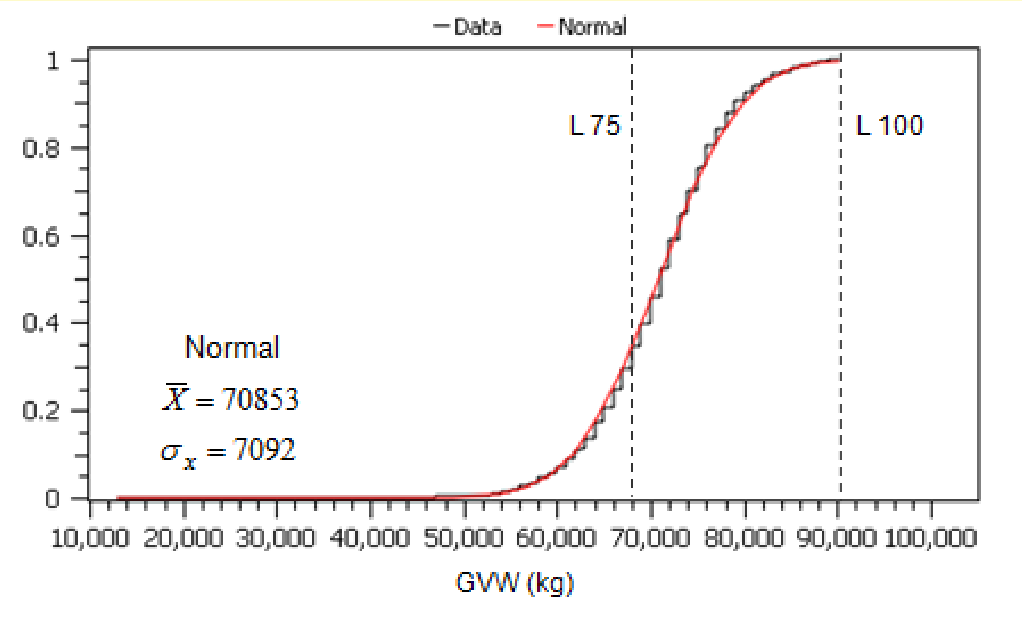


L-165 (OFF HIGHWAY) GVW 149,700 kg

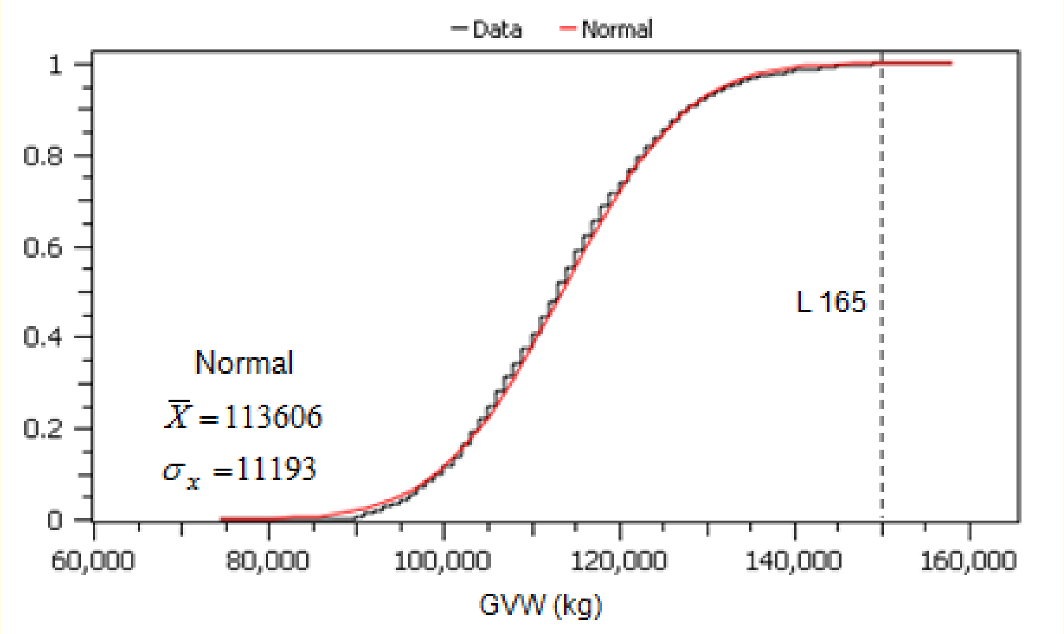




