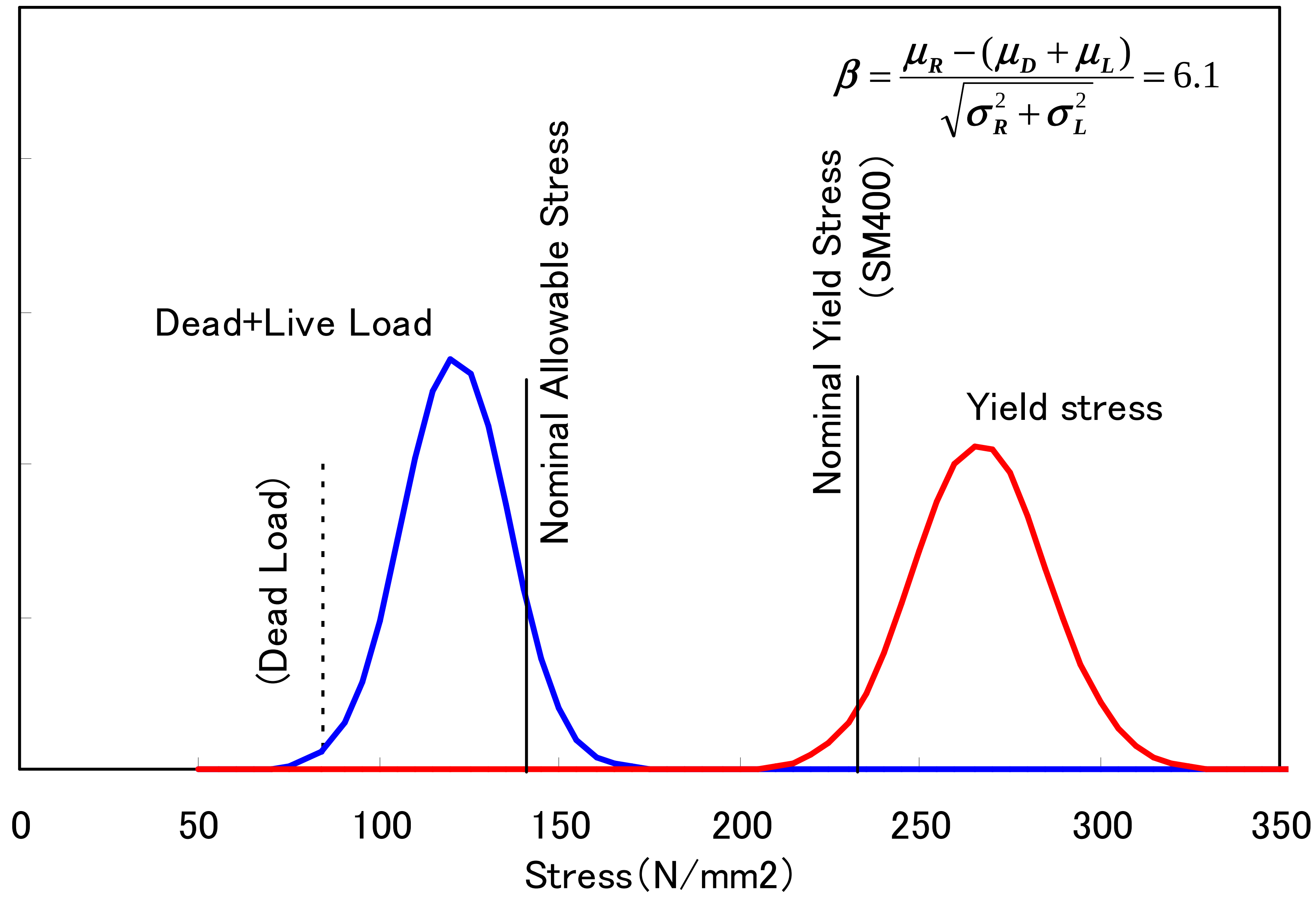
Random Number simulation for the Correlation between the Allowable stress design and the Reliability Analysis

Osamu Yoshida

Yoshida Engineering Laboratory, Chiba City, Japan

May 26, 2014 REC 2014

Conversion to Reliability Index



Random Number Simulation

Generate the Random vehicle weight for each category

↓

Merge and Shuffle the all samples

↓

Count the serial vehicle weights for loading length

↓

Derive the Distributed Load intensities

Traffic Flow Model

(component percentages of vehicle category)

Traffic Flow Class	A	B	C	D	E
Passenger car	0.776	0.653	0.551	0.490	0.327
Small truck	0.174	0.147	0.124	0.110	0.073
Medium truck	0.020	0.081	0.131	0.161	0.242
Large truck	0.016	0.068	0.103	0.127	0.190
Large dump truck	0.005	0.018	0.030	0.037	0.056
Tank truck	0.003	0.011	0.017	0.021	0.032
Semi-trailer	0.005	0.021	0.034	0.042	0.063
Large bus	0.001	0.006	0.010	0.012	0.017

