WEIGHING IN MOTION AND BRIDGE EVALUATION

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OUTLINE OF PRESENTATION

- DLF and ADR
- Difference between design and evaluation
- A device for showing many truck loads graphically
- Several existing WIM methods
- A new WIM method
- An example

DYNAMIC LOAD FACTOR &

ASSESSMENT DYNAMIC RATIO

- Both are un-measurable entities
- 10 different (published) ways to ‘interpret’ their values from the same data
- 10 different results (Bakht & Pinjarkar, 1990)
- Both DLF and ADR drop with increase in weight
- Both DLF and ADR have never been interpreted from test data for the very high live loads corresponding to ULS

DYNAMIC LOAD FACTOR &

ASSESSMENT DYNAMIC RATIO

- Our recommendation (Mufti, Bakht, Tadros, Horosko, Saltzberg, Sparks, 2006)

DYNAMIC LOAD FACTOR &
ASSESSMENT DYNAMIC RATIO

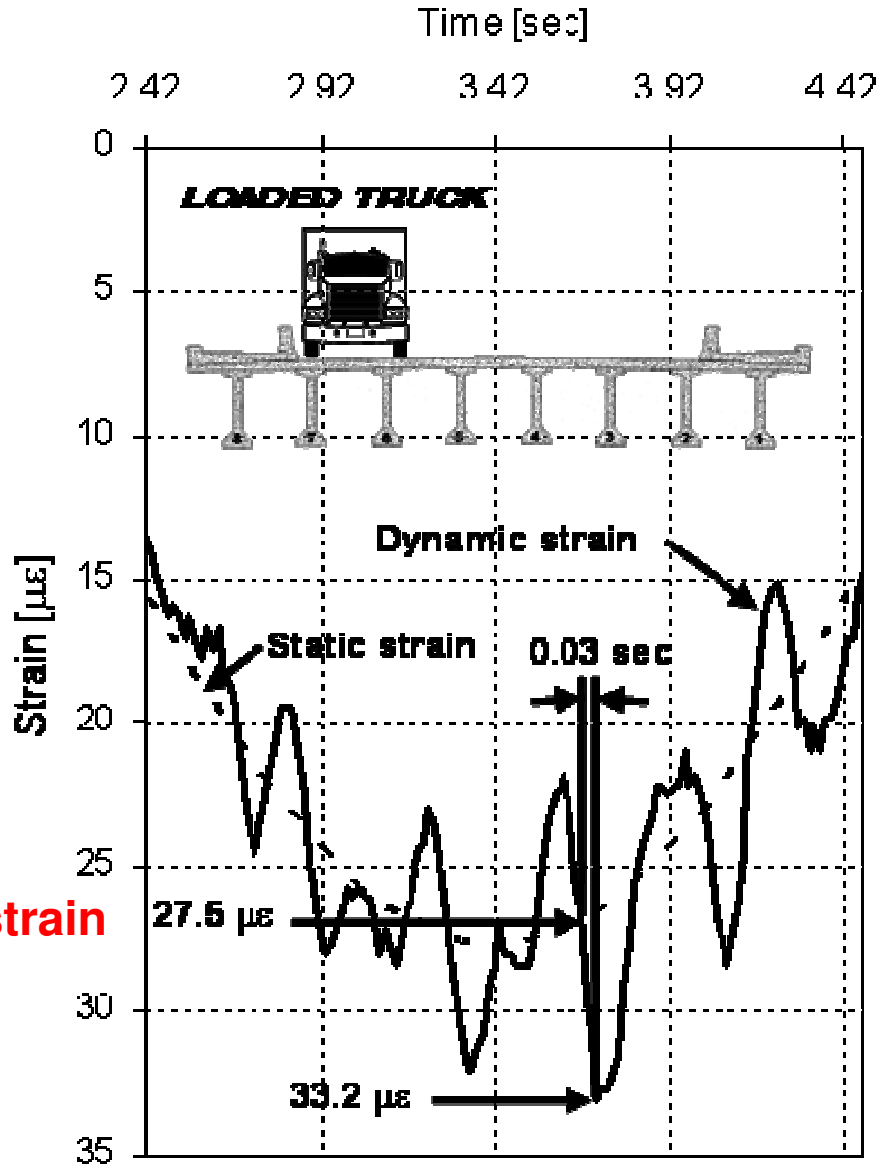
- Drop at least ADR from evaluation of bridge capacity

CLOSE UP OF STRAIN-TIME CURVE FOR TAYLOR BRIDGE

Strain rate above peak 'static' strain

$= (33.2\text{-}27.5)\times10^{-6}/0.03$

$= 1.9\times10^{-4}\ s^{-1}$

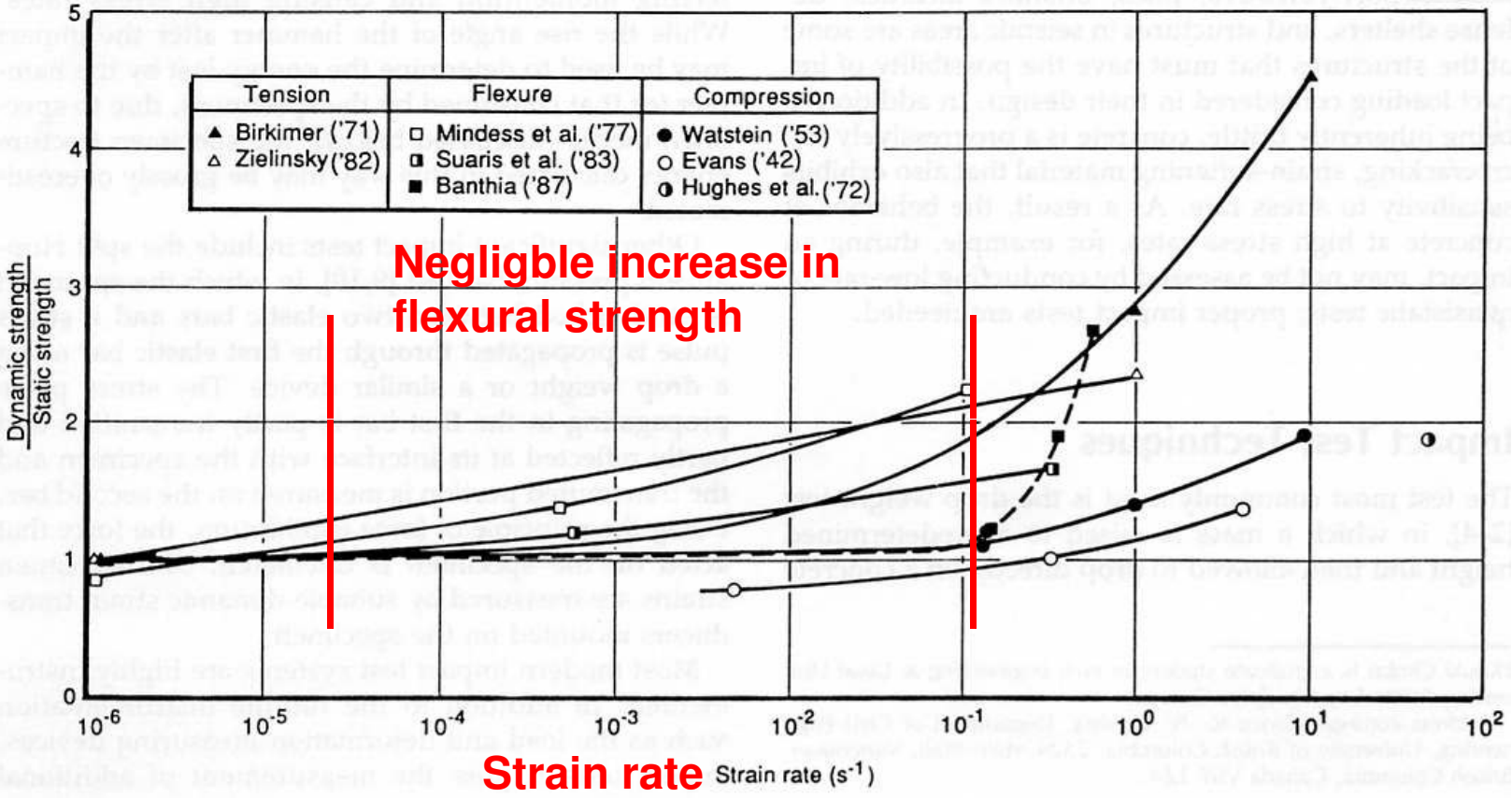


Peak static strain

EFFECT OF STRAIN RATE ON MATERIAL STRENGTH (Banthia 1987)

Dynamic strength

Static strength)



LOW (most ASTM tests)

INTERMEDIATE (dynamic increment)

HIGH (blast loading)