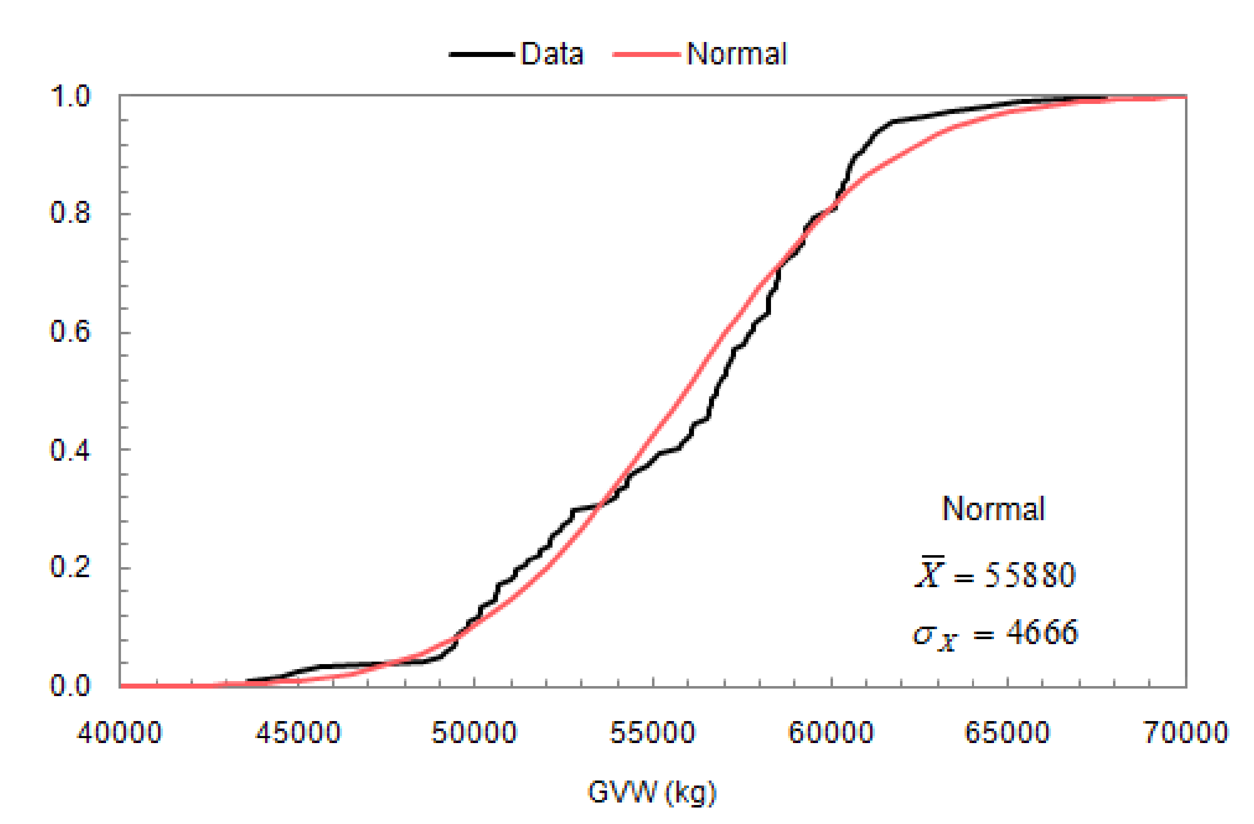
Interior Truck GVW (kg) probability distribution



Coastal lighter trucks GVW (kg) probability distribution (7 axles)