（from “Fatigue Design Guide Line”, JRS）

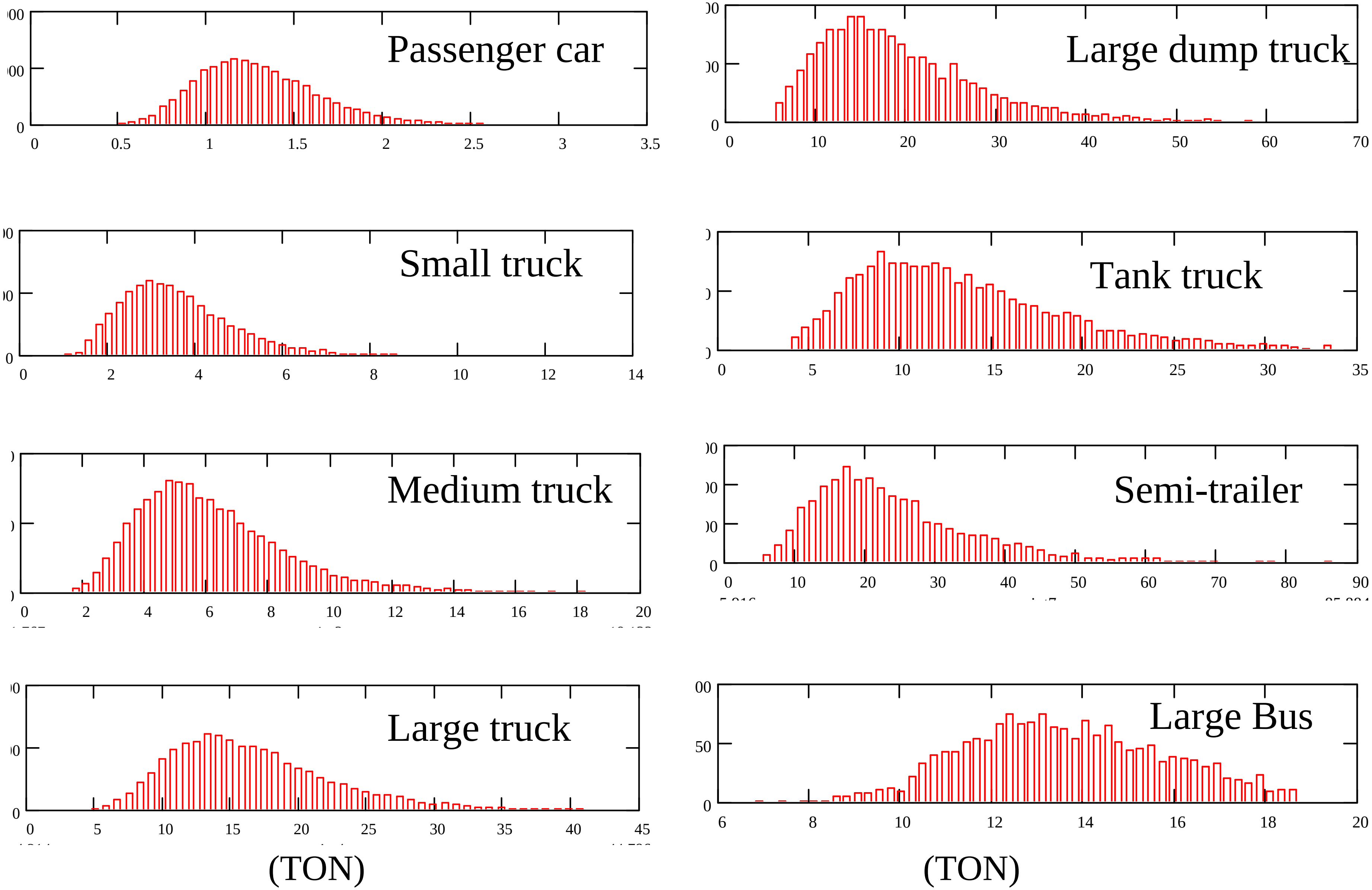
Probability of Vehicle Weight

(ton)

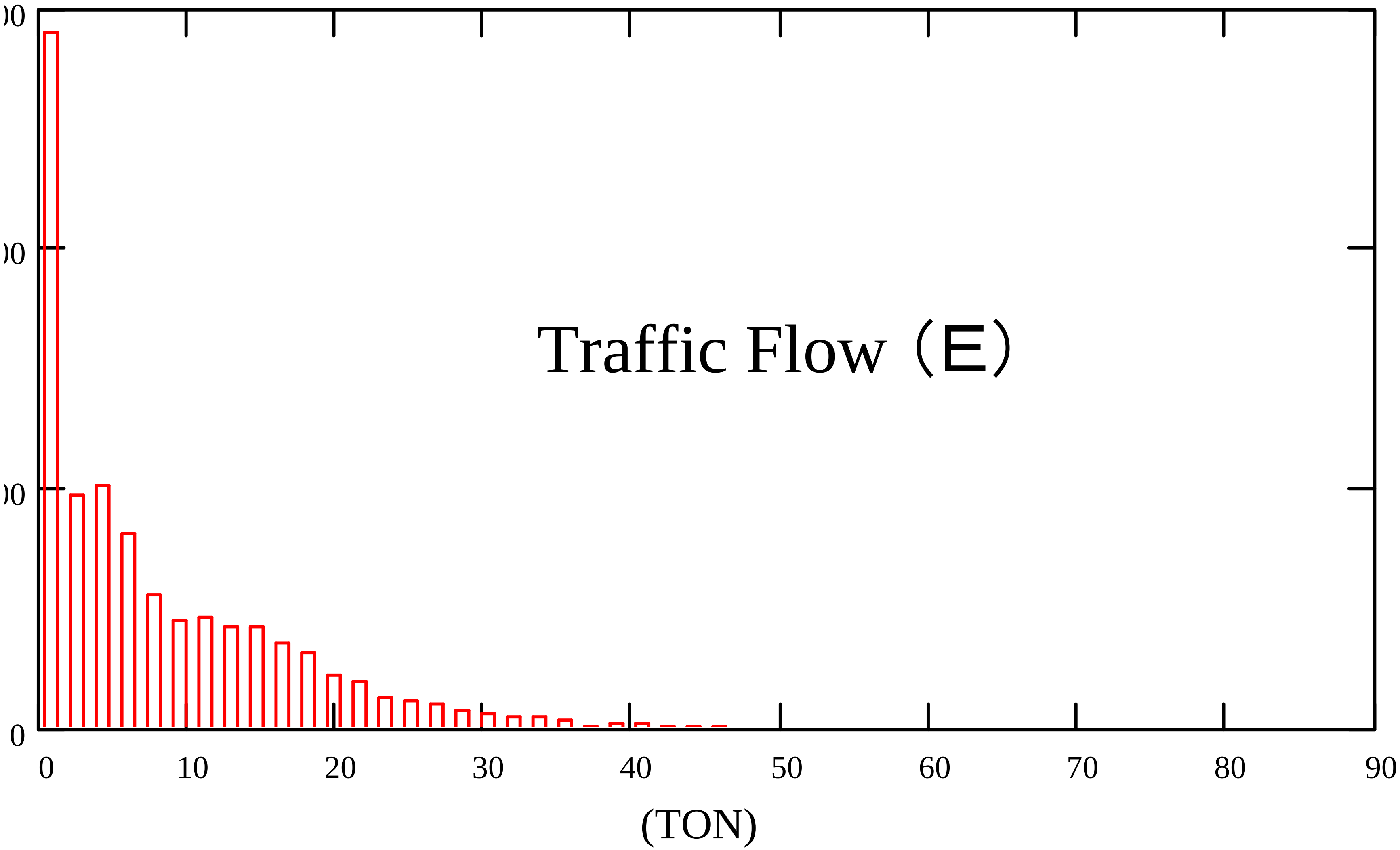
Categories	μ	σ	Max.	Min.
Passenger car	1.30	0.36	3.10	0.20
Small truck	3.62	1.31	12.60	1.00
Medium truck	6.19	2.50	18.30	1.60
Large truck	16.75	6.29	45.20	3.80
Large dump truck	19.62	9.54	61.90	5.40
Tank truck	13.82	6.31	33.70	3.90
Semi-trailer	24.78	12.92	86.70	5.10
Large Bus	13.84	2.41	18.70	6.80

(All Log-Normal Distribution)