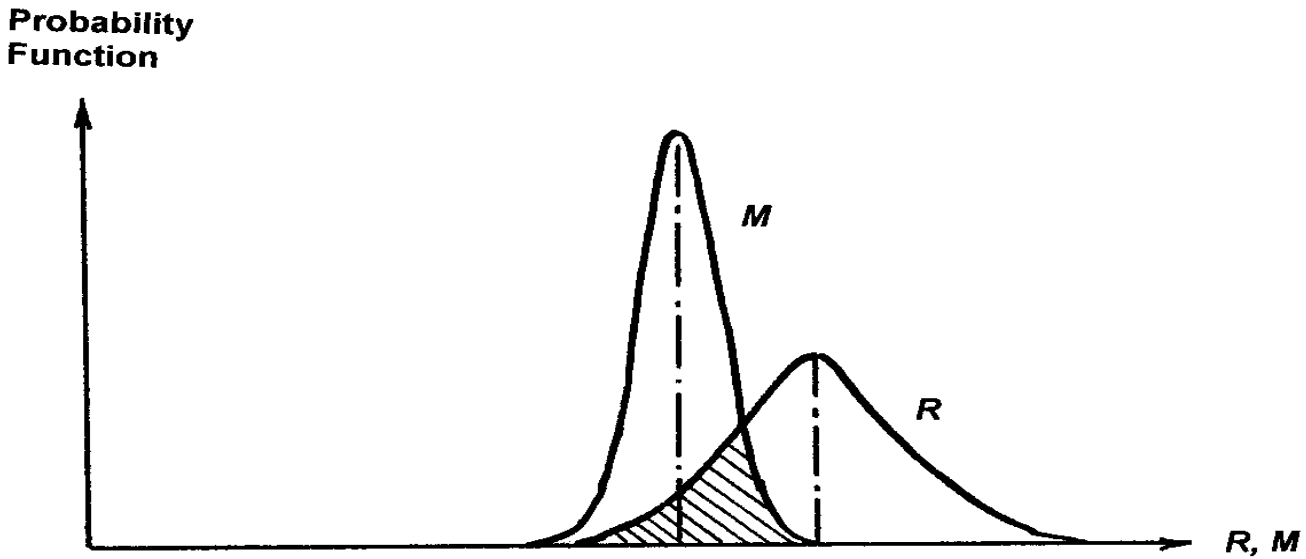
DIFFERENCE BETWEEN DESIGN AND EVALUATION

GIRDERS IN A 4-SPAN BRIDGE

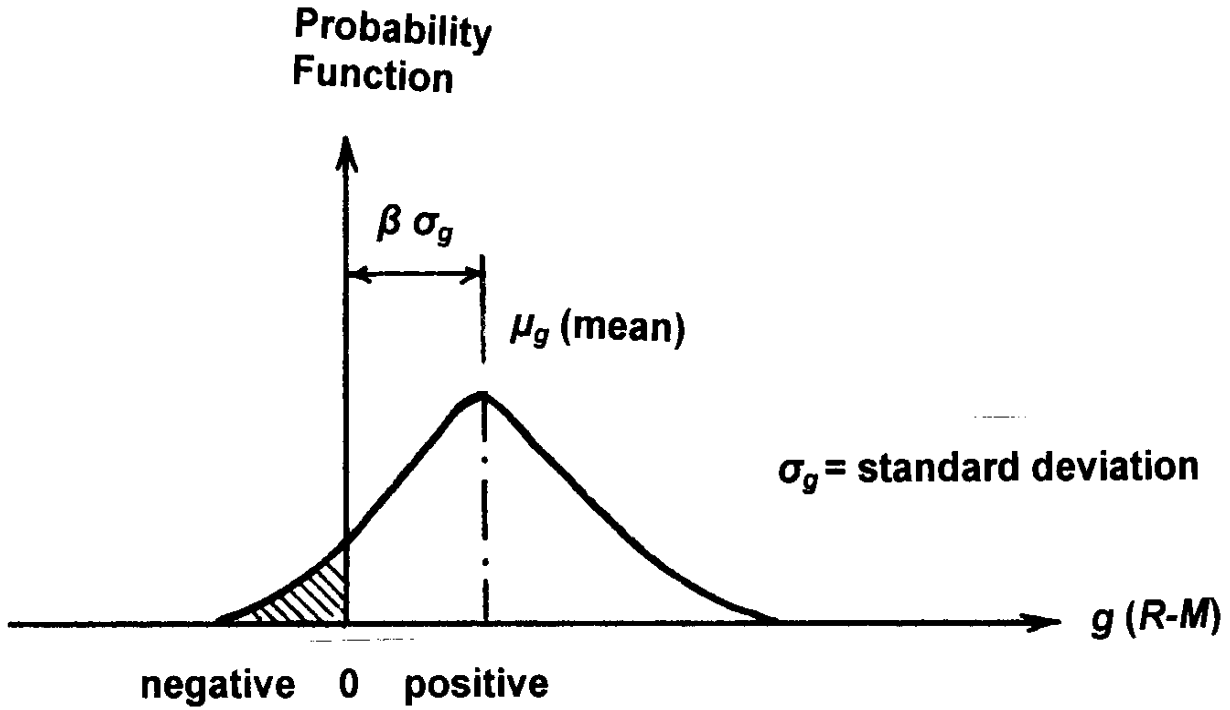
Span 1 Span 2 Span 3 Span 4

Imaginary bridge
Future data obtained by magic for 50 or 100 years

SAFETY INDEX



SAFETY INDEX



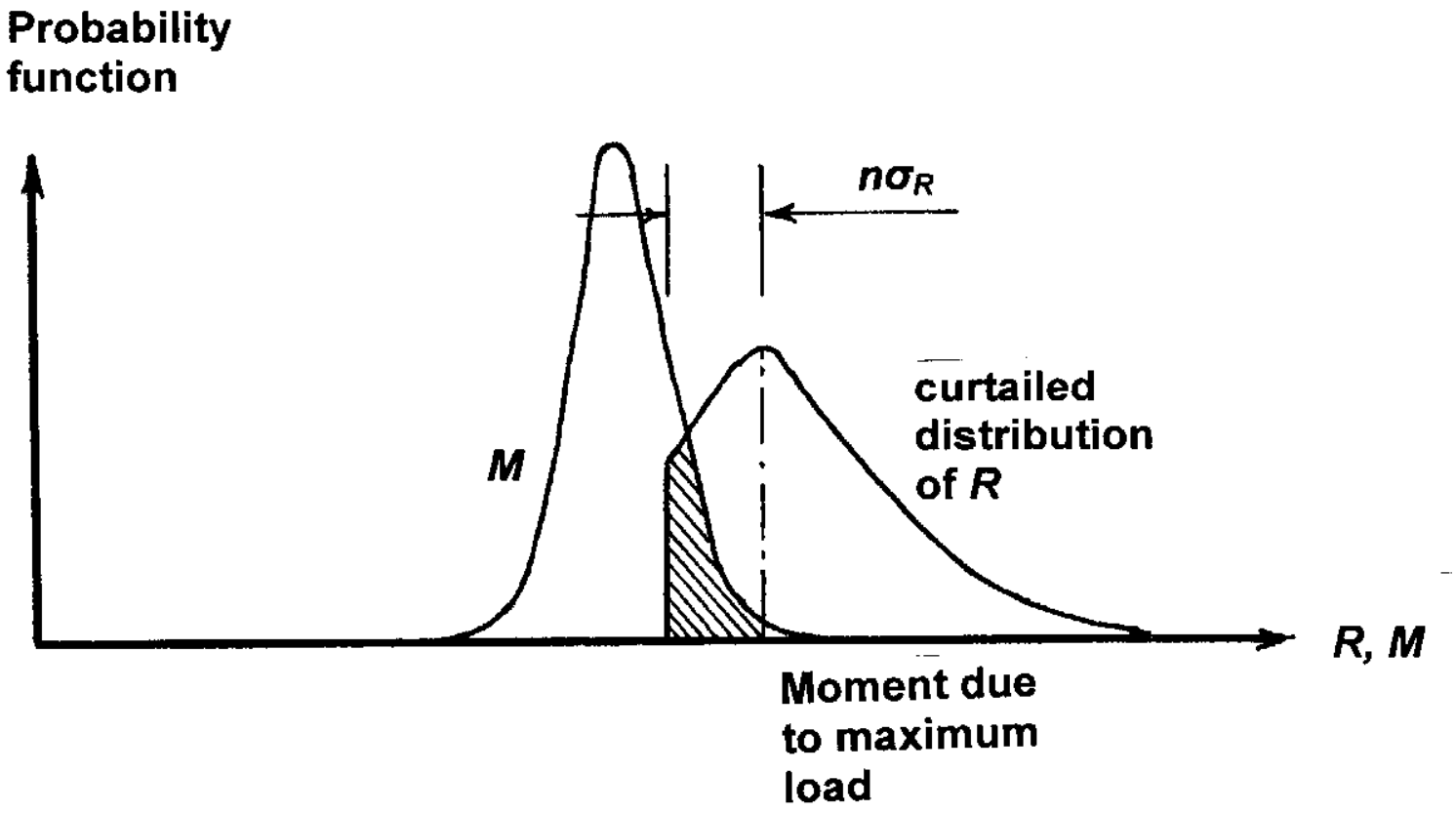
$$\beta = \frac{\mu_R - \mu_M}{\left(\sigma_R^2 + \sigma_M^2\right)^{0.5}}$$

GIRDERS IN A 4-SPAN BRIDGE

Span 1 Span 2 Span 3 Span 4

Real bridge
Data obtained by SHM for 5 year

BASIC DIFFERENCE BETWEEN DESIGN OF A NEW GIRDER AND EVALUATION OF CAPACITY OF EXISTING GIRDER



We can determine what maximum load an existing girder has sustained.

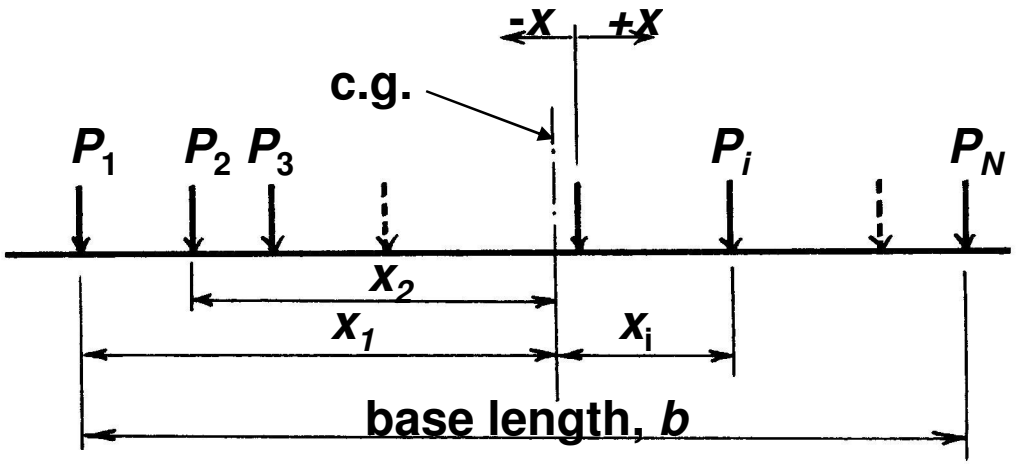
Bakht, Jaeger & Mufti (2004) have given a framework for taking advantage of load effects that a bridge component has sustained

A DEVICE FOR SHOWING MANY TRUCK LOADS AND THEIR SUBCONFIGURATIONS GRAPHICALLY

A histogram of total truck weight is useful but not very helpful in bridge design and evaluation because it lacks the length of the truck

