Dipendenza dell'affidabilità strutturale dalle assunzioni iniziali – Analisi di sensitività

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Azioni $\gamma_F = \gamma_f \, \gamma_{Sd}$

γ_f — **Aleatorietà dell'azione**

γ_{Sd} — **Incertezza di Modello – Azioni/sollecitazioni**

Metodo del <u>Fattore Parziale</u> (semi probabilistico)

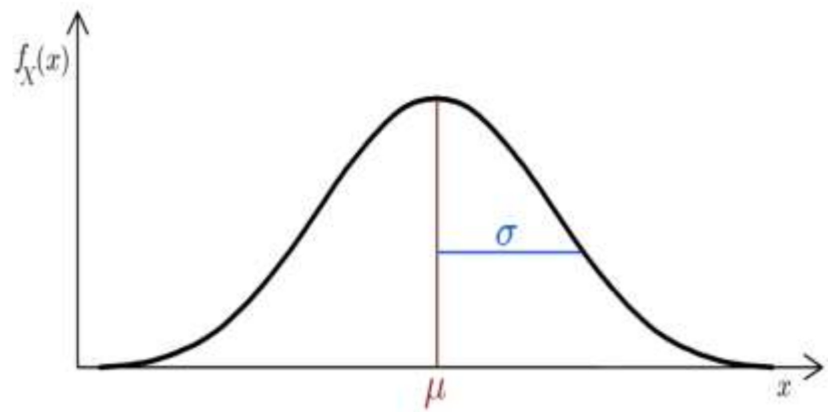
$$x_d = \frac{x_k}{\boldsymbol{\gamma_M}}$$

$$\gamma_M = \gamma_m \, \gamma_{Rd}$$

- γ_m → **Aleatorietà delle caratteristiche meccaniche**
- γ_{Rd} → **Incertezza di modello**