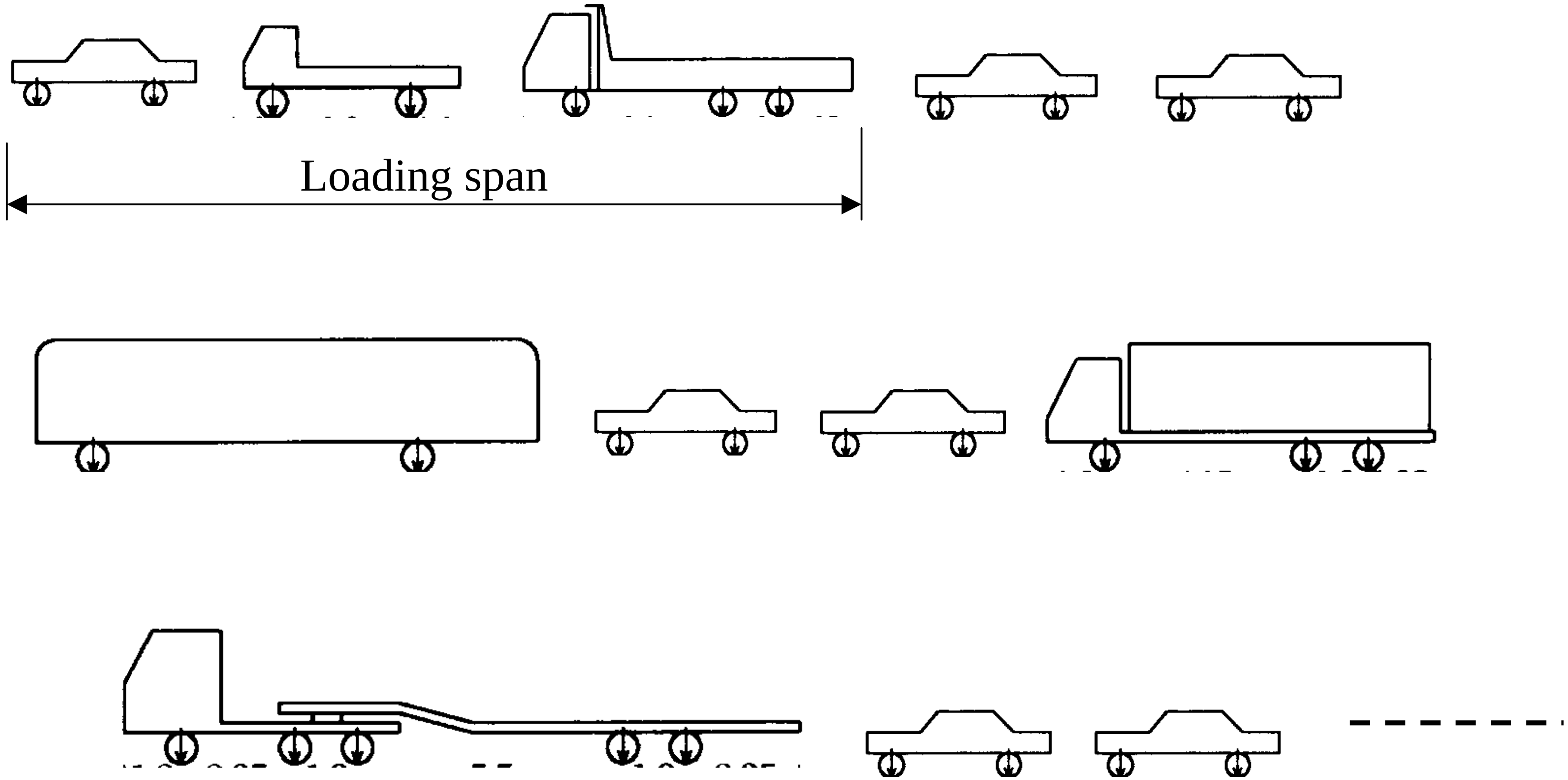
Vehicle weight Histogram of each category