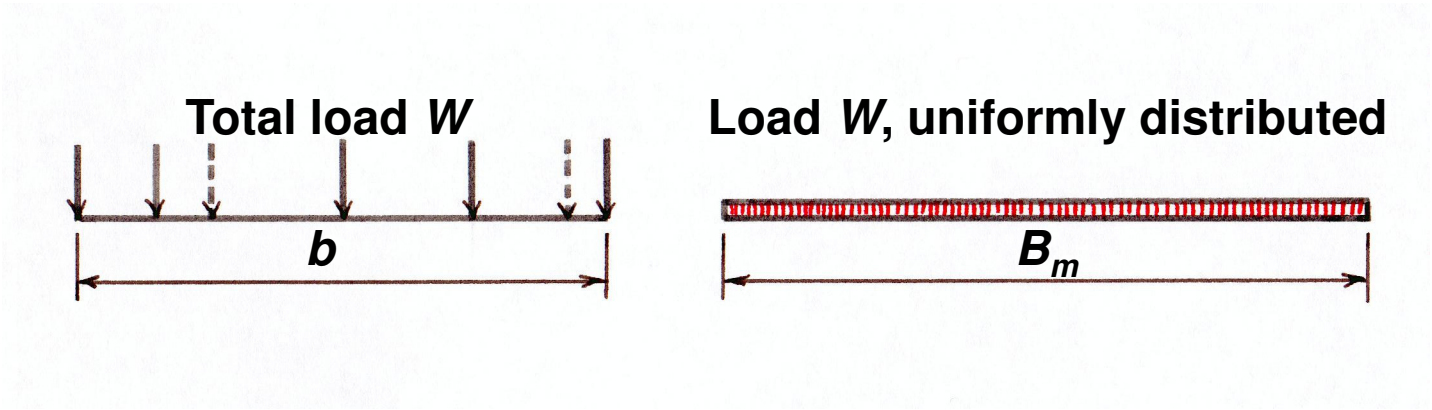
A GIVEN SET OF POINT LOADS

Axle weights of trucks are idealized as point loads



Total weight = *W*

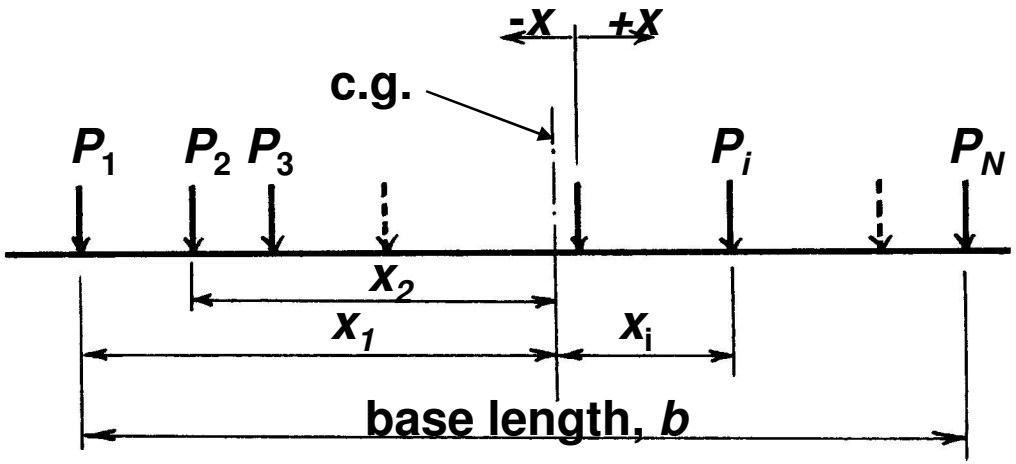
THESE TWO LOADS WILL GIVE NEARLY THE SAME RESPONSES IN SIMPLY SUPPORTED BEAMS



APPROXIMATE EQUATION FOR B_m

$$B_m = \frac{4}{W}\sum_{i=1}^{N}|P_i x_i| - \frac{2(N-1)}{bNW^2}\left\{\sum_{i=1}^{N}(P_i x_i)\right\}^2$$