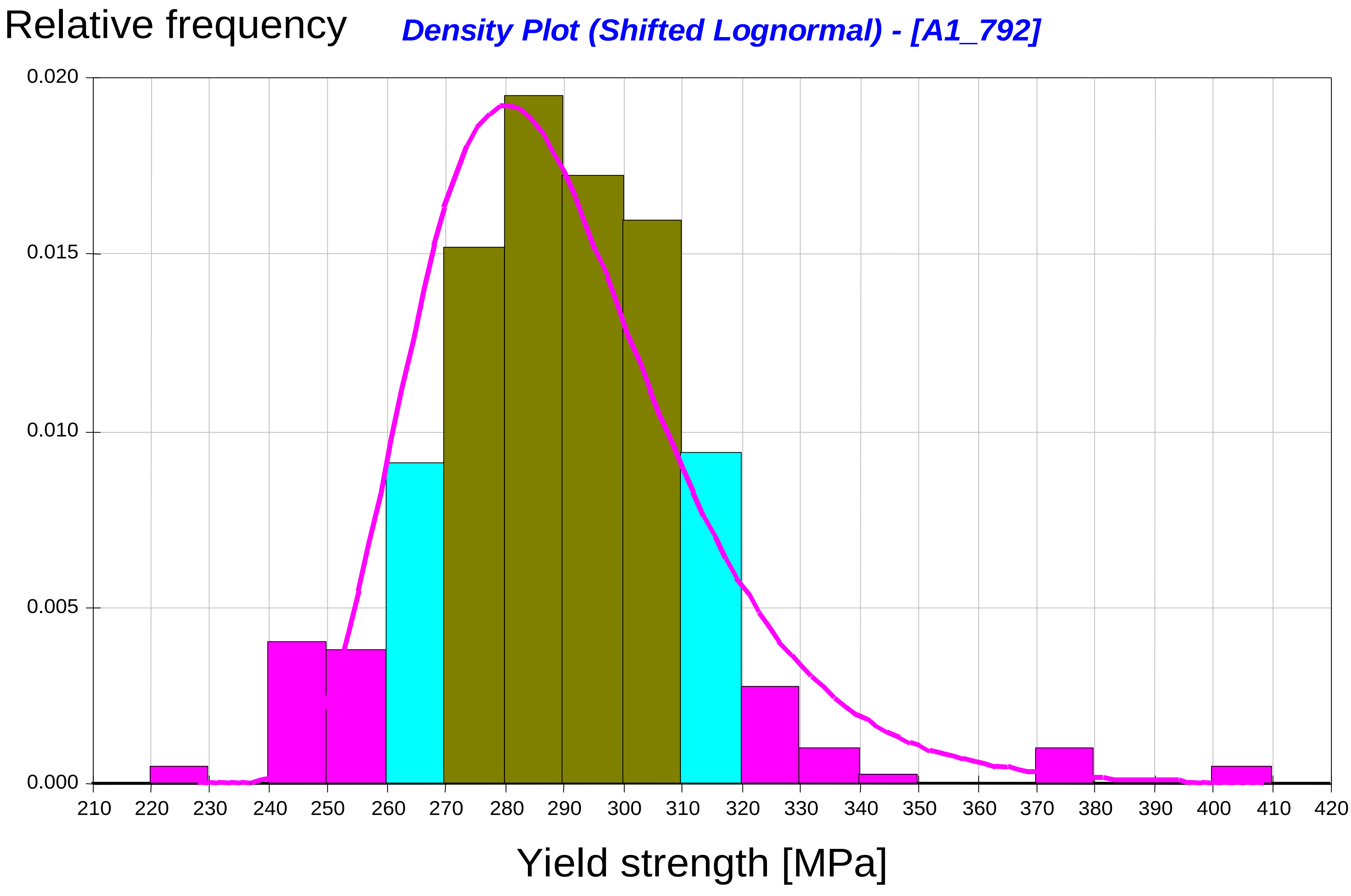
Metodi <u>probabilistici</u>

$$x_d = f(\boldsymbol{\mu}, \boldsymbol{\sigma}, \dots)$$

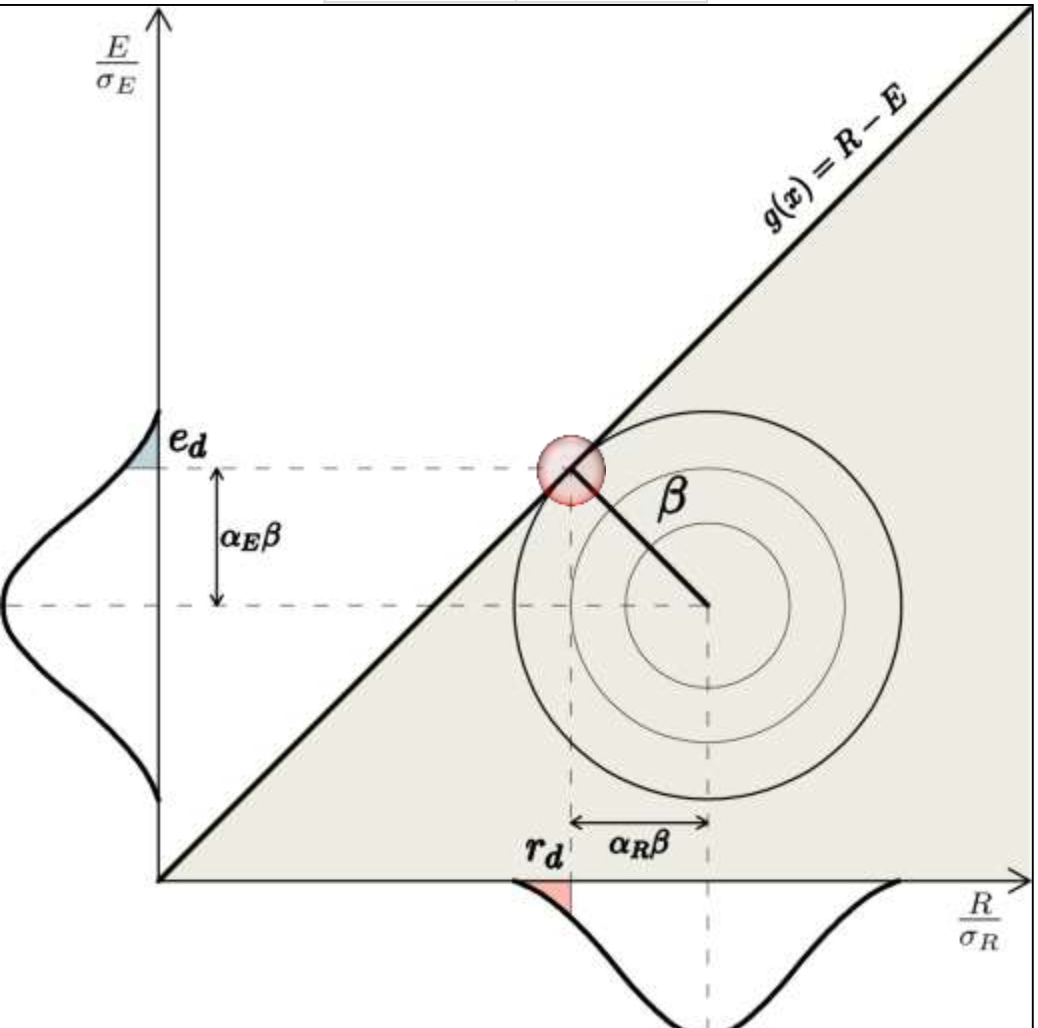


$\boldsymbol{\mu}$: media

$\boldsymbol{\sigma}$: deviazione standard


Relative frequency
Density Plot (Shifted Lognormal) - [A1_792]
0.020
0.015
0.010
0.005
0.000
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
Yield strength [MPa]