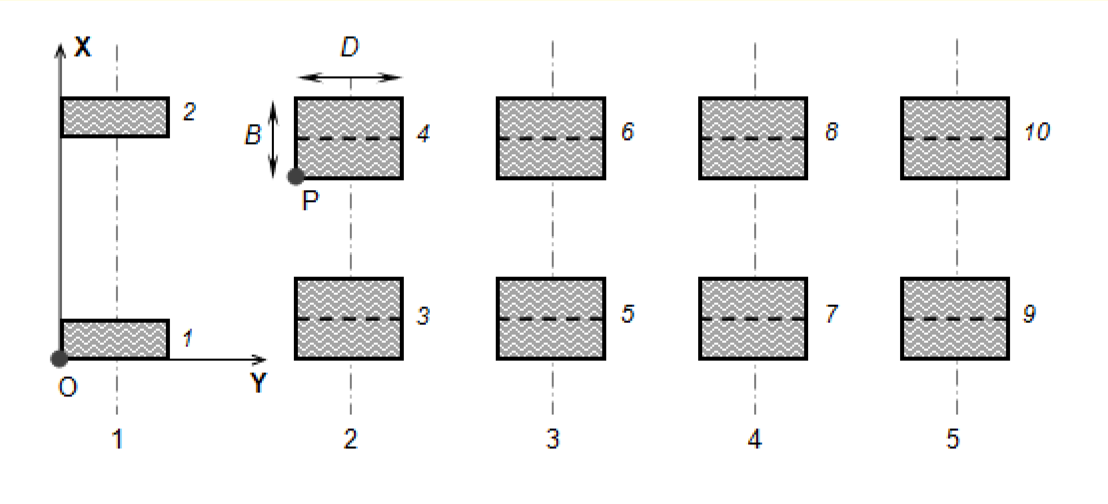


Coastal heavier trucks GVW (kg) probability distribution (5 axles)



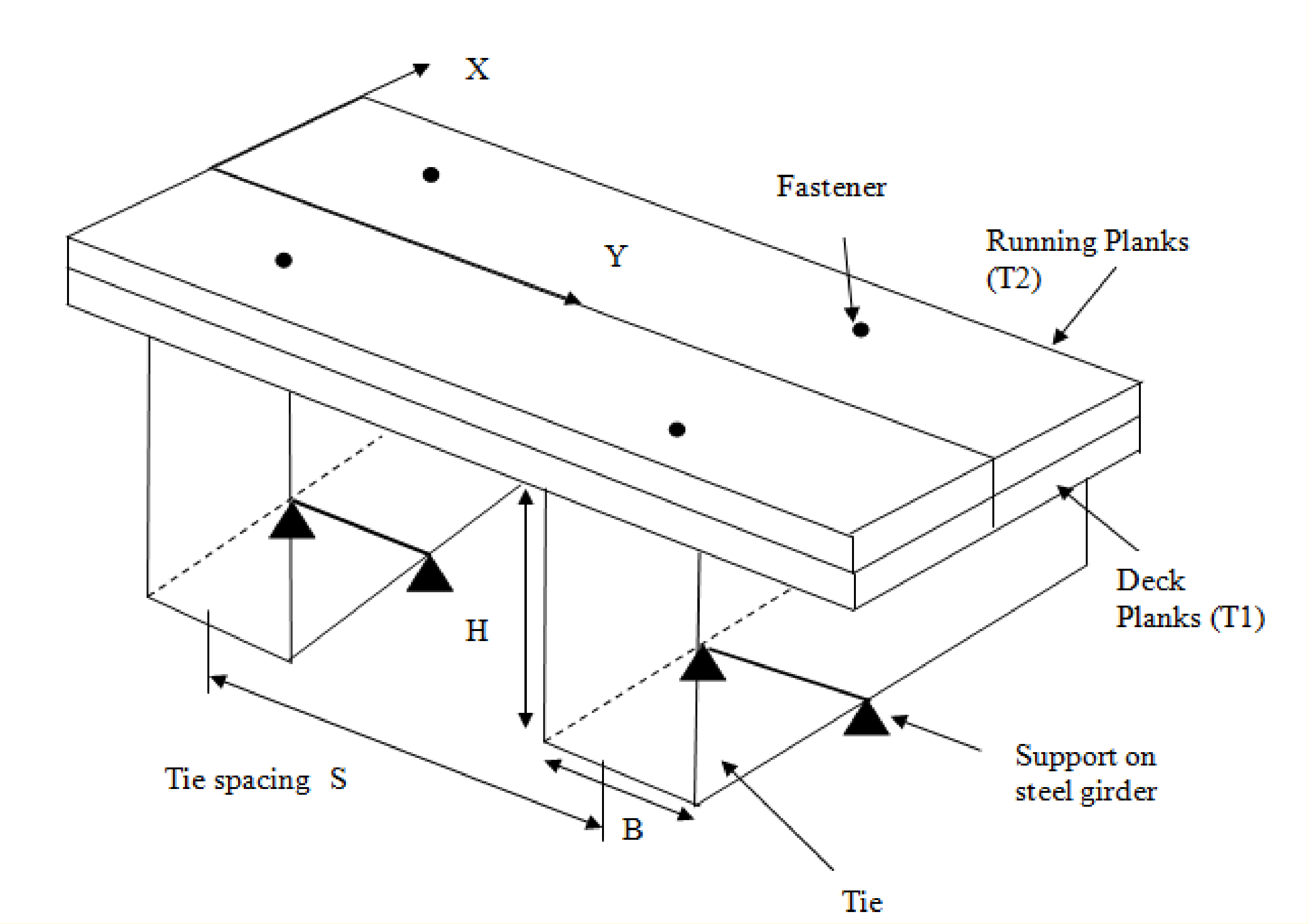
Highway legal trucks GVW (kg) probability distribution