equivalent base length

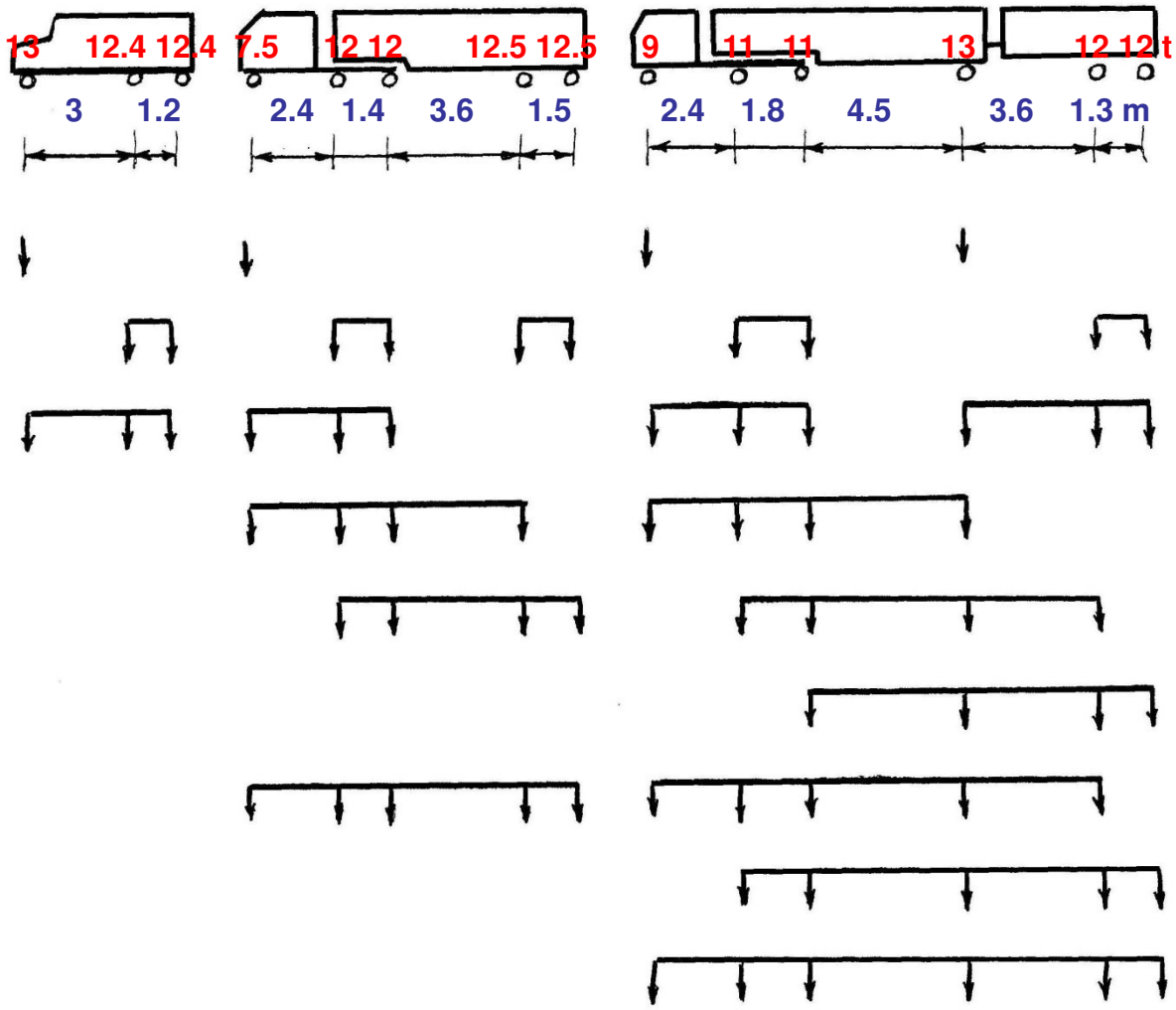


Total weight = W

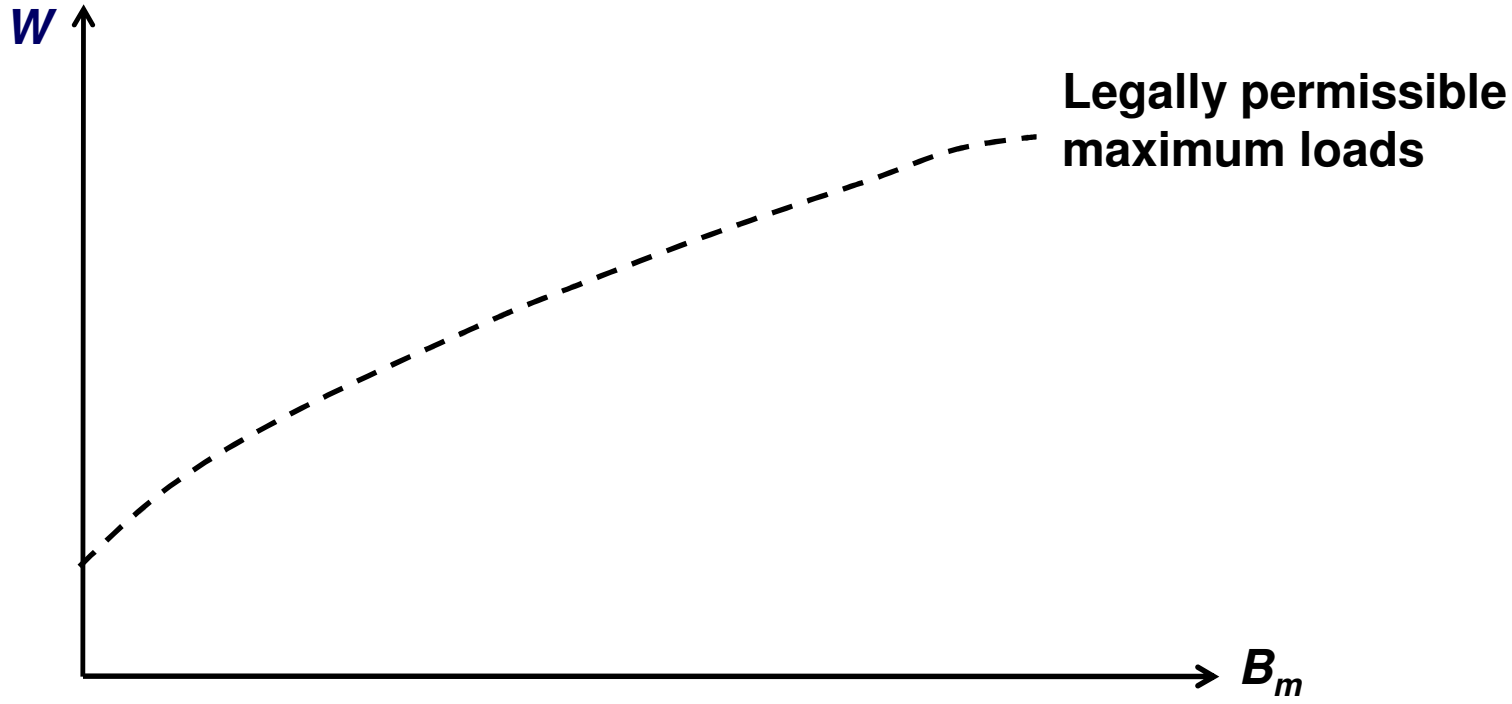
Equation is independent of beam span

EXAMPLE OF THREE ACTUAL TRUCKS

and their sub-configurations



2-D SPACE OF W-B_m



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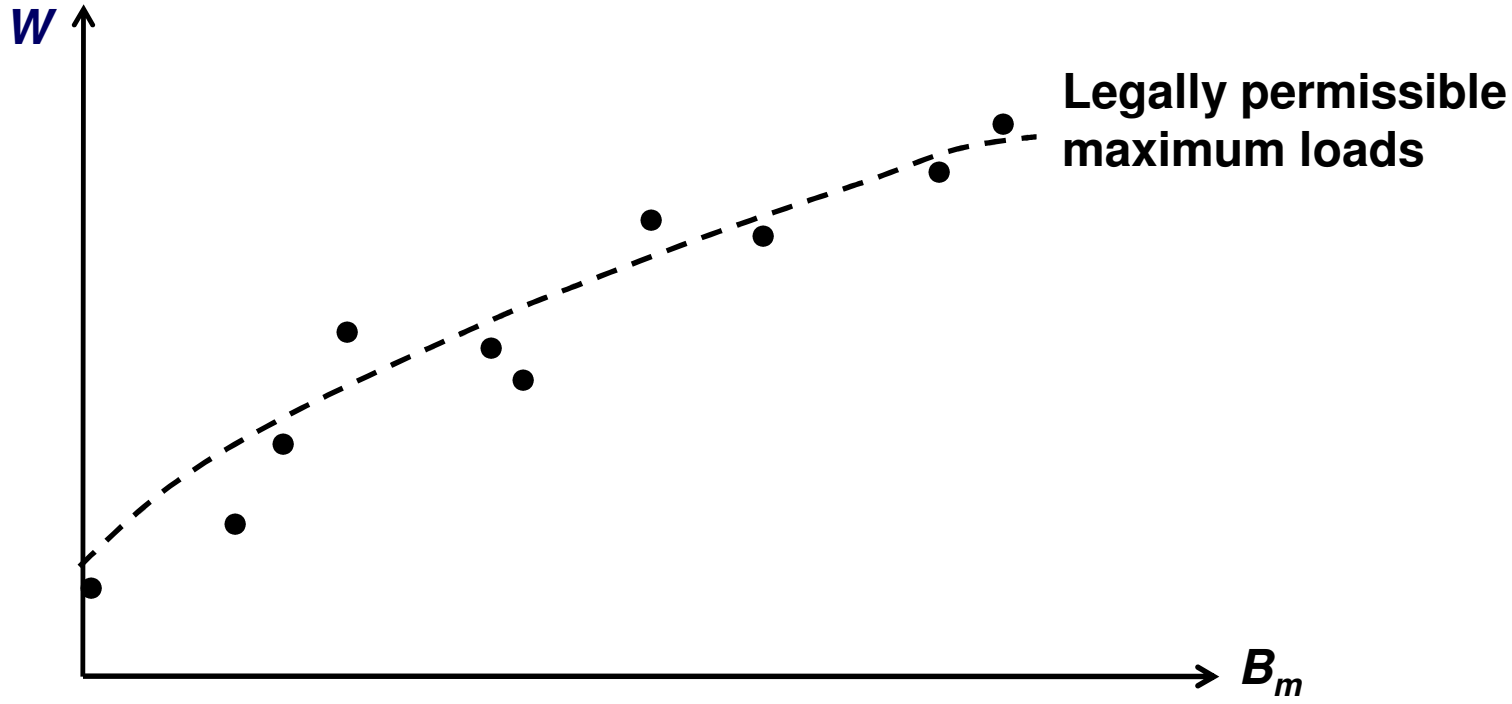
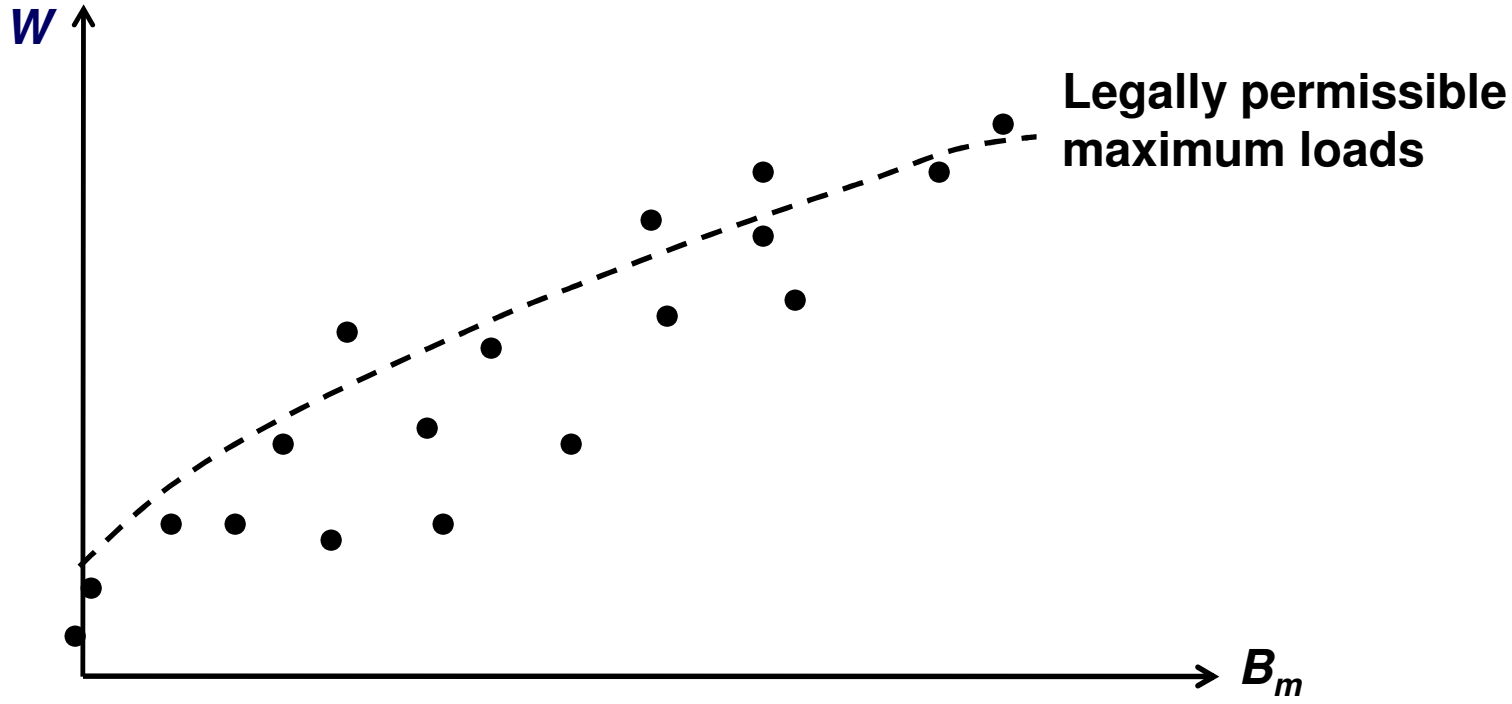
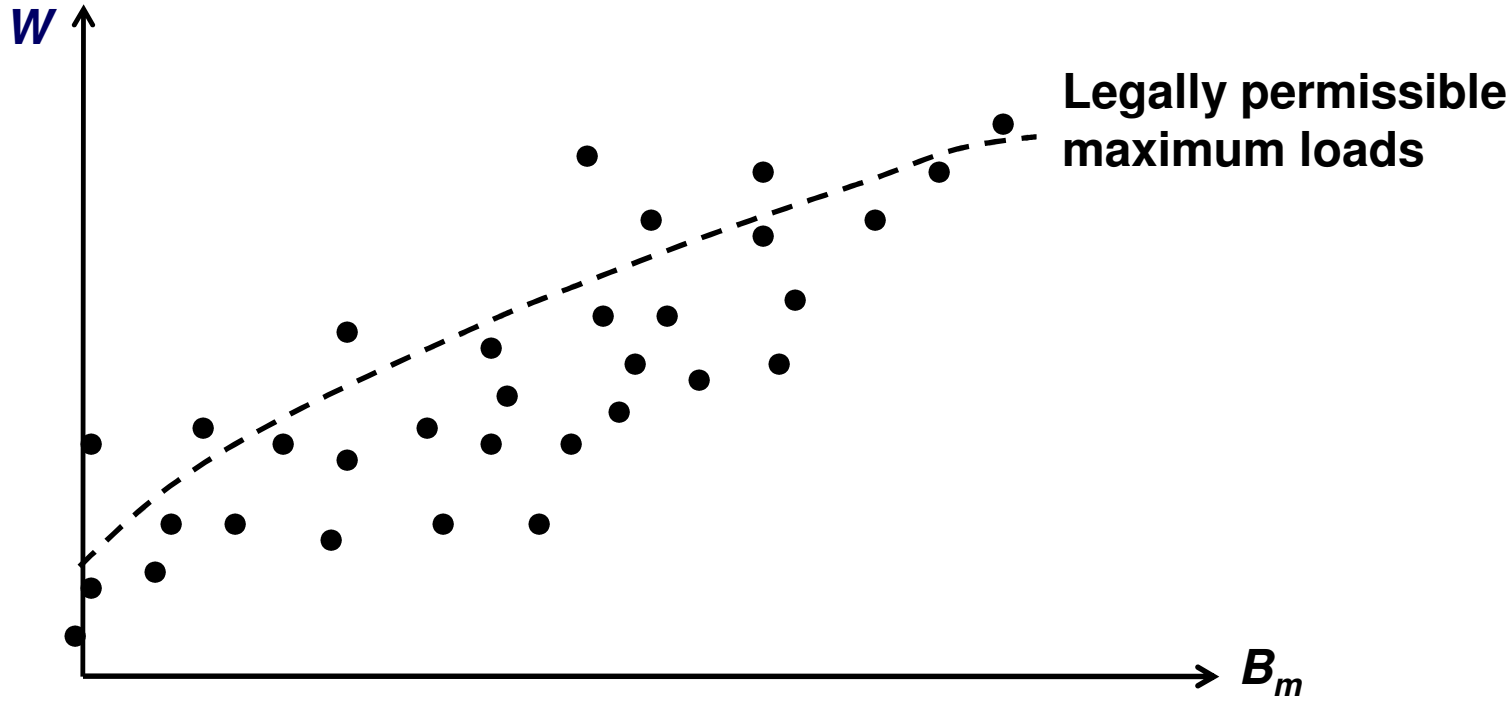


A computer program, TRUCK Mufti et al. (2000), can generate W-B_m points for a given set of axles