β	$1/P_f$
2,3	93
2,8	391
3,3	2069
3,8	13822
4,3	117097
4,8	1260512



Distribuzioni normali

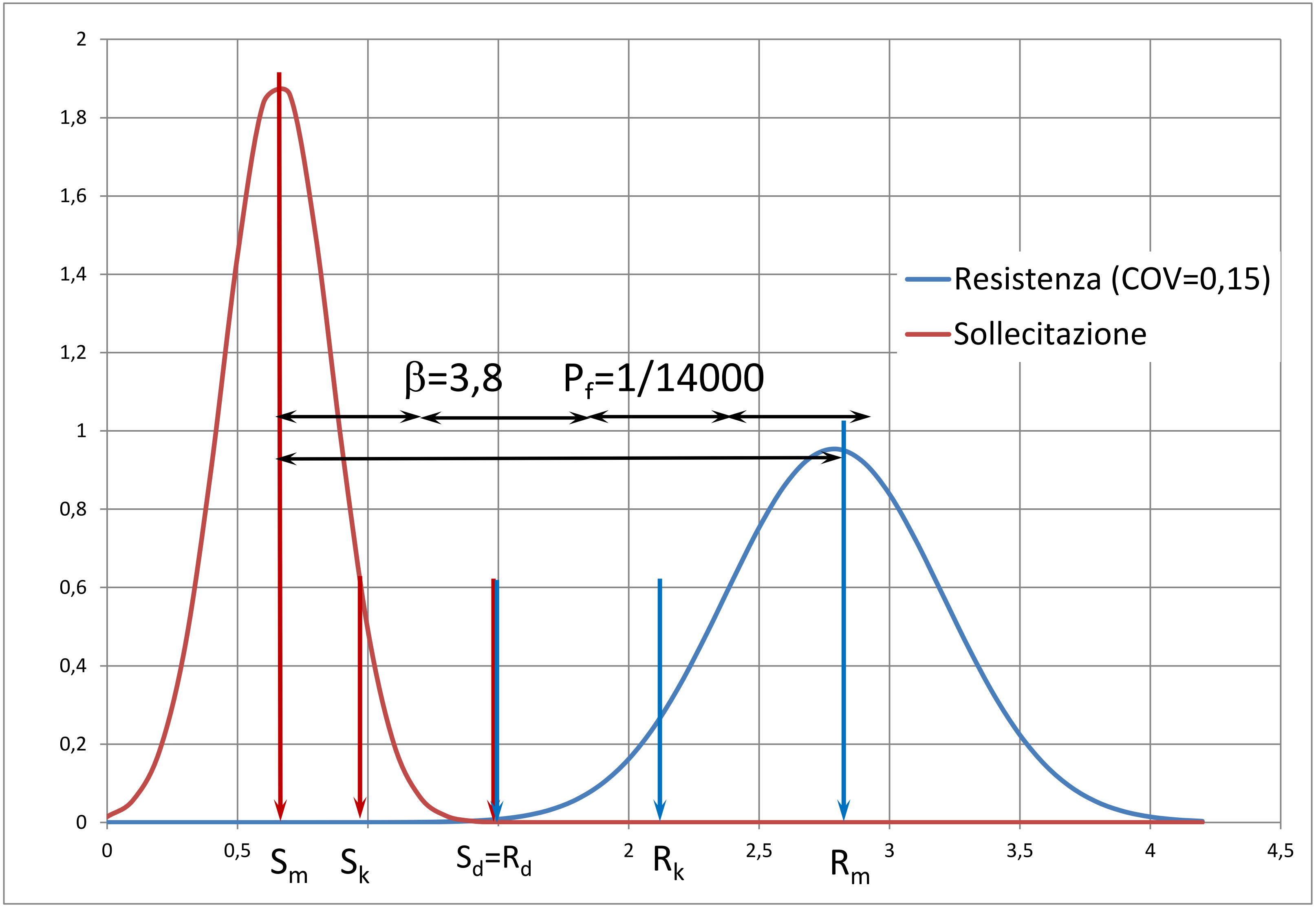
$$g(x) = R - E$$

$$\beta = -\Phi^{-1}(P_f)$$

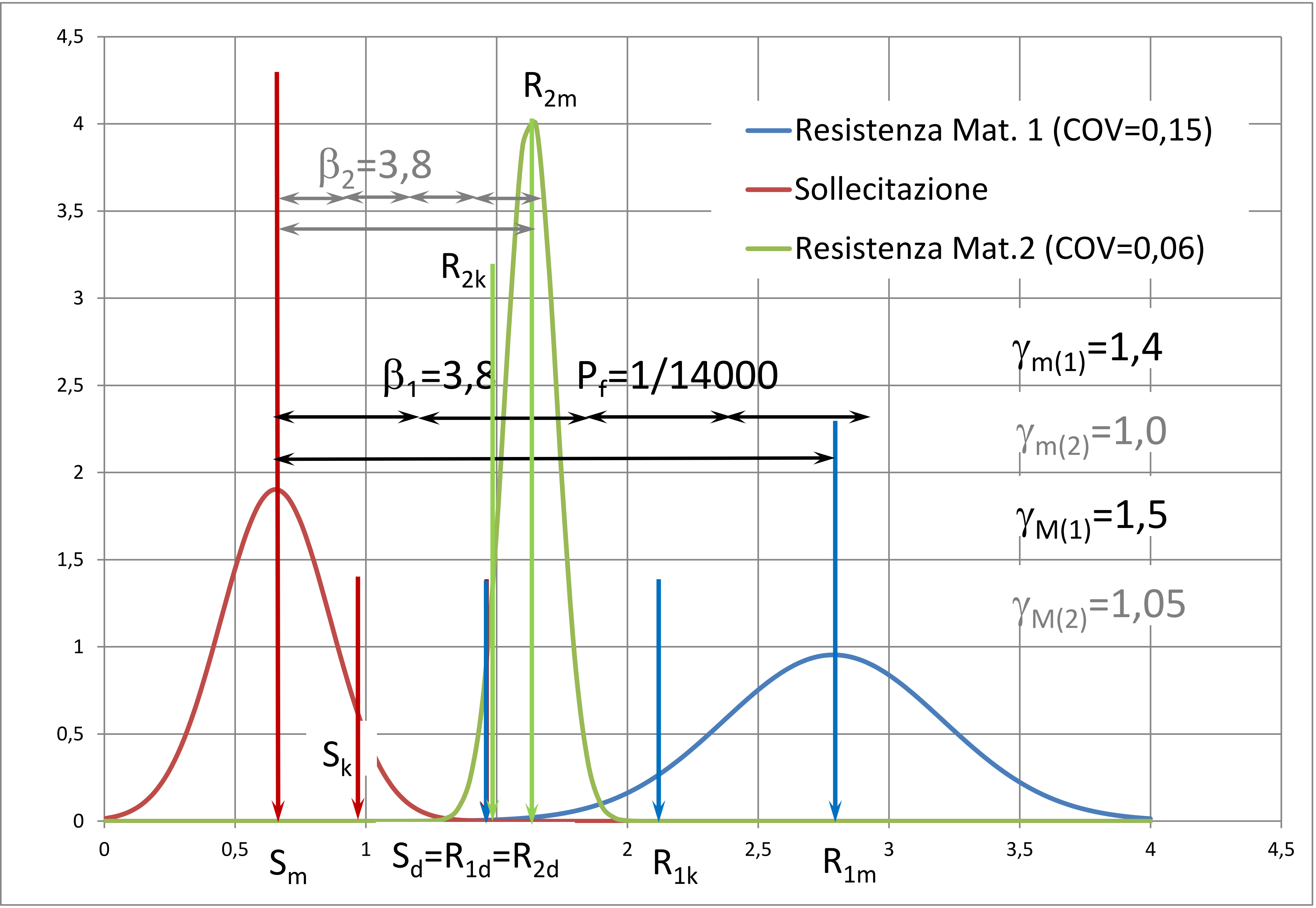
$$e_d, r_d$$

$$e_d = \mu_E + \alpha_E \beta \sigma_E$$