Histogram of Sum of samples



Distributed Load of Random arrayed Motorcade

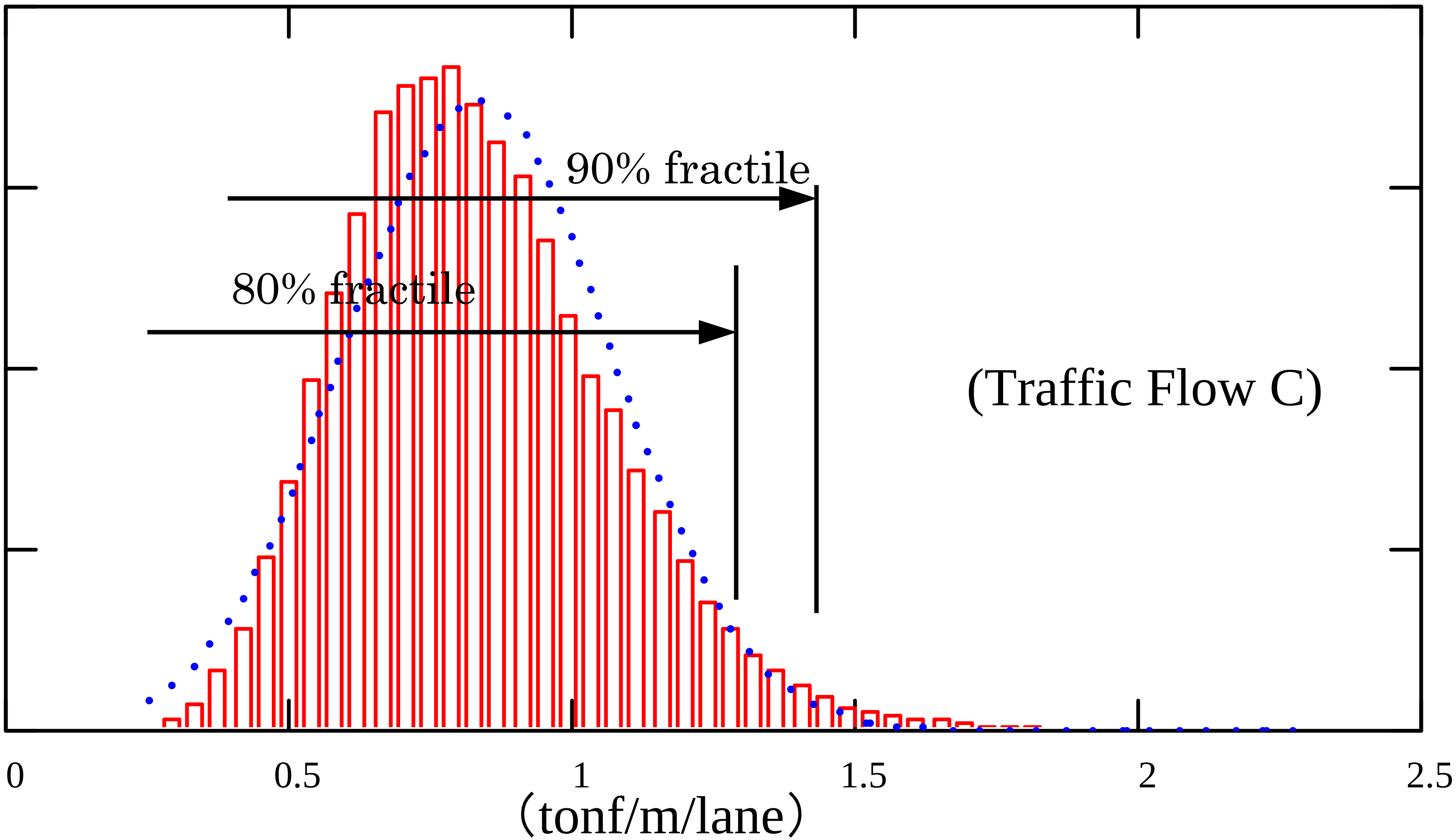


Characteristics of Probability of Distributed Load

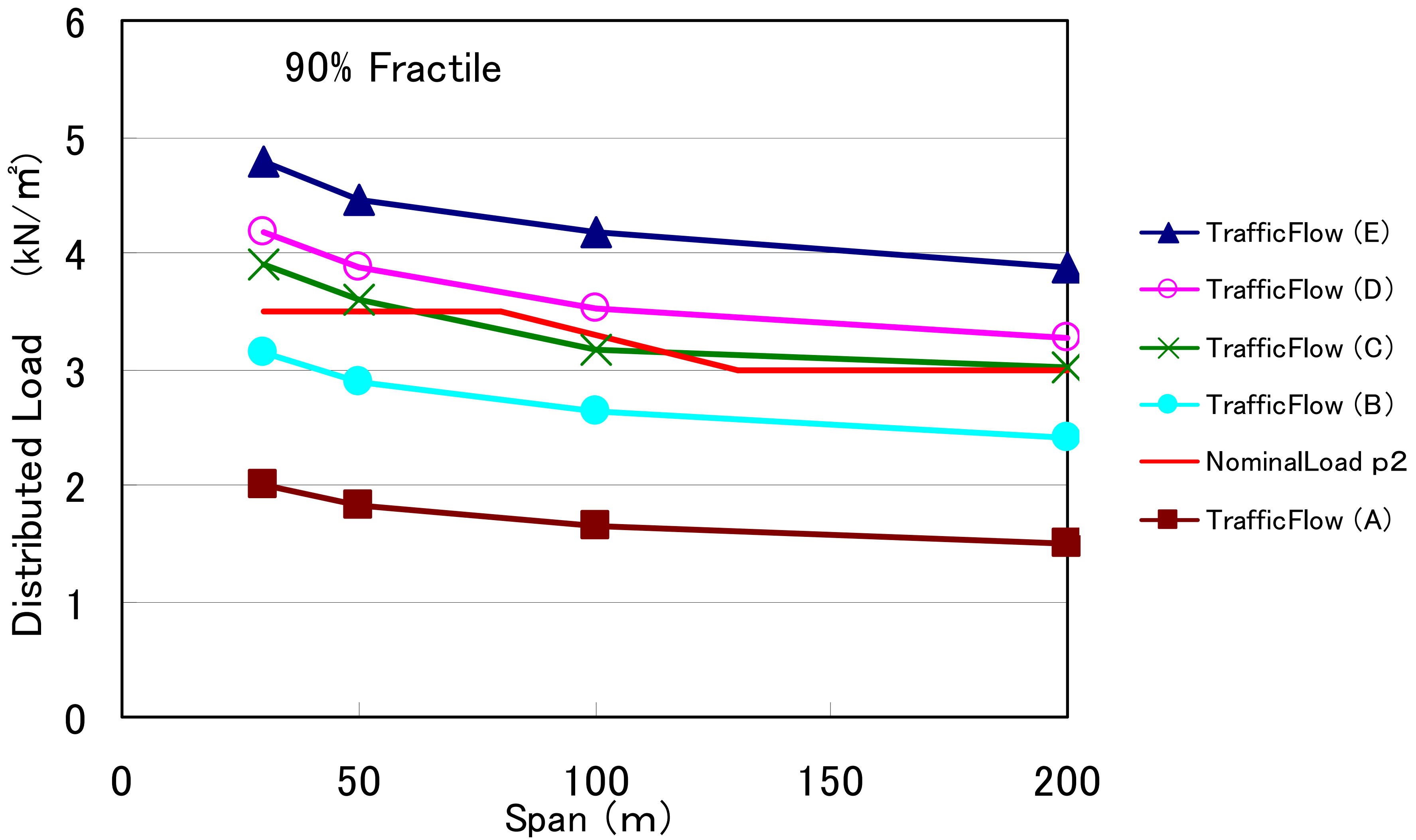
(tonf/m/lane)

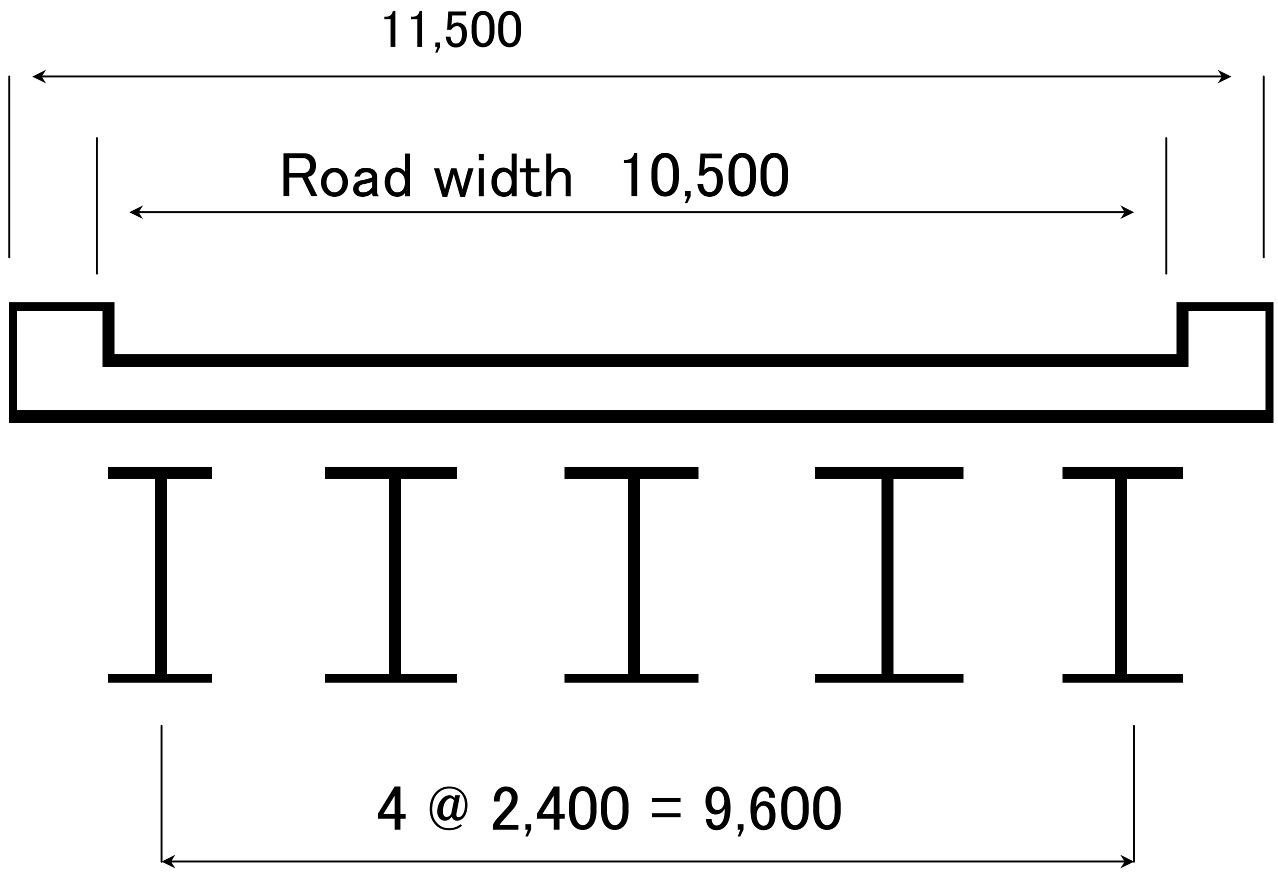
Traffic Flow		L=30	L=40	L=50	L=60
A	Mean	0.416	0.417	0.416	0.417
	Median	0.342	0.360	0.385	0.403
	σ	0.234	0.185	0.132	0.093
	V	0.563	0.444	0.317	0.223
B	Mean	0.654	0.655	0.657	0.658
	Median	0.565	0.598	0.628	0.644
	σ	0.363	0.297	0.219	0.158
	V	0.555	0.453	0.333	0.240
C	Mean	0.841	0.846	0.833	0.847
	Median	0.769	0.801	0.818	0.834
	σ	0.428	0.343	0.234	0.177
	V	0.509	0.405	0.281	0.209
D	Mean	0.932	0.939	0.940	0.940
	Median	0.863	0.895	0.920	0.928
	σ	0.435	0.350	0.251	0.178
	V	0.467	0.373	0.267	0.189
E	Mean	1.148	1.151	1.159	1.154
	Median	1.092	1.113	1.143	1.145
	σ	0.436	0.347	0.258	0.179
	V	0.380	0.301	0.223	0.155