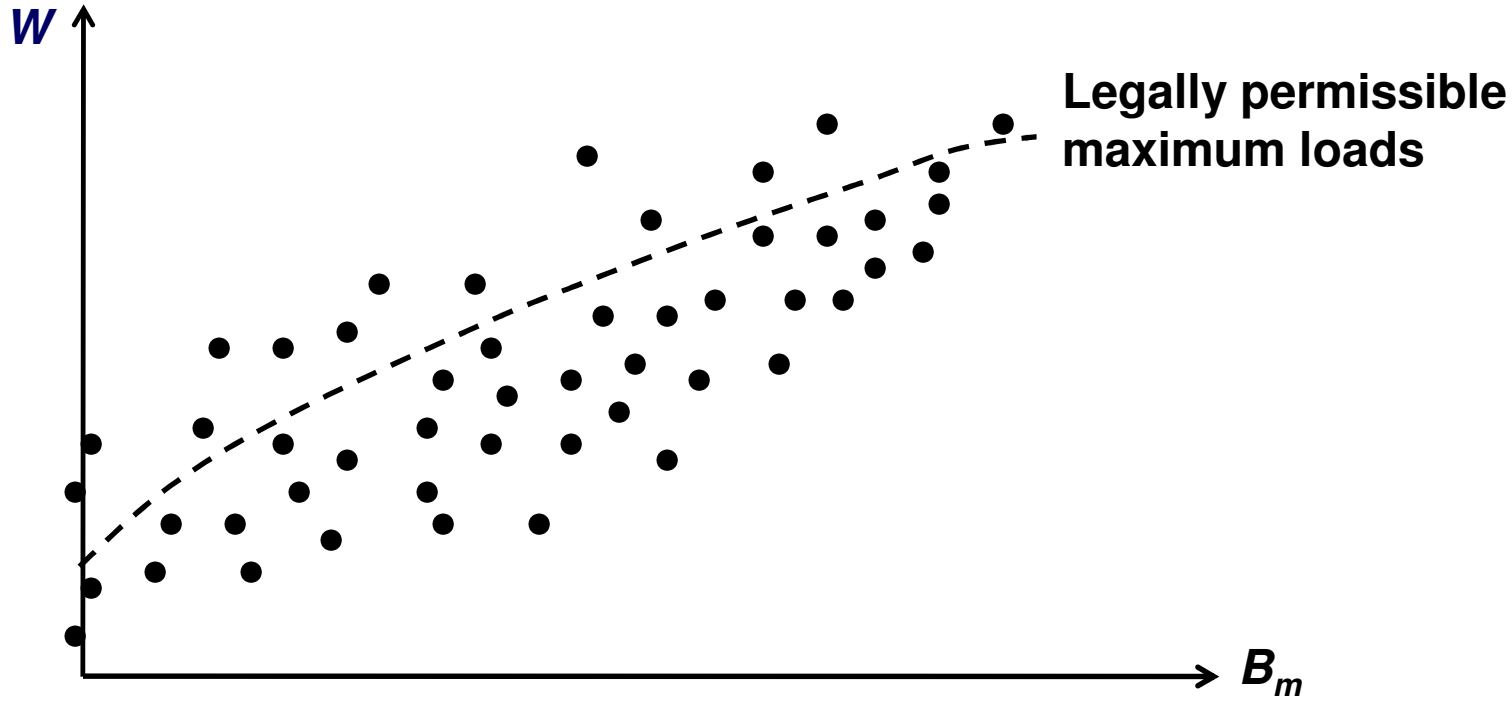
2-D SPACE OF W-B_m



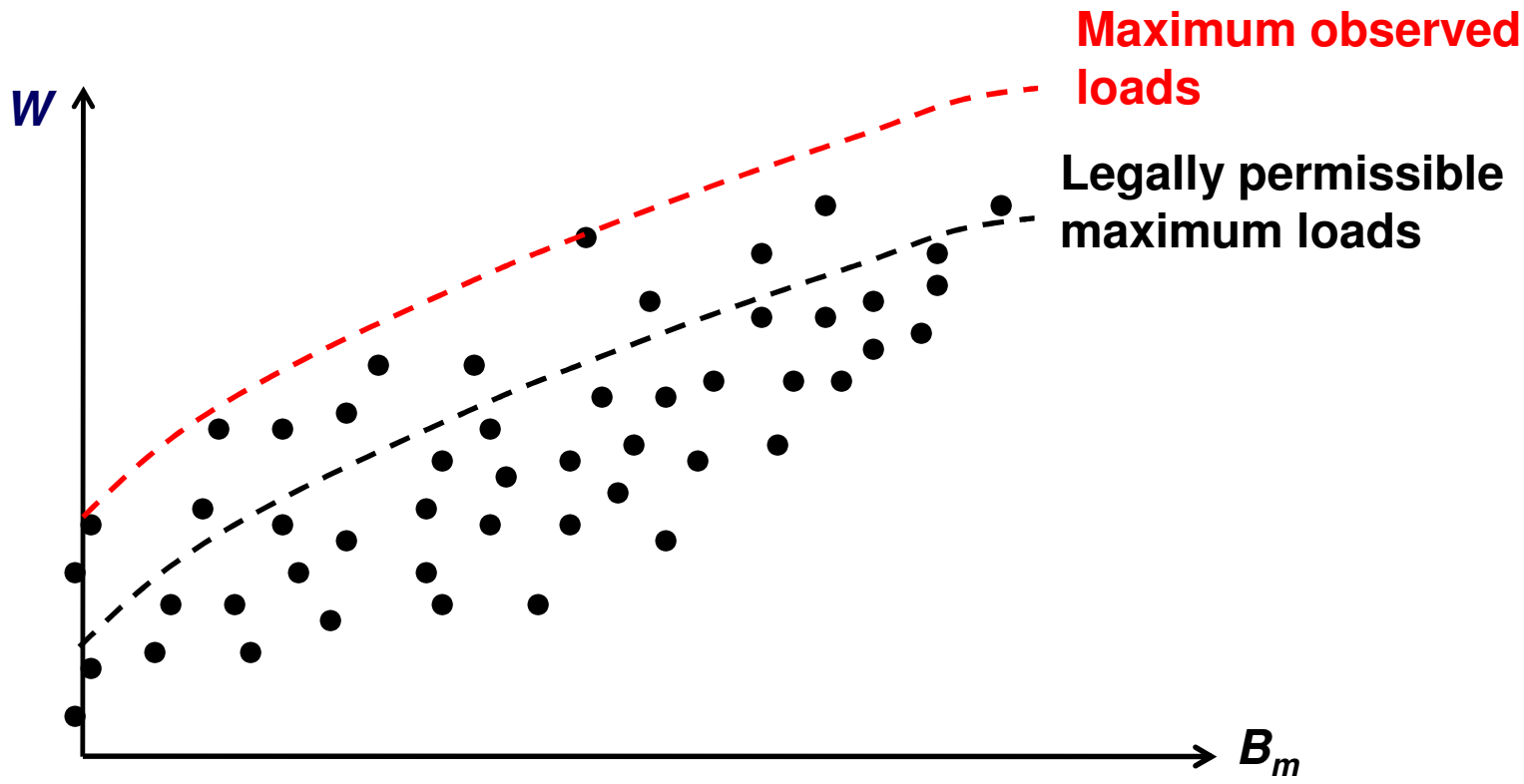
2-D SPACE OF W-B_m



2-D SPACE OF W-B_m



2-D SPACE OF W-B_m



SEVERAL EXISTING WIM METHODS

OHIO method (late 1970s)

- **strain gauges on girders at mid-span**
- **Numbers of axles, their spacings and vehicle speed determined by tape switches**
- **Many knowns, few unknowns**
- **Error function (ill-defined matrix) reduces the No. of knowns to No. of unknowns**
- **Axle weights cannot be determined accurately (up to 50% error)**
- **Total truck weight is determined more accurately**

SEVERAL EXISTING WIM METHODS

ONTARIO method I (early 1980s)

- **Modification of Ohio method**
- **Strain gauges on girders at mid-span**
- **Predetermination of axle Nos. and weights not required**
- **Truck is initially considered to be composed of equally spaced axles (unwanted axles are eliminated by error function)**
- **Axle weight are determined**
- **Highly ill-conditioned equations**
- **Never went beyond the drawing board**

SEVERAL EXISTING WIM METHODS

ONTARIO method II (middle 1980s)

- **strain gauges on girders at mid-span**
- **Predetermination of axle numbers and weights are not required**
- **Truck load represented as UDL**
- **Calculates *W* and B_m**
- **High error**

SEVERAL EXISTING WIM METHODS

ONTARIO method III (middle 1980s)

- **strain gauges on girders at mid-span**
- **Modification of Ontario II method**
- **Calculates W and B_m**
- **Tried with calibrated trucks**
- **Total weight error between -8 and +11%**
- **Error in estimation of B_m large for truck with fewer axles**

SEVERAL EXISTING WIM METHODS

Agarwal & Bakht (1986) demonstrate that errors in data are least magnified by OHIO method

Strain (at mid-span) vs. time plots do not have well-defined peaks corresponding to axle or closely spaced group of axles

All methods predict axle and total loads with a degree of error

SEVERAL EXISTING WIM METHODS

AUSTRALIA method (mid 1990s)

- **Uses small span concrete box culverts with fill at top (to minimize dynamic effects)**
- **Strain-time plots have well-defined peaks corresponding to axles**
- **Strain transducer at mid-spans**
- **Measures axle weights fairly accurately (provided that transverse position of truck is known, or there are many transducers)**
- **Does not measure axle spacings**
- **Strain transducers drift a lot**