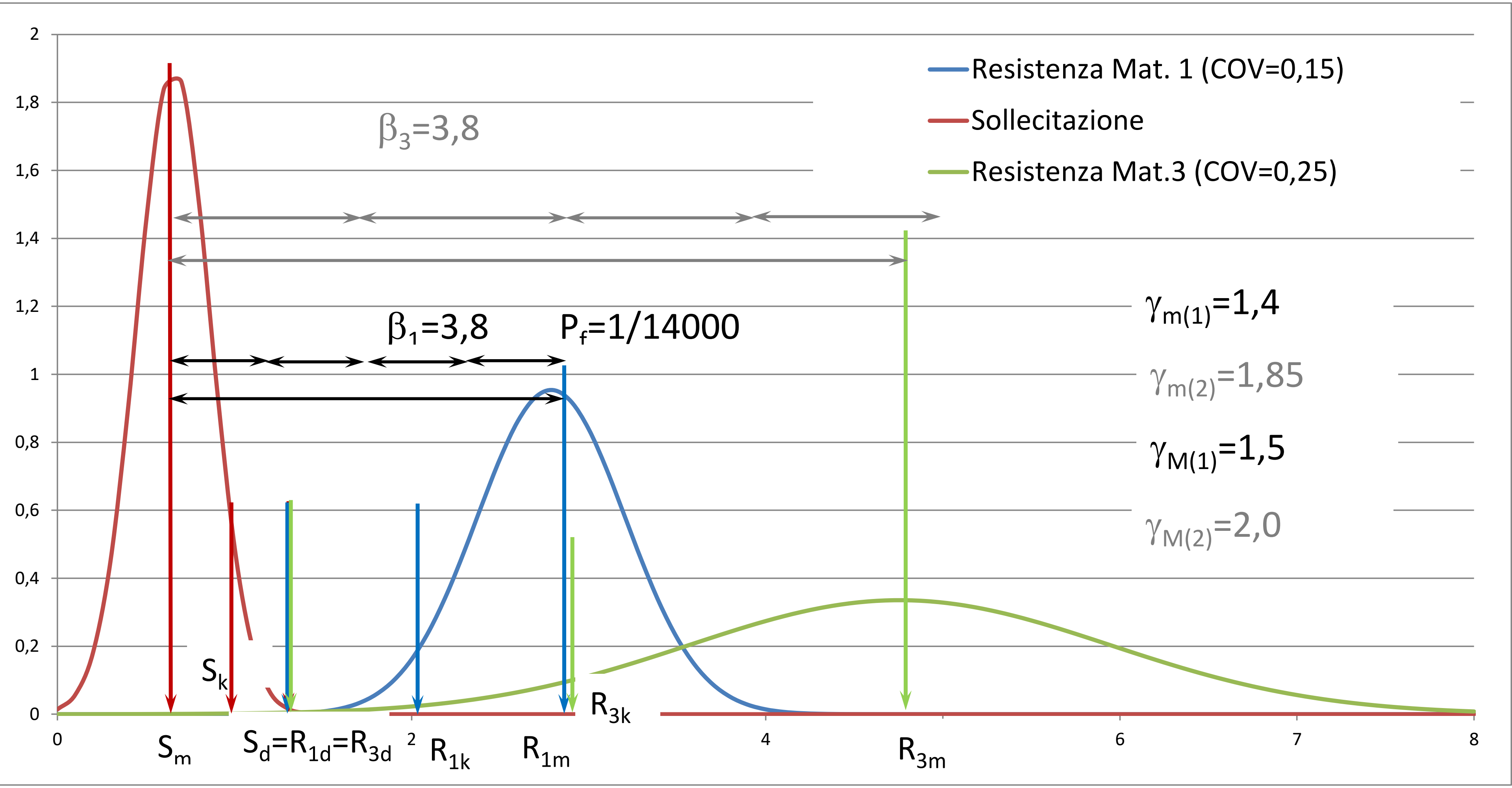
$$r_d = \mu_R - \alpha_R \beta \sigma_R$$



2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
0
0,5
2
2,5
3
3,5
4
4,5
Resistenza (COV=0,15)
Sollecitazione
β=3,8
Pf=1/14000
Sm
Sk
Sd=Rd
Rk
Rm



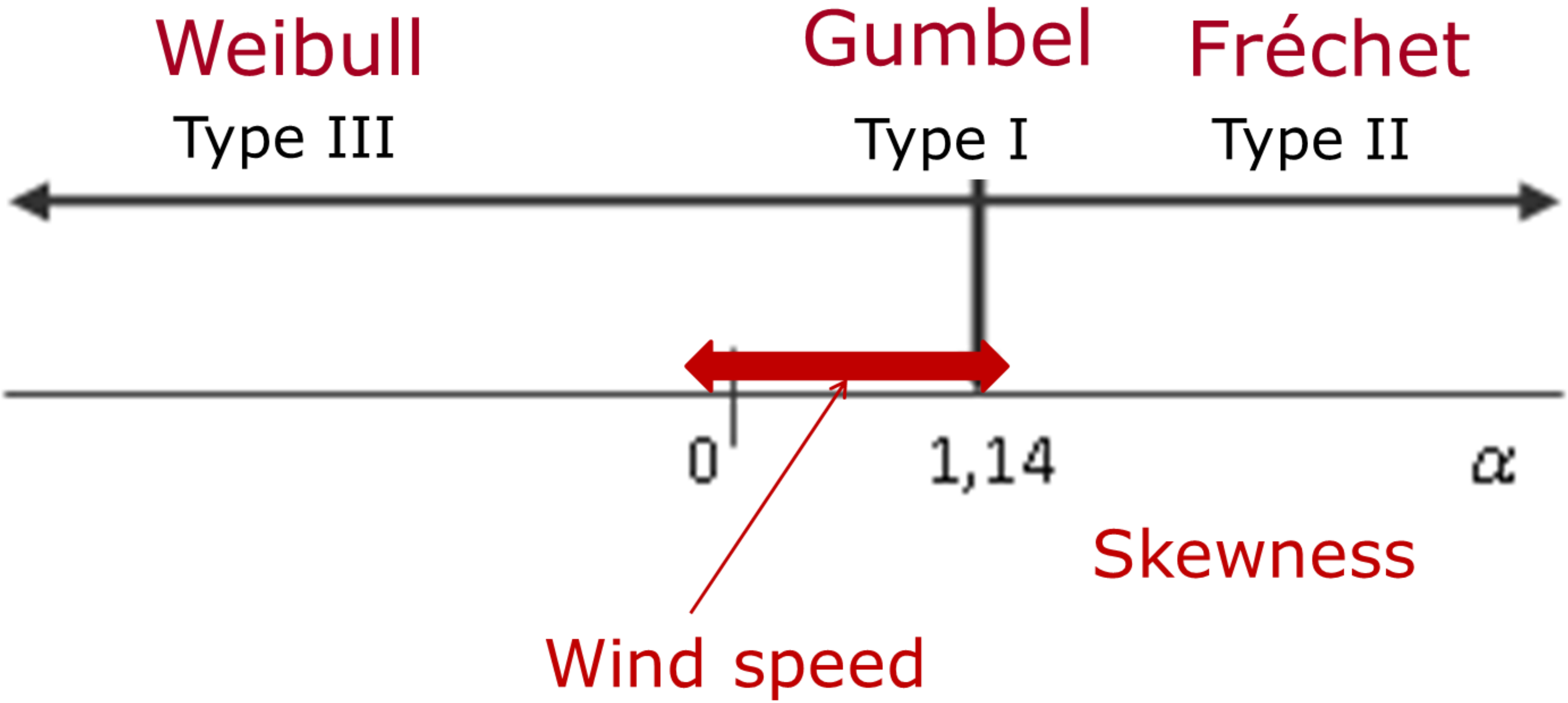
Resistenza Mat. 1 (COV=0,15)
Sollecitazione
Resistenza Mat.2 (COV=0,06)
R_{2m}
$\beta_2=3,8$
R_{2k}
$\beta_1=3,8$
$P_f=1/14000$
$\gamma_{m(1)}=1,4$
$\gamma_{m(2)}=1,0$
$\gamma_{M(1)}=1,5$
$\gamma_{M(2)}=1,05$
S_k
S_m
$S_d=R_{1d}=R_{2d}$
R_{1k}
R_{1m}
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5