Truck configuration, axle spacing and weight distribution:



- Number of axles
- Tire foot prints (B, D) (load patch)
- Coordinates of points P, for each patch, in reference to point O
- Percentage of total weight carried by each load patch
- The global coordinates of point O, in reference to the bridge, gives the truck location.

STRUCTURAL MODEL



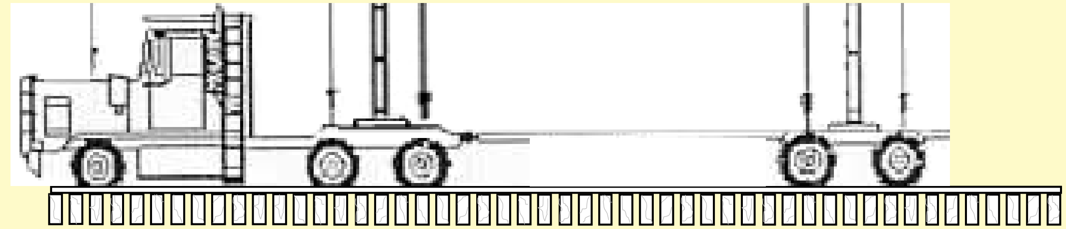
Shape function, beam finite element for the tie:

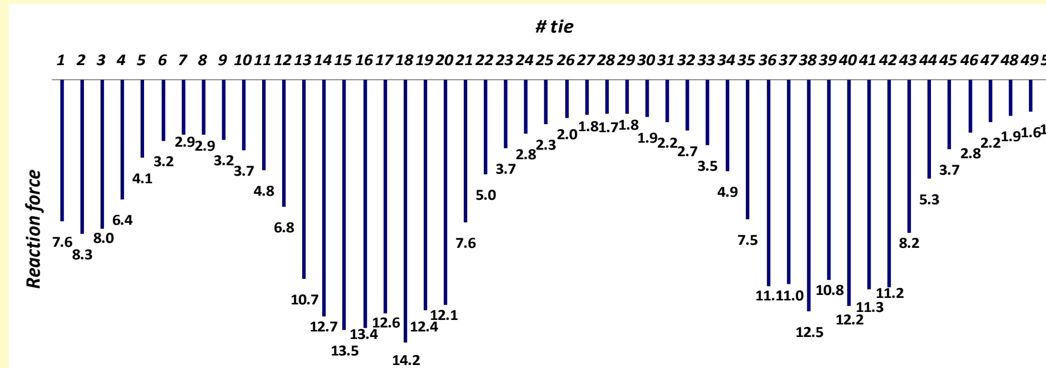
$$w(x) = \theta_1 \cdot \left(x + \frac{x^3}{L^2} - 2 \cdot \frac{x^2}{L} \right) + \omega_1 \cdot \left(1 - 3 \cdot \frac{x^2}{L^2} + 2 \cdot \frac{x^3}{L^3} \right) + \theta_2 \cdot \left(\frac{x^3}{L^2} - \frac{x^2}{L} \right) + \omega_2 \cdot \left(3 \cdot \frac{x^2}{L^2} - 2 \cdot \frac{x^3}{L^3} \right)$$

Shape function, plate finite element for the planks in the deck:

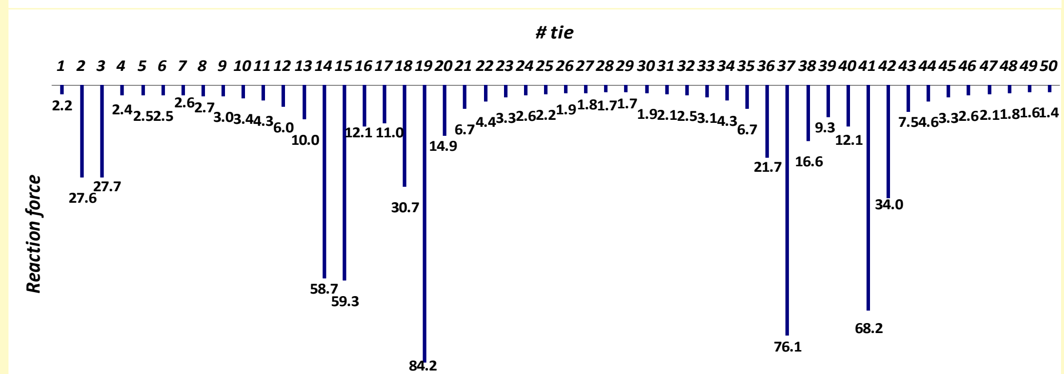
$$\begin{aligned} w(x, y) = {} & \theta_1 \cdot \left(x + \frac{x^3}{L^2} - 2 \cdot \frac{x^2}{L} \right) \cdot \left(1 - 3 \cdot \frac{y^2}{s^2} + 2 \cdot \frac{y^3}{s^3} \right) + \omega_1 \cdot \left(1 - 3 \cdot \frac{x^2}{L^2} + 2 \cdot \frac{x^3}{L^3} \right) \cdot \left(1 - 3 \cdot \frac{y^2}{s^2} + 2 \cdot \frac{y^3}{s^3} \right) \\ & + \theta_2 \cdot \left(\frac{x^3}{L^2} - \frac{x^2}{L} \right) \cdot \left(1 - 3 \cdot \frac{y^2}{s^2} + 2 \cdot \frac{y^3}{s^3} \right) + \omega_2 \cdot \left(3 \cdot \frac{x^2}{L^2} - 2 \cdot \frac{x^3}{L^3} \right) \cdot \left(1 - 3 \cdot \frac{y^2}{s^2} + 2 \cdot \frac{y^3}{s^3} \right) \\ & + \theta_3 \cdot \left(x + \frac{x^3}{L^2} - 2 \cdot \frac{x^2}{L} \right) \cdot \left(3 \cdot \frac{y^2}{s^2} - 2 \cdot \frac{y^3}{s^3} \right) + \omega_3 \cdot \left(1 - 3 \cdot \frac{x^2}{L^2} + 2 \cdot \frac{x^3}{L^3} \right) \cdot \left(3 \cdot \frac{y^2}{s^2} - 2 \cdot \frac{y^3}{s^3} \right) \\ & + \theta_4 \cdot \left(\frac{x^3}{L^2} - \frac{x^2}{L} \right) \cdot \left(3 \cdot \frac{y^2}{s^2} - 2 \cdot \frac{y^3}{s^3} \right) + \omega_4 \cdot \left(3 \cdot \frac{x^2}{L^2} - 2 \cdot \frac{x^3}{L^3} \right) \cdot \left(3 \cdot \frac{y^2}{s^2} - 2 \cdot \frac{y^3}{s^3} \right) \end{aligned}$$

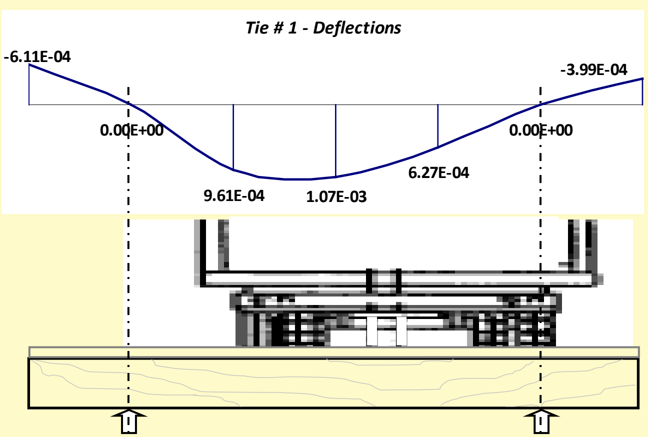
STRUCTURAL ANALYSIS EXAMPLE RESULTS





Reactions on girder supports





Deflections, non-symmetric truck position

RUN DECK

Reliability Analysis - Random variables

56 variables, for 50 ties (program can run up to 60 ties) :

X(1) – X(50) the modulus of elasticity *E* for the ties, Lognormal

X(51) the bending strength for the ties, 2-parameter Weibull distribution

X(52) coordinate X for the location of the truck, Uniform , with limits controlled by the distance between curbs and the truck width

X(53) coordinate Y for the location of the truck along the bridge, Uniform, limits controlled by the lengths of the deck and the truck

X(54) the GVW of the truck, given as ratio between the actual GVW and 1000kN, the load used for the structural analysis