Histogram of distributed load



Distributed Load Fractile Value

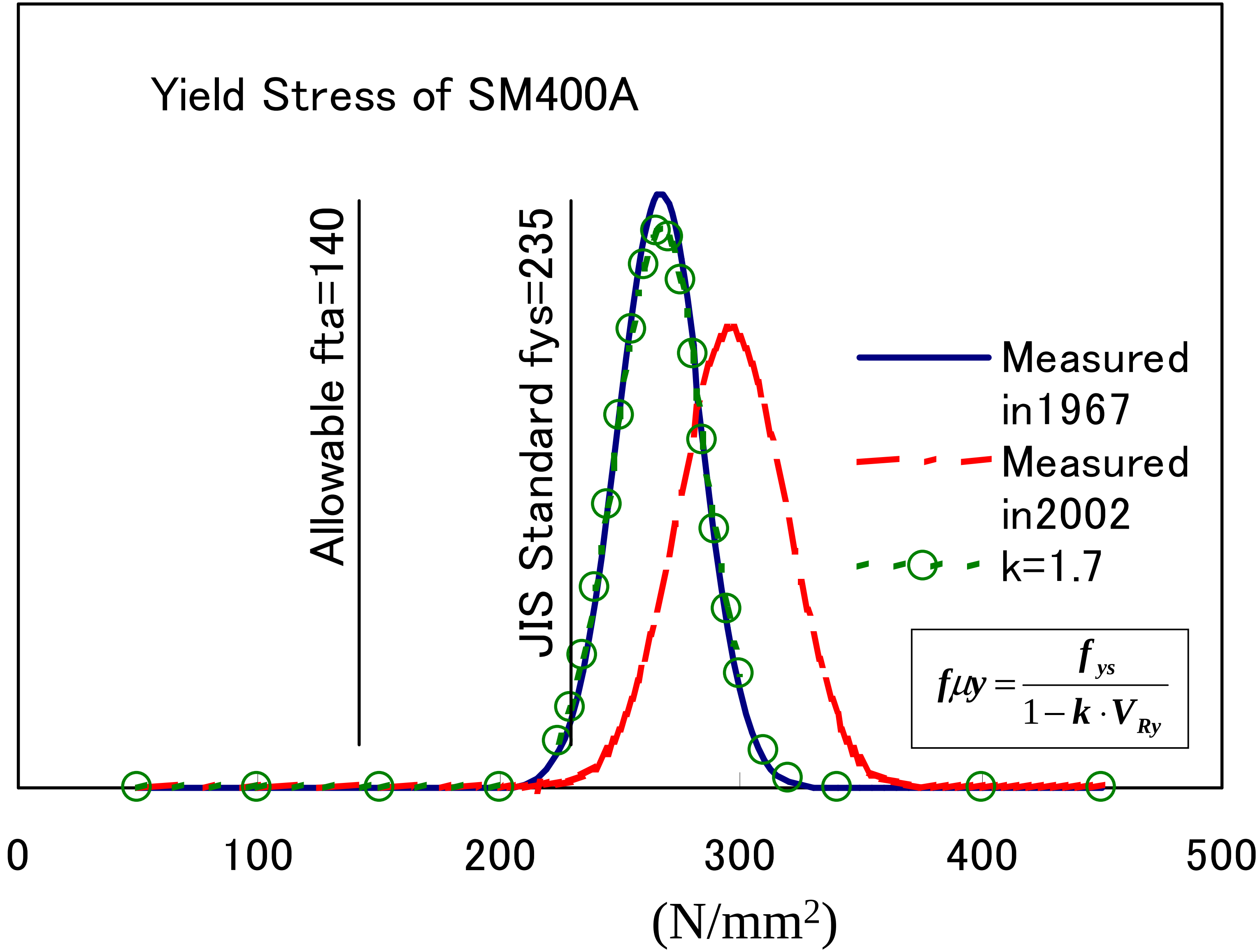




[Cross section of the object Bridge]

Bridge Type	: Simple Steel Girder with RC deck
Road Width	: 10.5 (m)
Span Length	: 30.0 ~ 60.0 (m)
Steel material	: SM400 (JIS), f_{ta} ; 140 (N/mm2)

Distribution of Yield Stress



Reliability Index β

$$\beta = \frac{f\mu y - (f\mu d + f\mu p1 + f\mu p2)}{\sqrt{(f\mu y \cdot V_{Ry})^2 + (f\mu d \cdot Vd)^2 + (f\mu p1 \cdot Vp1)^2 + (f\mu p2 \cdot Vp2)^2}}$$

$f\mu y$: Mean value of yield stress

$f\mu d$: Mean value of fiber stress by Dead Load

$f\mu p1$: Mean value of fiber stress by Live Load $p1$

$f\mu p2$: Mean value of fiber stress by Live Load $p2$

$$f\mu p1 = \frac{M\mu p1}{Z_g}$$

$$f\mu p2 = \frac{M\mu p2}{Z_g}$$

V_{Ry} 、Vd 、$Vp1$ 、$Vp2$: Coefficient of variance

(of yield stress, Dead Load , and Live Load)

This is the substituted form of $\beta = \dfrac{\mu_R - (\mu_D + \mu_L)}{\sqrt{\sigma_R^2 + \sigma_L^2}}$

Reliability Assessment

(for Redesigned Bridge) (N/mm^2)

Span (m)		30	40	50	60
Dead Load	$f\mu d$	81.5	91.8	98.9	104.2
Live Load p1	$f\mu p1$	22.9	19.0	15.8	13.2
	$Vp1$	0.486	0.486	0.486	0.486
Live Load p1	$f\mu p2$	17.6	18.9	19.3	19.1
	$Vp2$	0.509	0.441	0.394	0.360
Yield Stress (SM400A)	$f\mu y$	267			
	V_y	0.07			
Reliability Index β		6.1	6.1	6.2	6.2