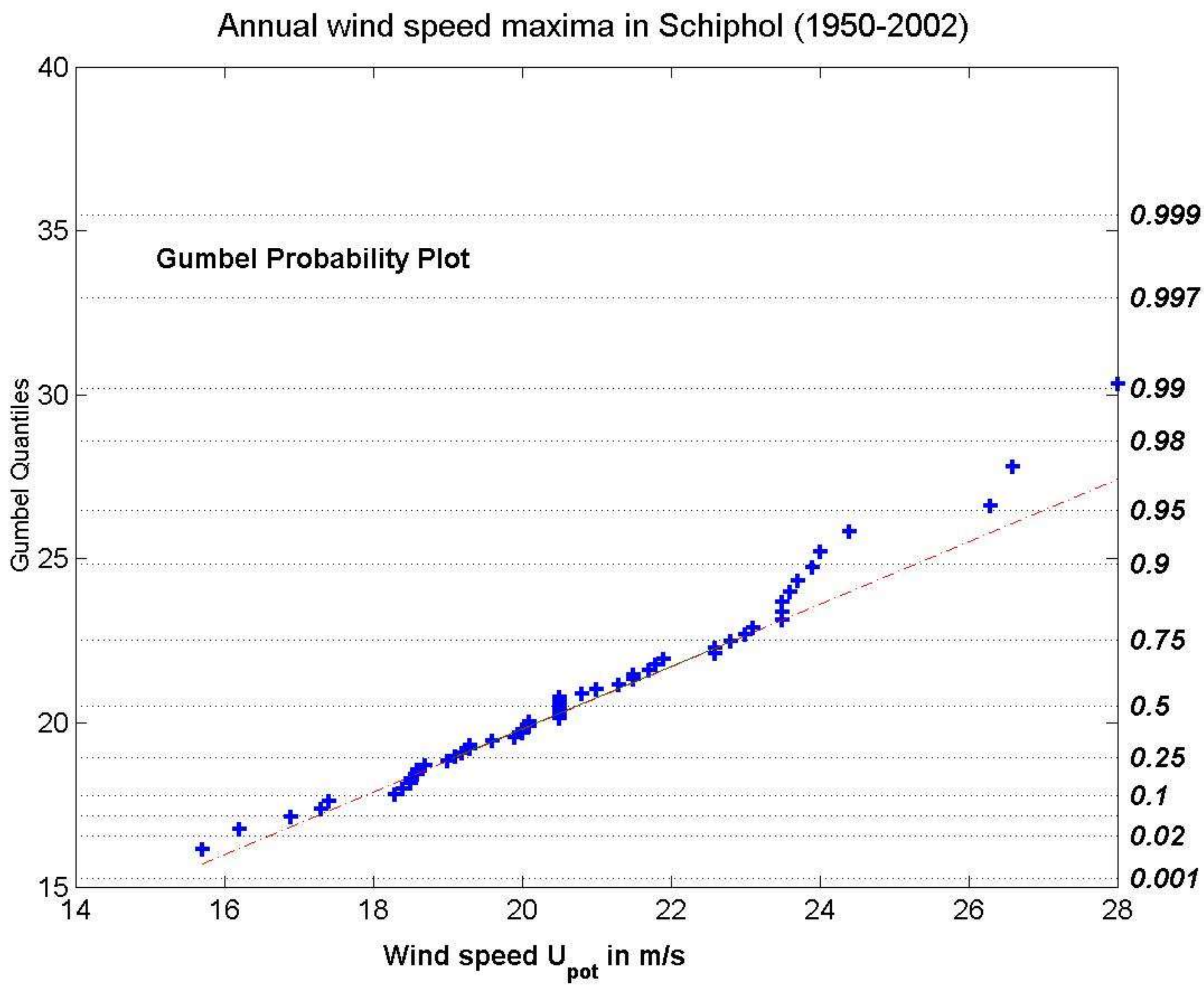
Resistenza Mat. 1 (COV=0,15)
Sollecitazione
Resistenza Mat.3 (COV=0,25)
β3=3,8
β1=3,8
Pf=1/14000
γm(1)=1,4
γm(2)=1,85
γM(1)=1,5
γM(2)=2,0
Sk
R3k
Sm
Sd=R1d=R3d
R1k
R1m
R3m
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
0
2
4
6
7
8