SEVERAL EXISTING WIM METHODS

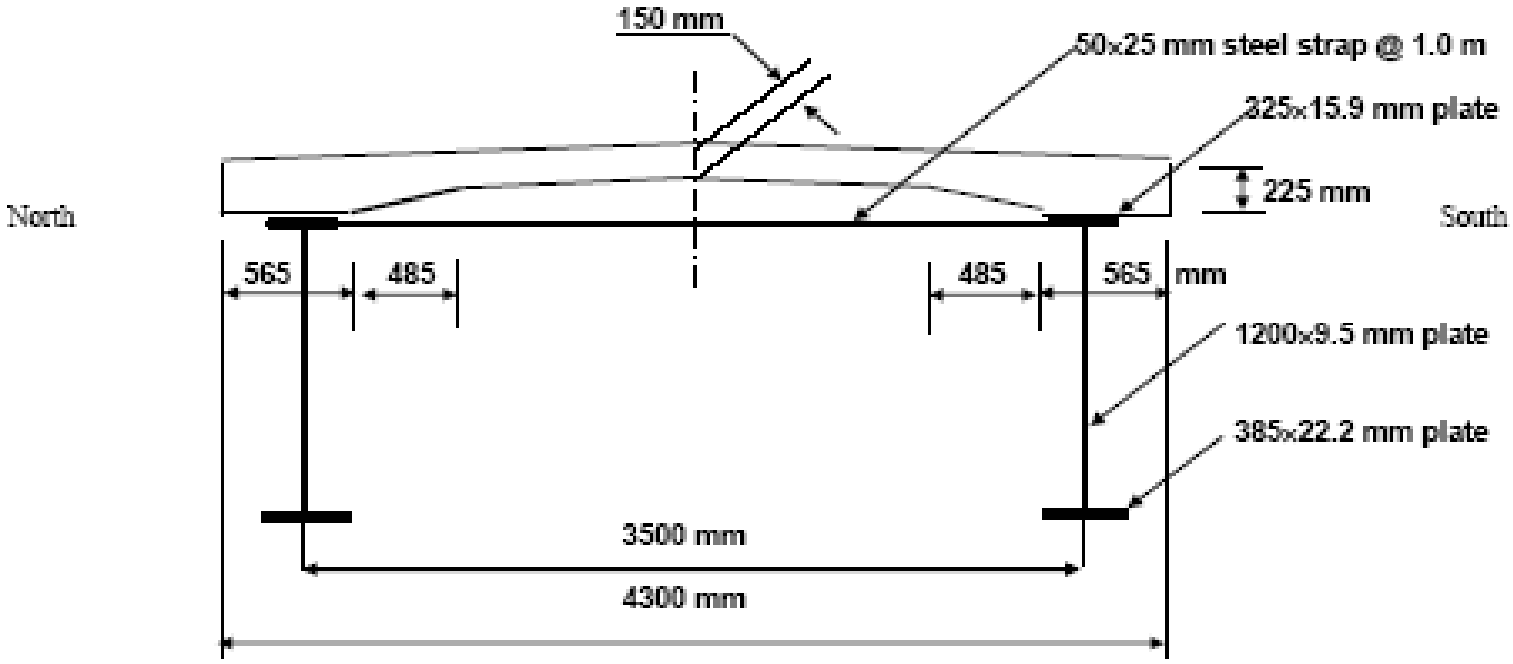
JAPAN method (early 2000s)

- **Uses strain gauges on vertical stiffeners of support diaphragms**
- **Well-defined peaks**
- **Has good potential, but good accuracy of prediction is yet to be demonstrated**
- **Some stiffeners on support diaphragms are subjected to the effects of transverse bending as well.**

A NEW WIM METHOD

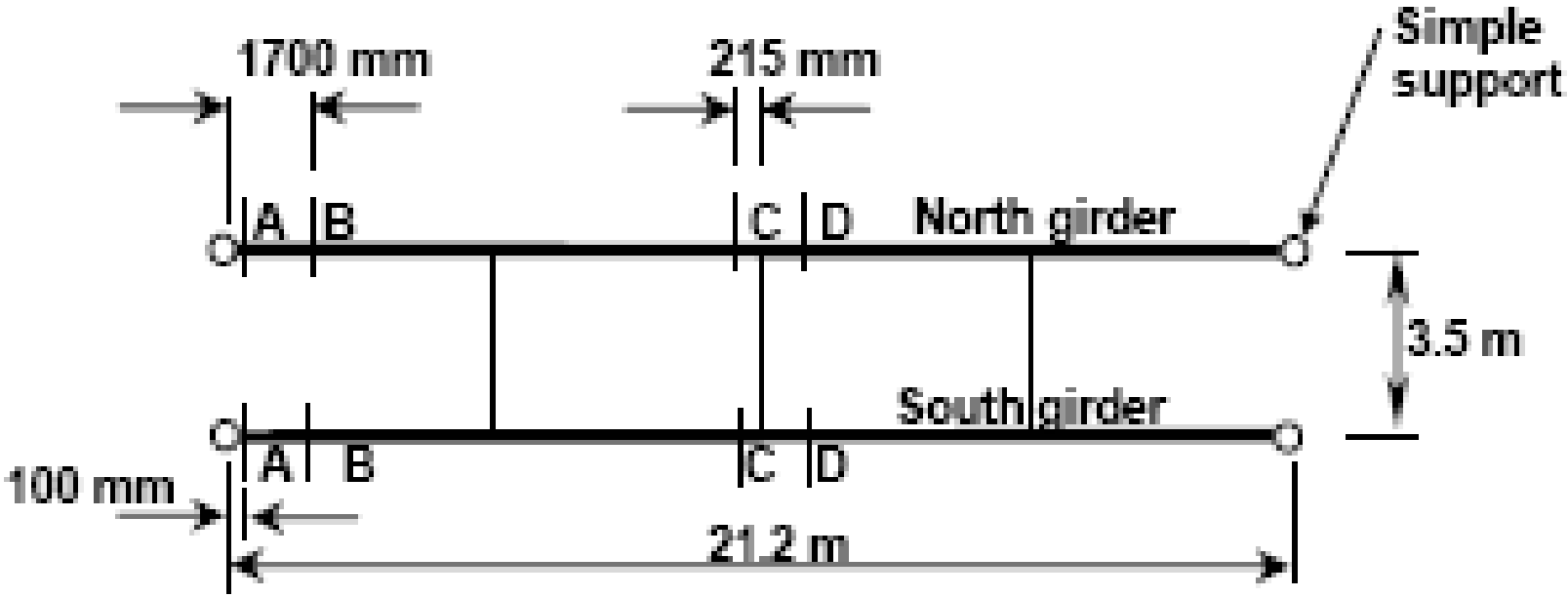
- Modification of Japanese method
- Call it Winnipeg method