Aspect of Uncertainty

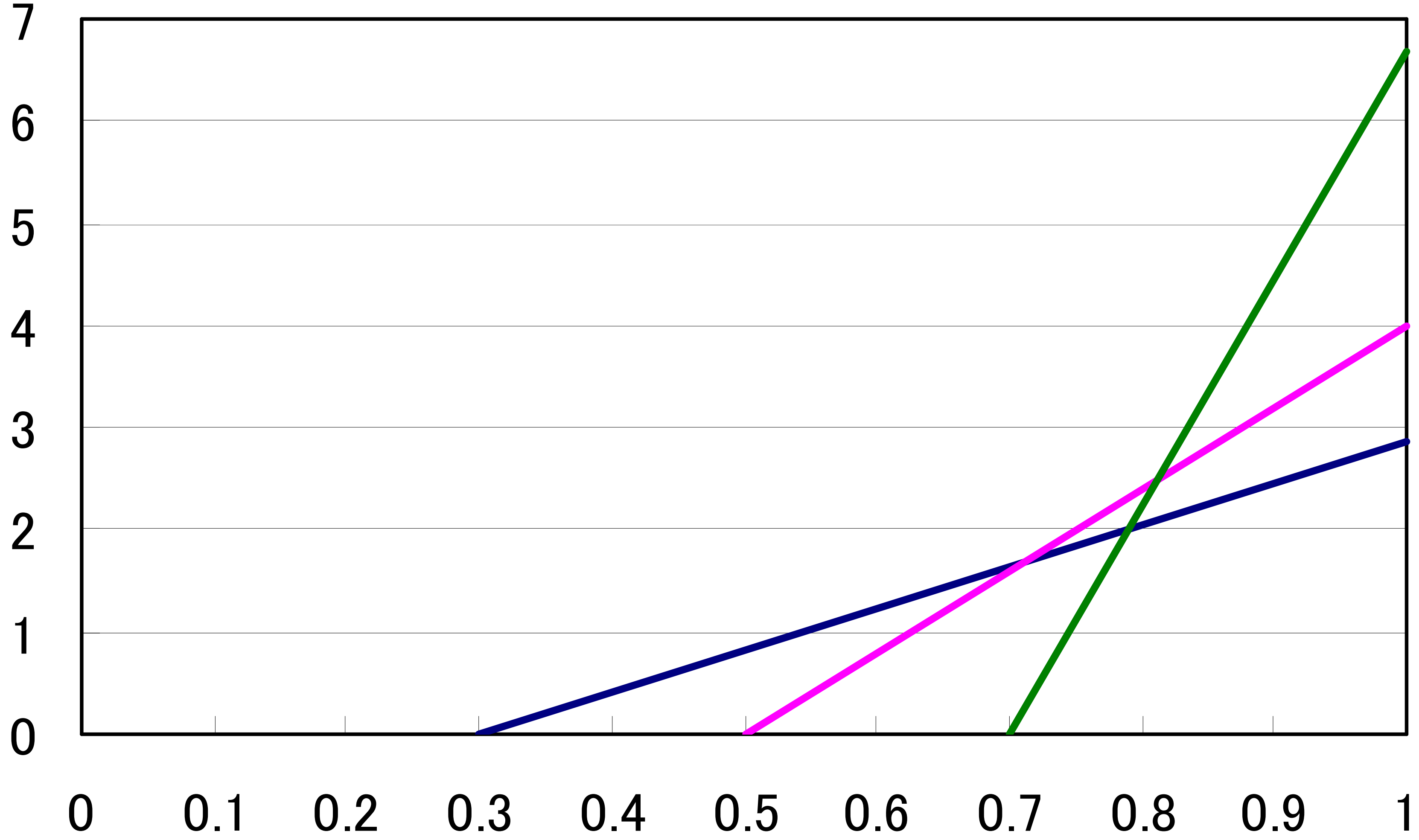
[Assumption of Deterioration Factor]

$$fr = fy \cdot Cr$$

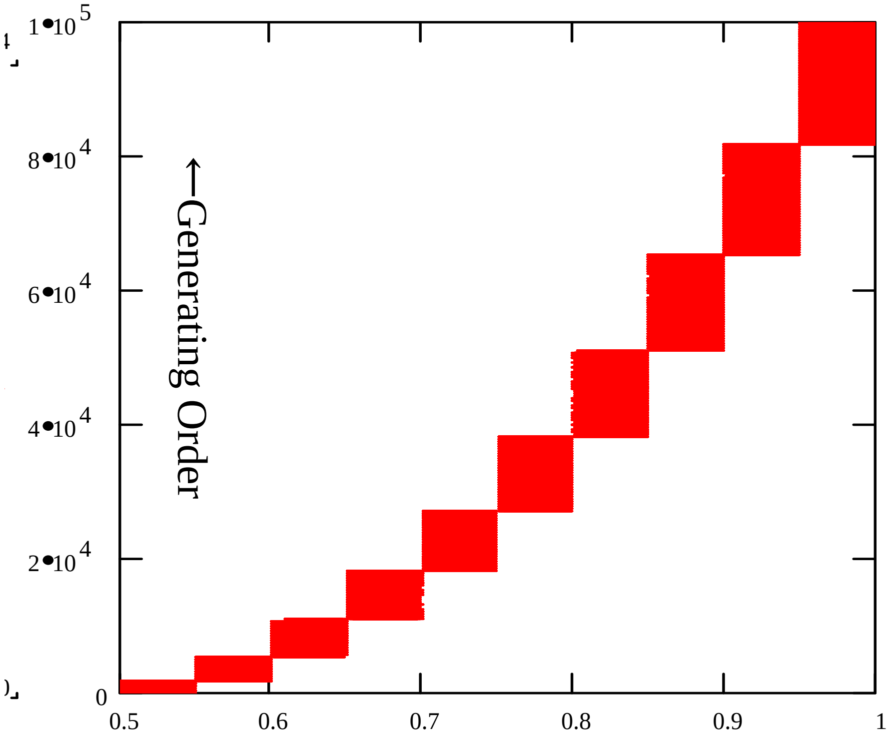
fr : deteriorated strength of the material
fy : yield strength of the sound material
Cr : coefficient of deterioration

$$fy = norm(f\mu y, \sigma_y)$$

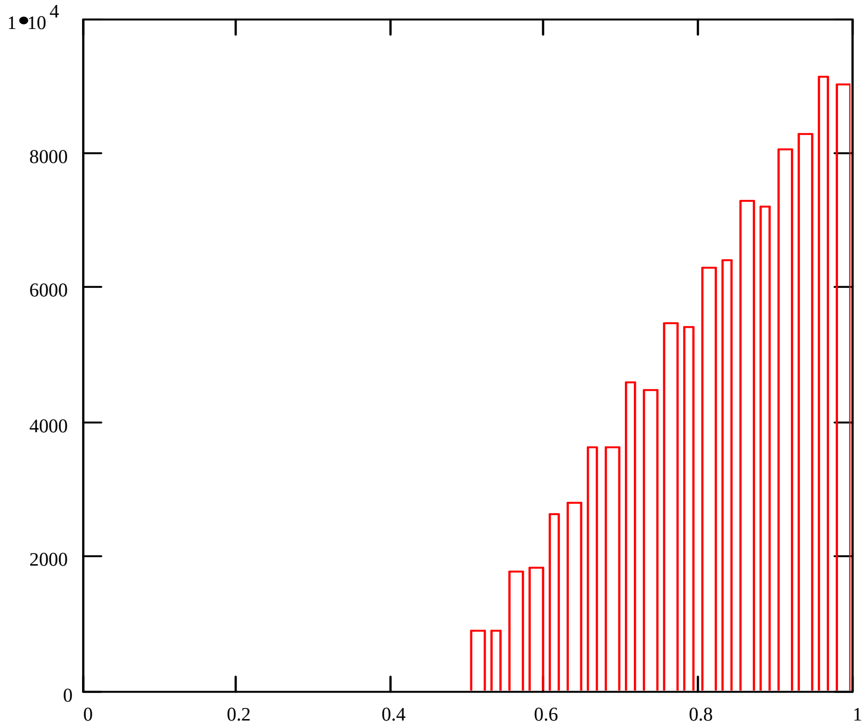
Probability Distribution Image of ***Cr***