Random Variables (Cont.):

X(55) shear strength of the wood in the tie, given for a unit volume ($1m^3$) under uniform shear, 2-Parameter Weibull

X(56) compression perpendicular strength of the wood in the tie, Lognormal

Performance functions

1.Bending failure:

$$G = X(51) - (X(54)/1000.0)\ f_i\ S_{b\max}$$

2. Shear failure:

$$G = X(55) - (X(54)/1000.0)\ f_i\ \mathrm{T}_{\max}$$

3. Compression perpendicular to the grain failure:

$$G = X(56)\ A - (X(54)/1000.0)\ f_i\ R_{\max}$$

Scenarios considered for reliability analysis

Scenario	Truck data	No. of axles	Tie Spans (m)	Tie dimensions (mm)	Tie spacing (mm)
1	Interior	7	4.30 / 3.00	200 x 250	406
2	Interior	7	4.88 / 3.60	200 x 250	406
3	Coastal	5	4.88 / 3.60	250 x 300	406
4	Highway	7	4.30 / 3.00	200 x 250	406
5	Highway	7	4.88 / 3.60	200 x 250	406
6	Interior	7	4.30 / 3.00	200 x 300	406
7	Interior	7	4.88 / 3.60	200 x 300	406
8	Coastal	5	4.88 / 3.60	250 x 300	305
9	Coastal	5	4.88 / 3.60	250 x 300	406 (*)

Method: FORM, Importance Sampling

(*) Reduced nailing schedule

Bending Strength Characteristics, Douglas fir timbers

Douglas fir Grade	Mean MOE (MPa)	COV MOE (%)	5% MOR (MPa)
Select Structural (SS)	13,600	15.0	32.6
No.1	13,000	15.0	25.3
No.2	13,000	19.0	23.8

Reliability Results (β)

Scenario 1	Bending	Shear	Compression perpendicular
DF SS	3.5	3.0	3.9
DF No.1	3.1	3.0	3.9
DF No.2	3.0	3.0	3.9

Scenario 2	Bending	Shear	Compression perpendicular
DF SS	3.5	3.2	3.5
DF No.1	3.1	3.2	3.5
DF No.2	3.0	3.2	3.5

Scenario 3	Bending	Shear	Compression perpendicular
DF SS	3.3	2.4	3.0
DF No.1	2.8	2.4	3.0
DF No.2	2.6	2.4	3.0

Scenario 4	Bending	Shear	Compression perpendicular
DF SS	4.1	3.4	4.2
DF No.1	3.5	3.4	4.2
DF No.2	3.4	3.4	4.2

Scenario 5	Bending	Shear	Compression perpendicular
DF SS	3.9	3.5	4.6
DF No.1	3.5	3.5	4.6
DF No.2	3.4	3.5	4.6

Scenario 6	Bending	Shear	Compression perpendicular
DF SS	3.6	2.7	3.2
DF No.1	3.2	2.7	3.2
DF No.2	3.1	2.7	3.2

Scenario 7	Bending	Shear	Compression perpendicular
DF SS	3.6	2.9	3.4
DF No.1	3.2	2.9	3.4
DF No.2	3.1	2.9	3.4

Scenario 8	Bending	Shear	Compression perpendicular
DF SS	3.6	2.7	3.7
DF No.1	3.2	2.7	3.7
DF No.2	3.1	2.7	3.7

Scenario 9	Bending	Shear	Compression perpendicular
DF SS	3.2	2.4	3.0
DF No.1	2.8	2.4	3.0
DF No.2	2.6	2.4	3.0

CONCLUSIONS

- Reliability of bridge deck configurations were studied using BC truck configurations and weights, and data on Douglas fir timbers.

- Bending reliability indices are satisfactory and consistent with the aims of the Canadian Highway Bridge Code S6.

- Lower reliability indices were calculated for shear, but this result is based on shear strength data for lumber. More shear data should be collected for timbers .

- Compression perpendicular to the grain does not appear to be a problem.

- Reduced nailing pattern results in a small decrease in reliability in bending.

- The Code S6 calibration should be re-visited using BC conditions.

Are there any questions?

If there are no more questions, I would like to provide you with my contact information:

Dr. Ricardo O. Foschi
Professor Emeritus
Department of Civil Engineering
University of British Columbia
Vancouver, BC V6T 1Z4

Phone: 604 822 2560
Fax: 604 822 6901
E-Mail: rowfa1@civil.ubc.ca

THANK YOU!