LINDQUIST BRIDGE



Note: 150 mm thick slab has no tensile reinforcement

LINDQUIST BRIDGE

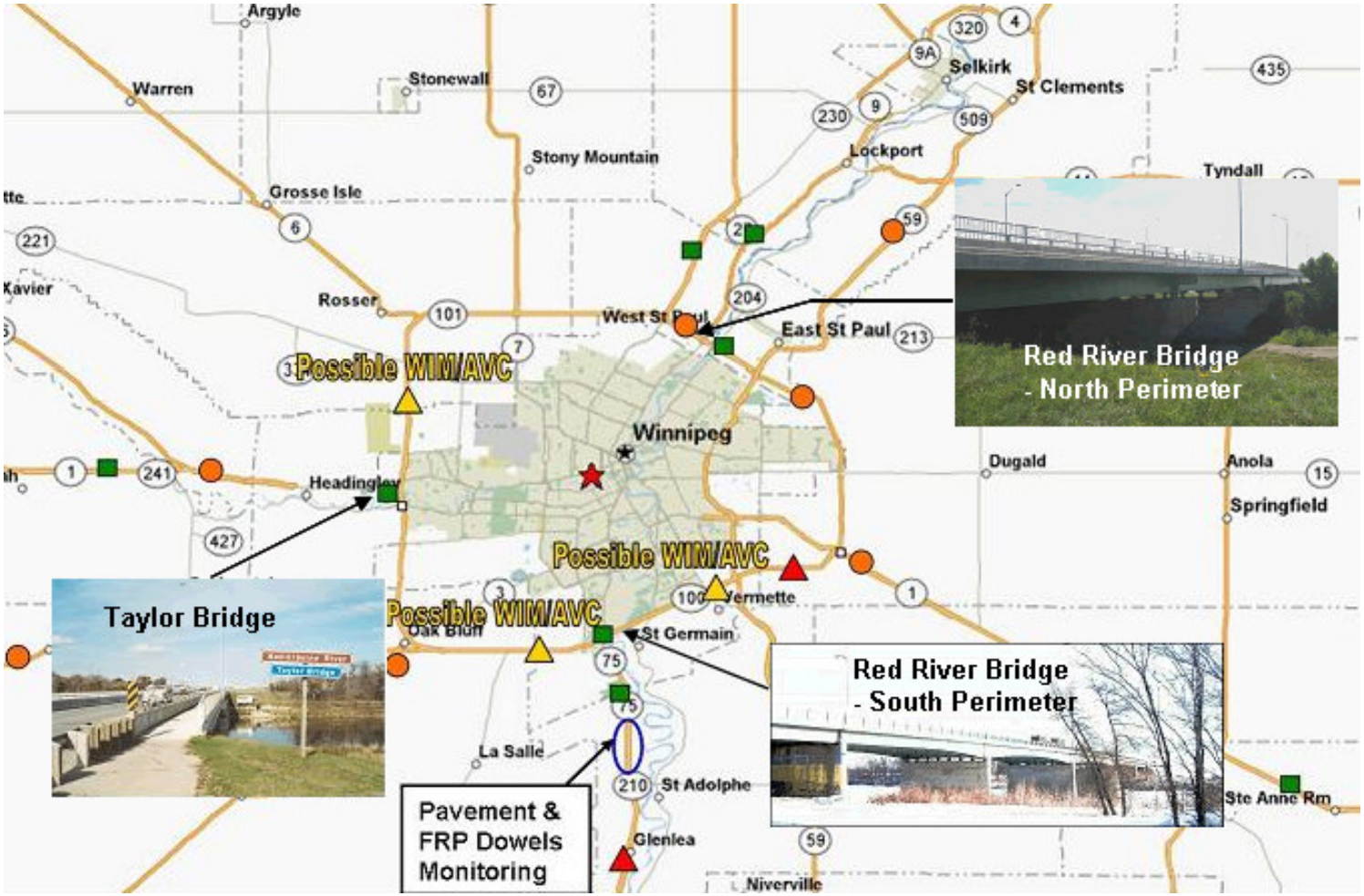


Plan of bridge

Strain gauges, meant for Section A, were placed in error at Section B

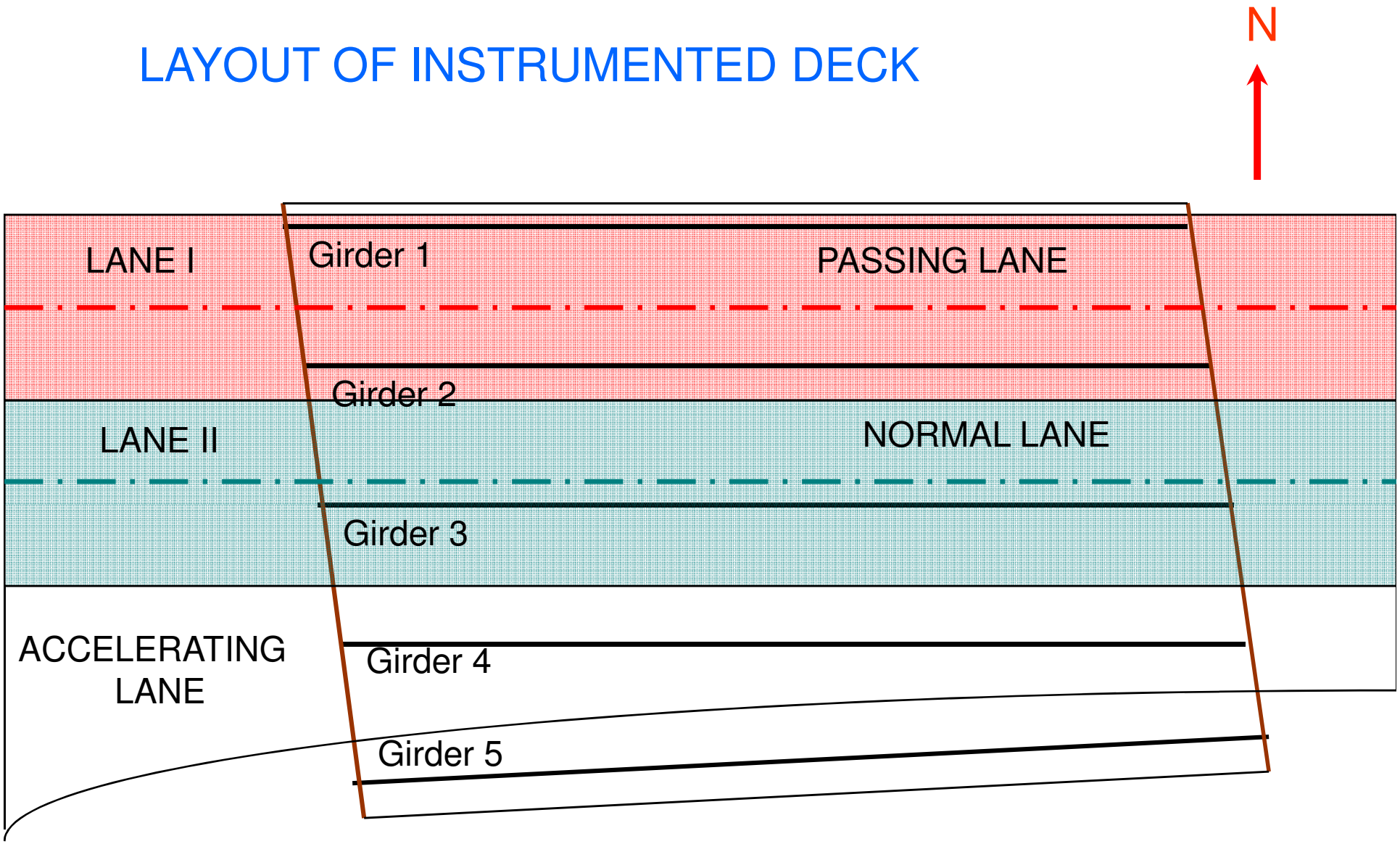
Strain-time curve at Section B had well-defined peaks for each axle load (concept of Winnipeg method)