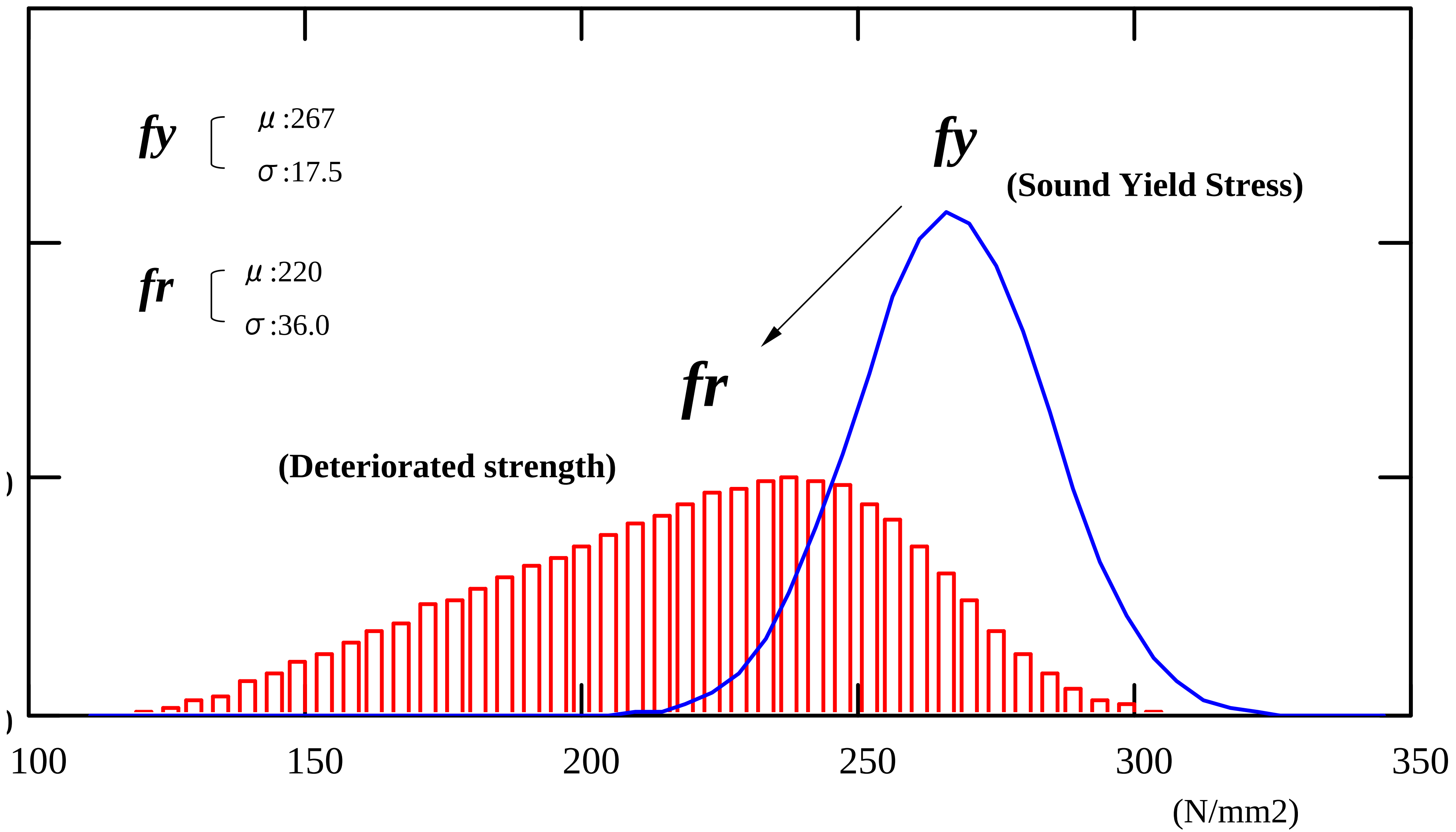
Coefficient of Deterioration *Cr*



Generated Samples

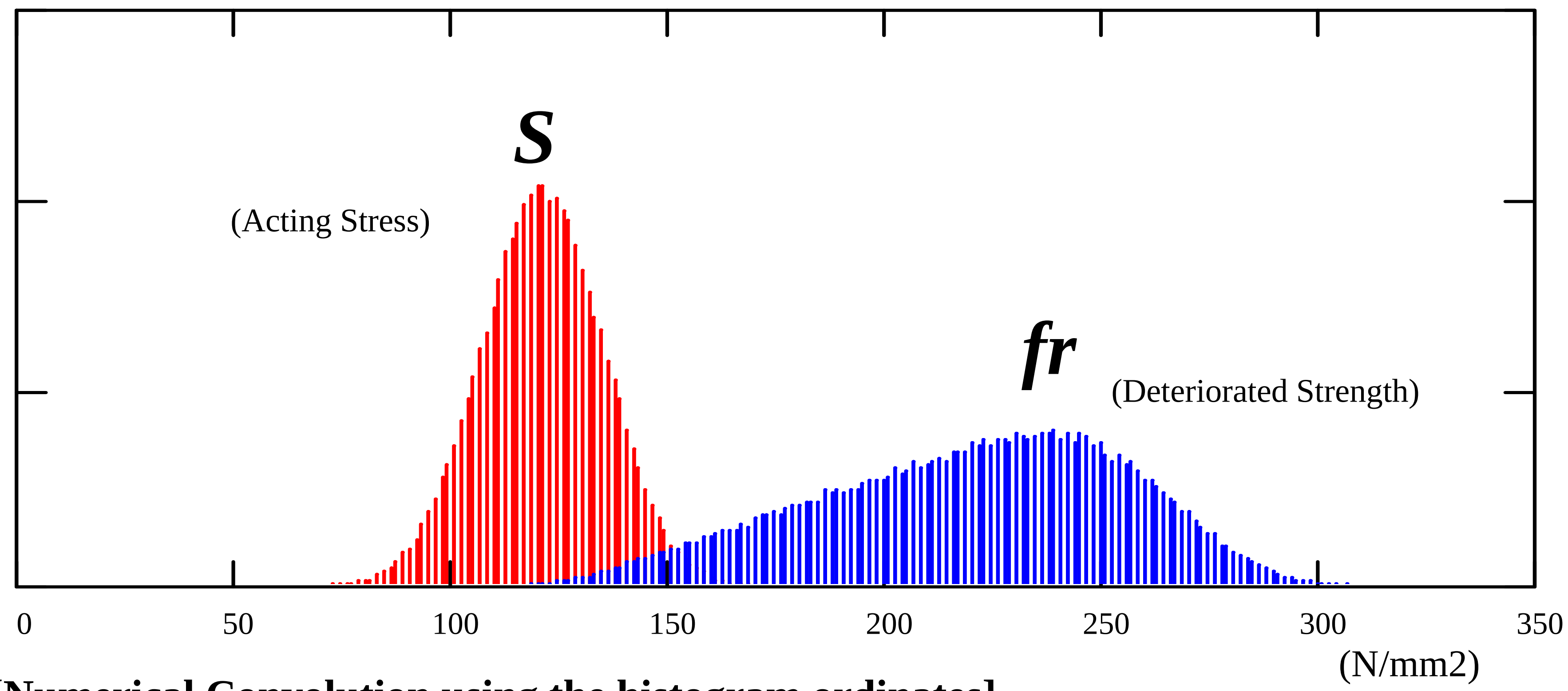


Histogram



fy
μ :267
σ :17.5
fr
μ :220
σ :36.0
fy
(Sound Yield Stress)
fr
(Deteriorated strength)
)
)
100
150
200
250
300
350
(N/mm2)

[Histogram of Acting Stress and Deteriorated Strength]



[Numerical Convolution using the histogram ordinates]

$$Pfx = \sum_{i=1}^{n} \left(\frac{Ys_i}{N} \cdot \frac{Yr_i}{N} \right)$$

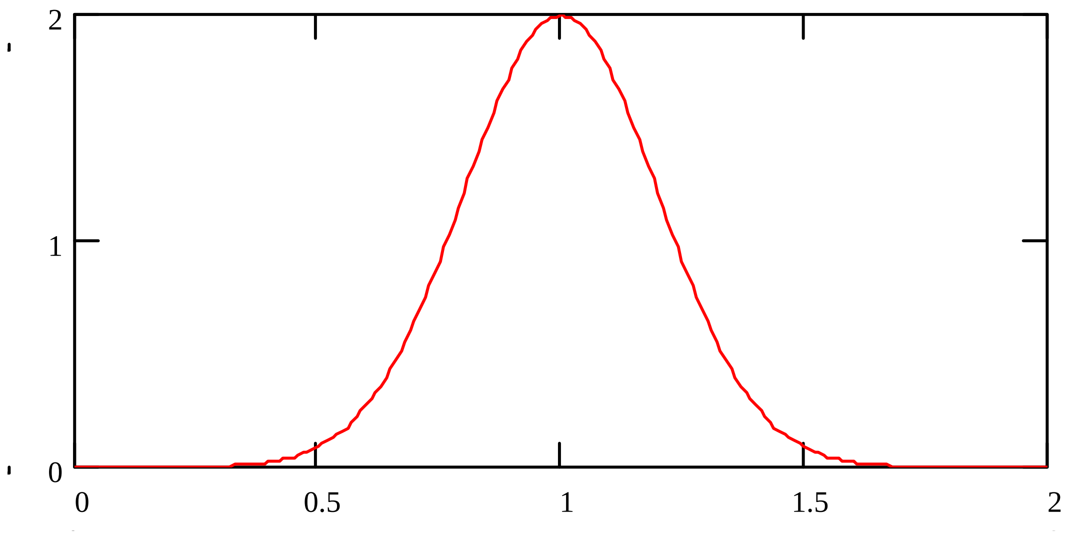
[Results]

	Convolution	2nd Moment Method
Probability of Failure	7.3×10^{-4}	5.6×10^{-3}
Reliability Index β	3.2	2.5

[Error Factor]

$$Se = S \cdot Ce$$

- Se : acting stress diffused by error
- S : correct acting stress
- Ce : coefficient of diffusion caused by error

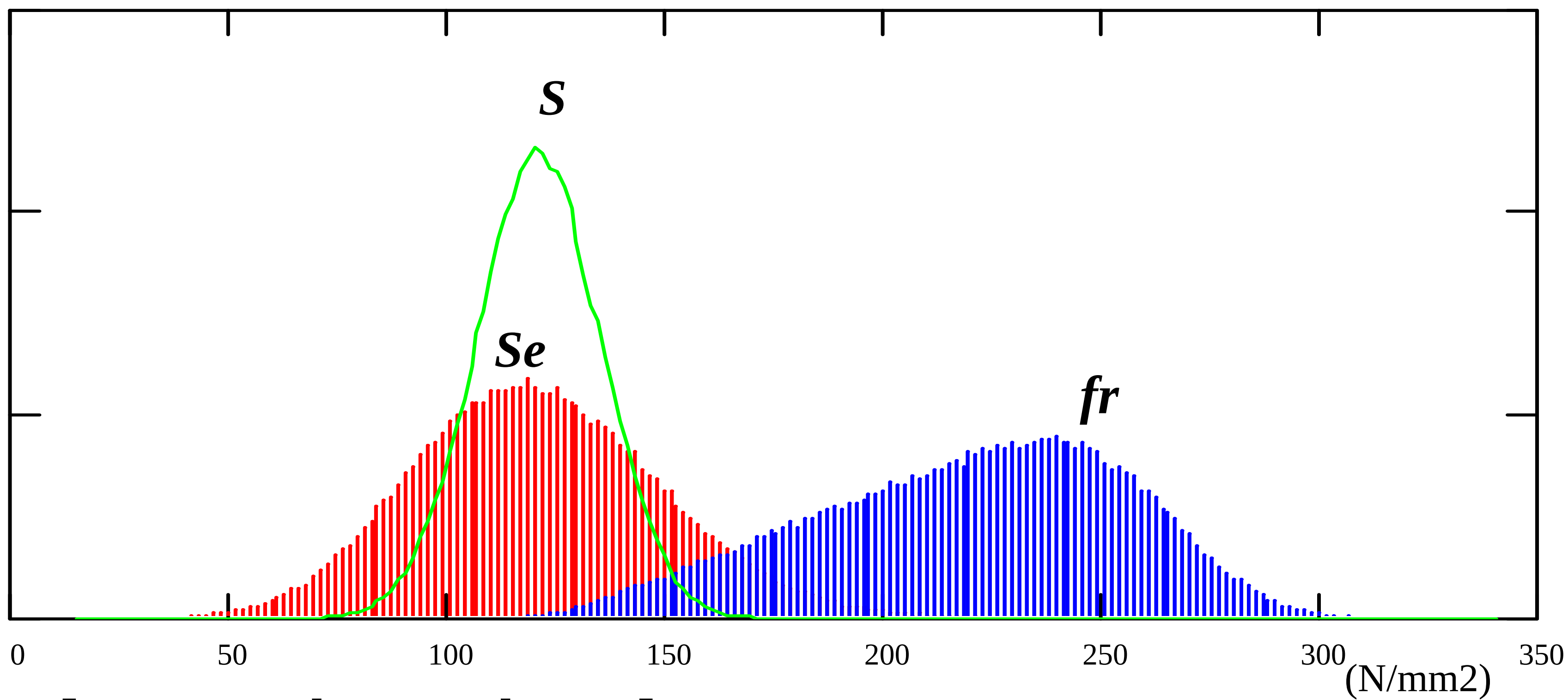


Normal Distribution of Ce

$$Se = S \cdot Ce$$

Se : acting stress diffused by error
S : correct acting stress
Ce : coefficient of diffusion caused by error

[Error Factor]



[Numerical Convolution]

Probability of Failure	1.7×10^{-3}
Reliability Index β	2.9

[Summary of Reliability Assessment]

	Without Uncertainty	Only Deterioration	Error Factor Added
Probability of Failure	5.3×10^{-10}	7.3×10^{-4}	1.7×10^{-3}
Reliability Index β	6.1	3.2	2.9

(span length 30m)

Conclusion

1) The reliability assessment without uncertainties for a bridge which is designed in accordance with the allowable stress method showed the reliability index about 6.0. It can be recognized that the allowable stress method provides a sufficiently safe solution.

2) When only the deterioration factor is introduced, the Reliability Index becomes 3.2 and it is barely safe.

3) When the error factor is added to above, the Reliability Index becomes 2.9 and it is slightly dangerous.

4) The background of the allowable stress design method implicitly contains some uncertainties.

5) The measured data is indispensable for ensuring the foundation of the Reliability. But the Reliability Assessment without the uncertainty factor can be accepted, until the evidence-based data is clarified.

“ My Comments ”

I think the error factor above is rough and too much optimistic.

The value setting of the error distribution is not based on evidence-based data, it is an initial assumption.

I guess the actual error is discontinuous.

My paper shows the procedure of calculating the various distribution of probability. Arbitrary shape of distribution can be analyzed.

The error comes from the mistake in the design and the construction, or the retrofitting stage. It must be eliminated by checking at that time.