PERIMETER HIGHWAY AROUND WINNIPEG, A LAB

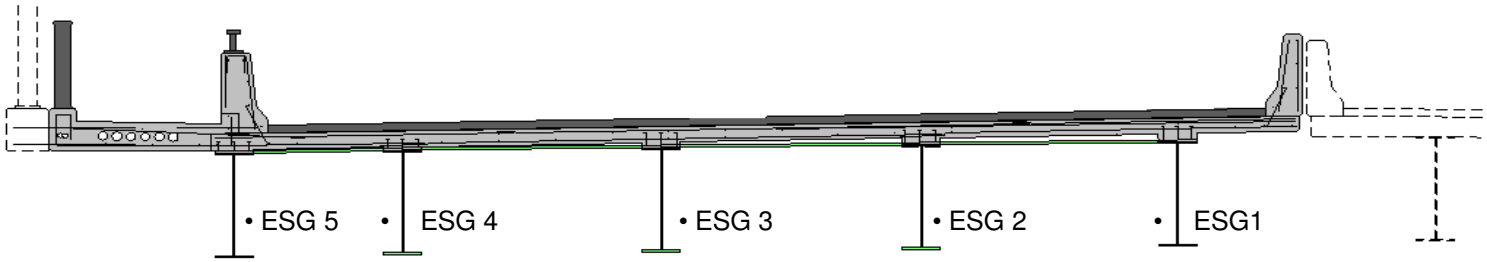


AN EXAMPLE OF WINNIPEG WIM METHOD

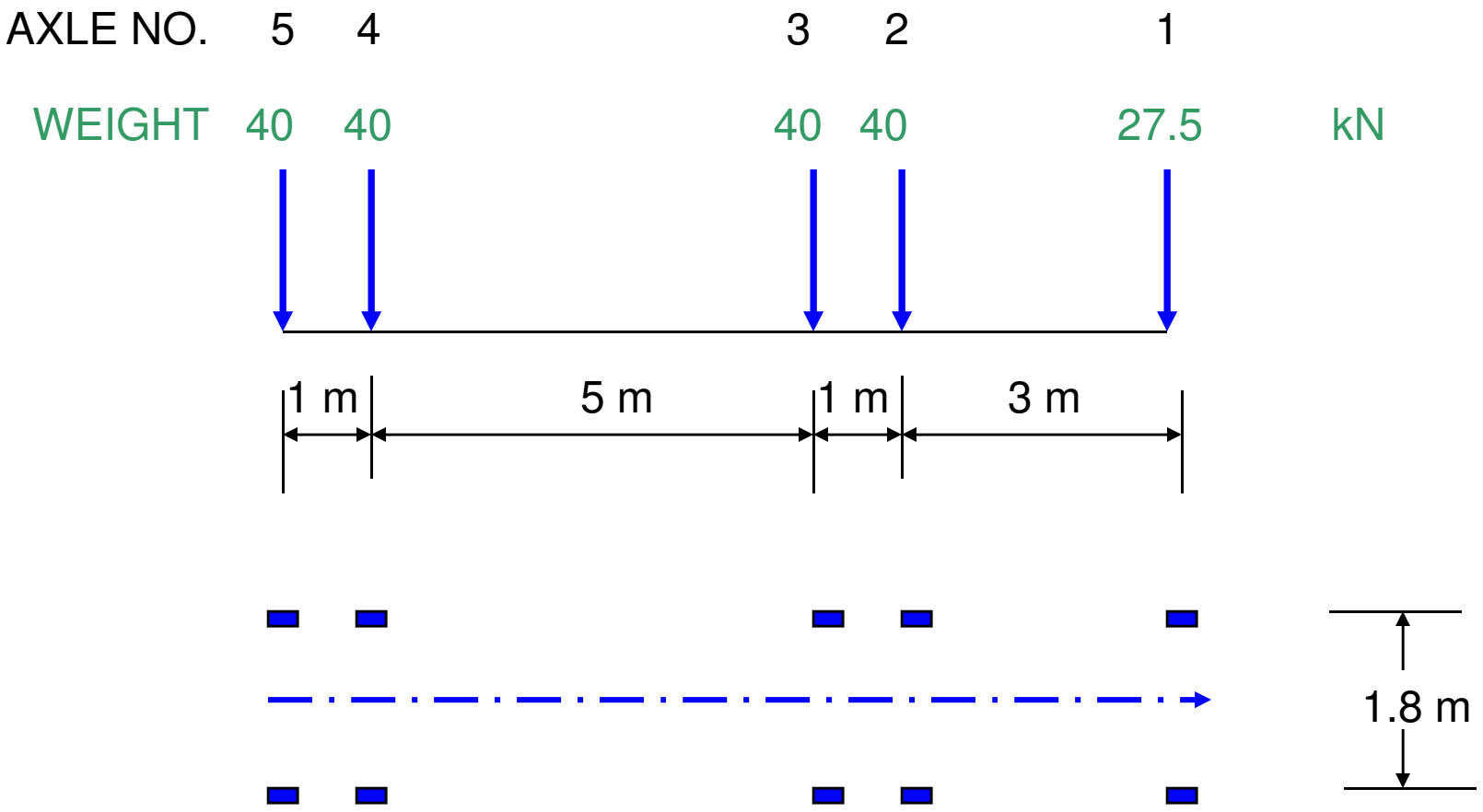
LAYOUT OF INSTRUMENTED DECK



SENSORS ON GIRDERS

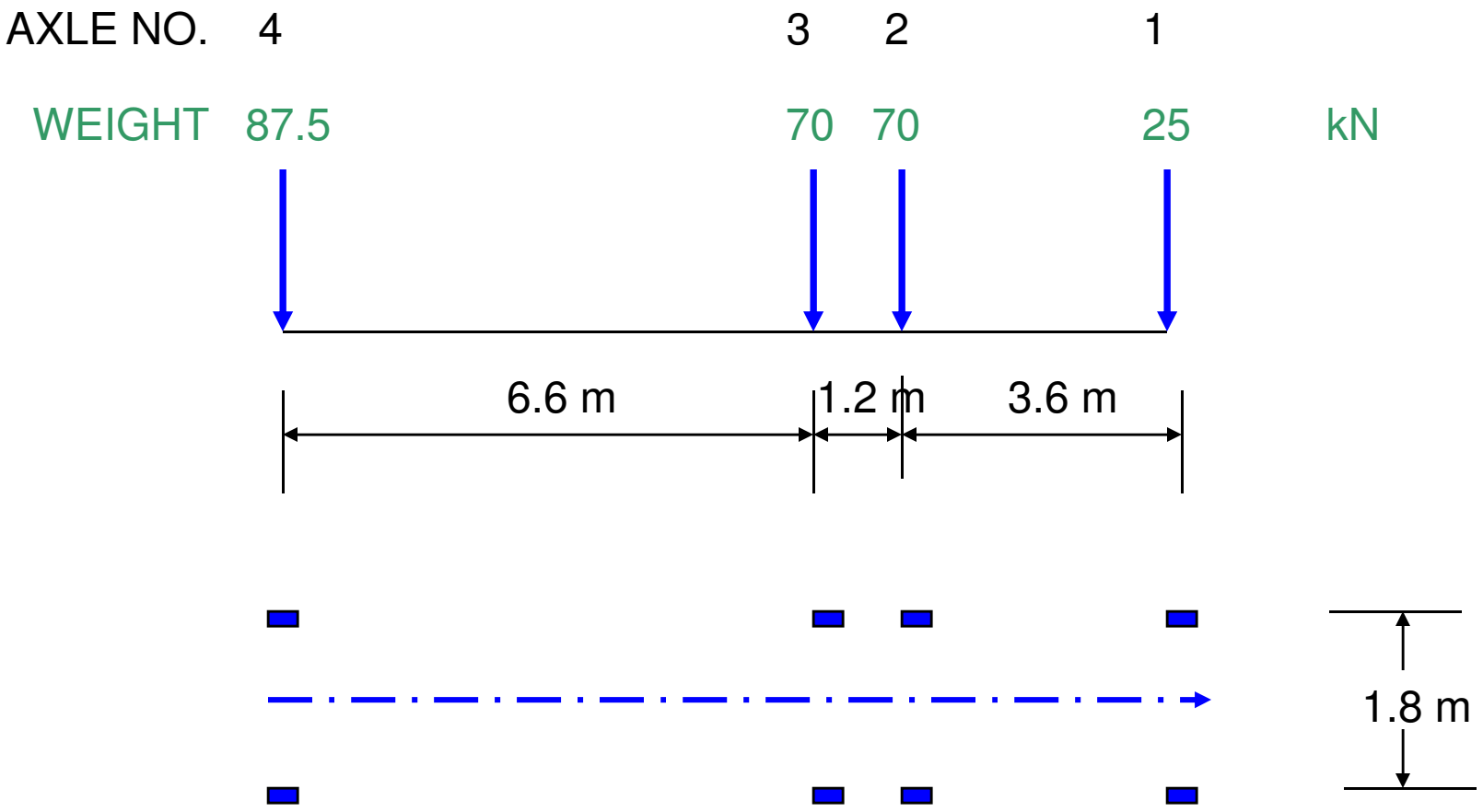


DETAILS OF TRUCK A



TOTAL WEIGHT OF TRUCK = 375 kN

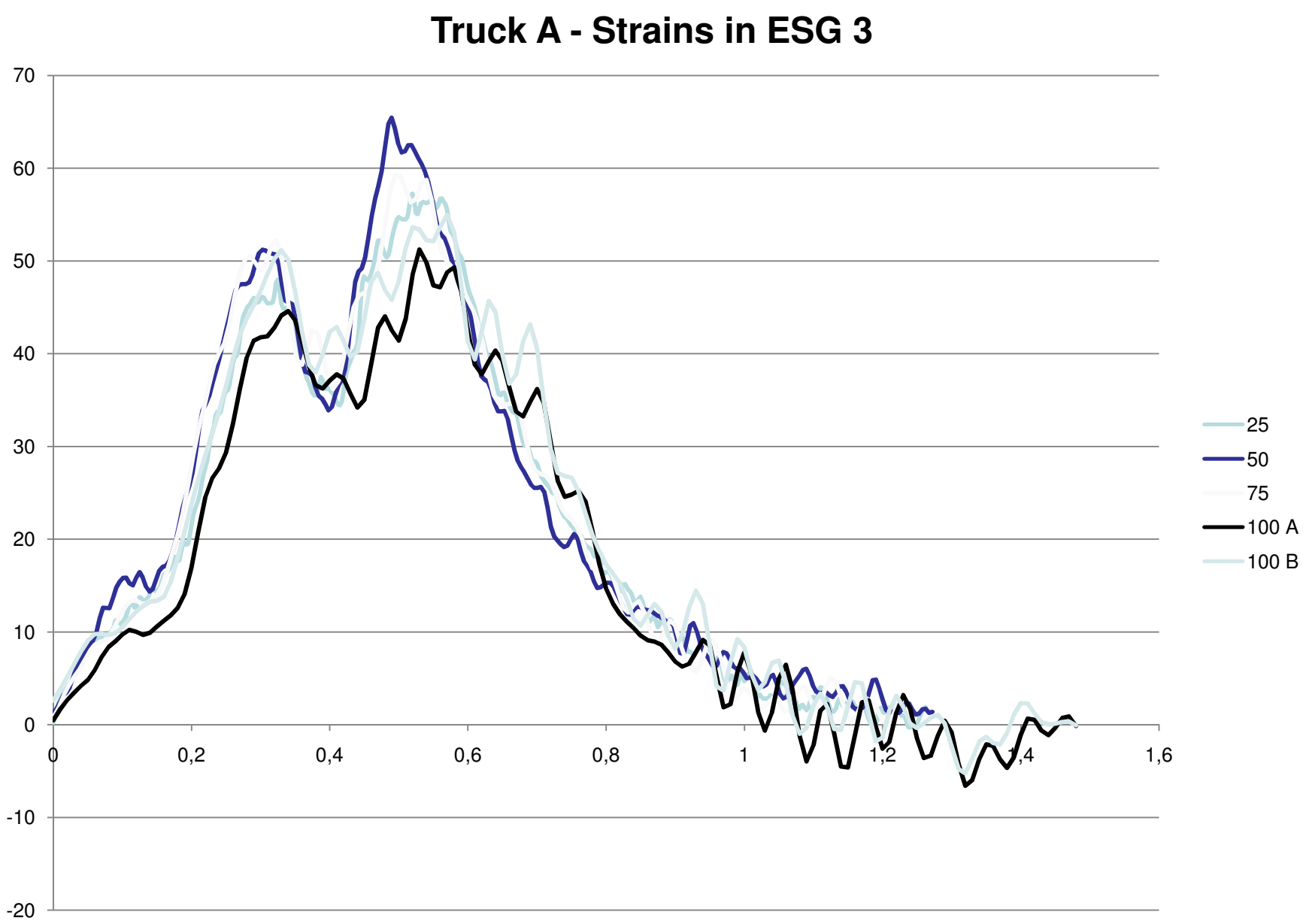
DETAILS OF TRUCK B

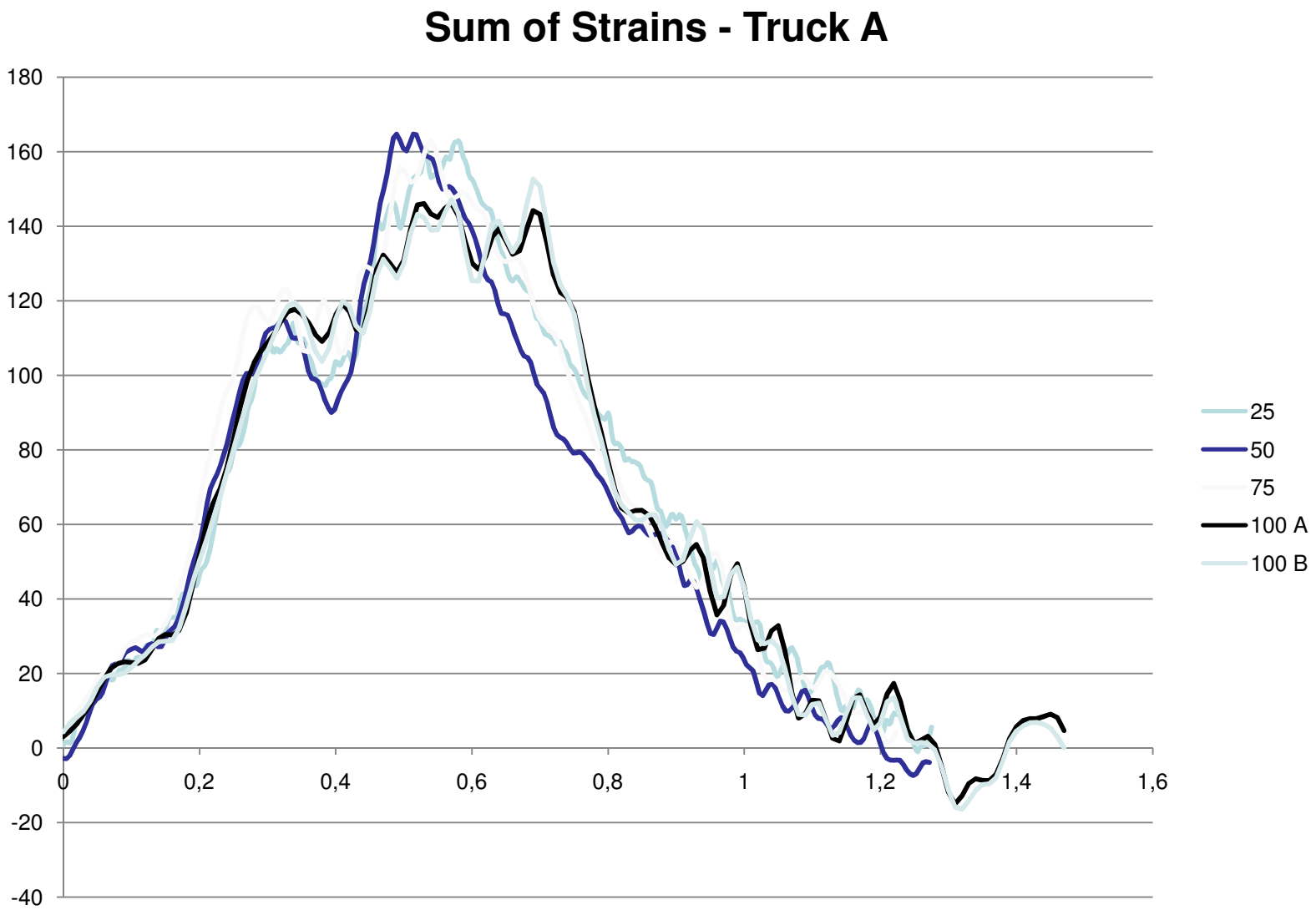


TOTAL WEIGHT OF TRUCK = 505 kN

LOAD TEST DETAILS

Test #	Description	Speed, km/h	Lane
1	TRUCK B → TRUCK A →	25	Normal
2	TRUCK B → TRUCK A →	50	Normal
3	TRUCK B → TRUCK A →	75	Normal
4	TRUCK B → TRUCK A →	100	Normal
5	TRUCK B → TRUCK A →	100	Passing
4a	TRUCK B → TRUCK A →	100	Normal
5a	TRUCK B → TRUCK A →	100	Passing
6	TRUCK B →	100	Passing
7	TRUCK A →	100	Passing
	TRUCK B →	100	Normal


Truck A - Strains in ESG 3
70
60
50
40
30
20
10
0
-10
-20
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
25
50
75
100 A
100 B


Sum of Strains - Truck A
180
160
140
120
100
80
60
40
20
0
-20
-40
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
25
50
75
100 A
100 B

AVERAGING OVER WHAT LENGTH OF TIME?

Ideal length of time over which the avaeraging should be done: 0.5 to 1.0 time the period corresponding to the first natural frequency

END OF SECOND PRESENTATION