Wind speed

Commonly adopted extreme value distributions

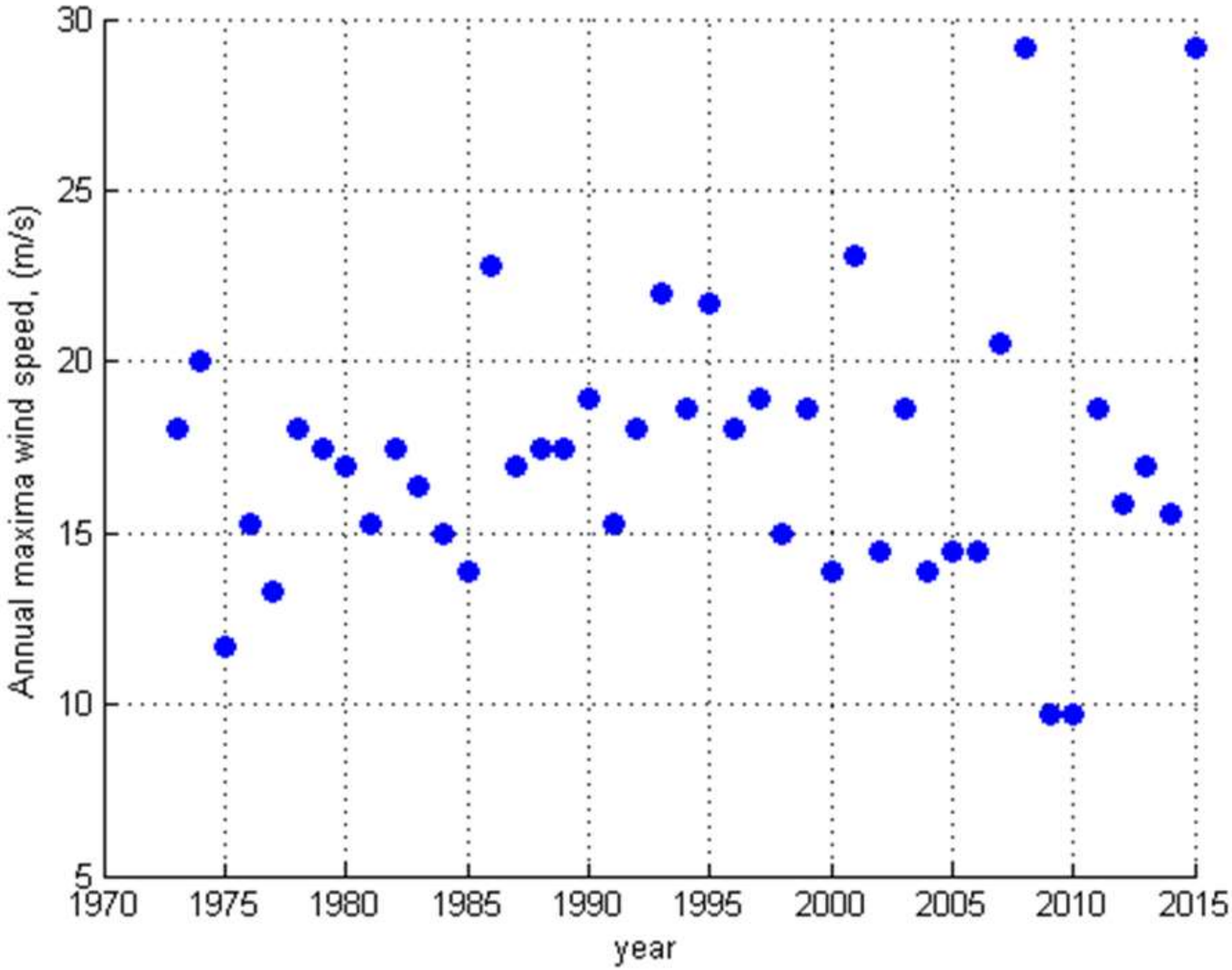


Wind speed



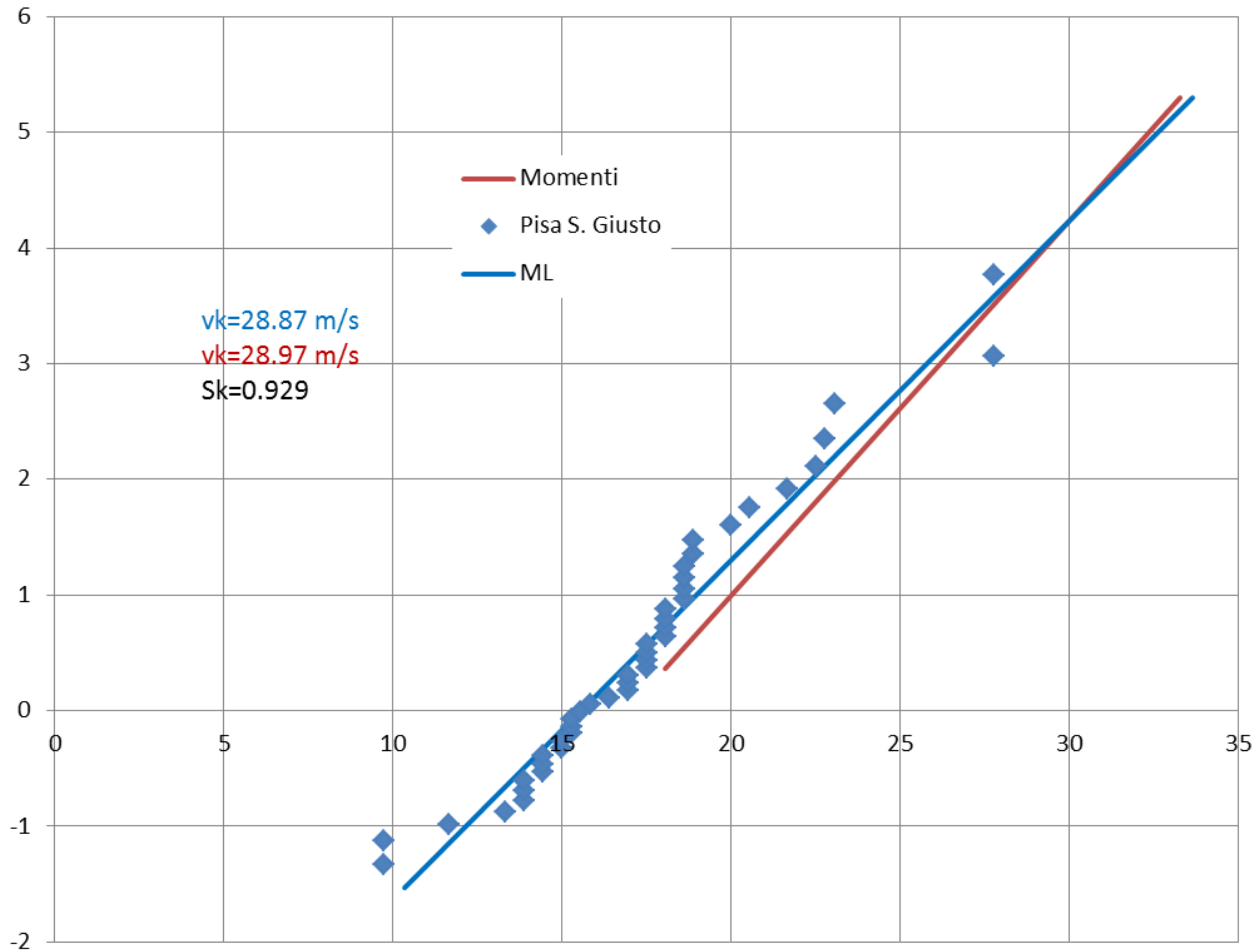
Annual wind speed maxima in Schiphol (1950-2002)
Gumbel Probability Plot
Gumbel Quantiles
Wind speed U_{pot} in m/s
40
35
30
25
20
15
14
16
18
20
22
24
26
28
0.999
0.997
0.99
0.98
0.95
0.9
0.75
0.5
0.25
0.1
0.02
0.001

Wind speed

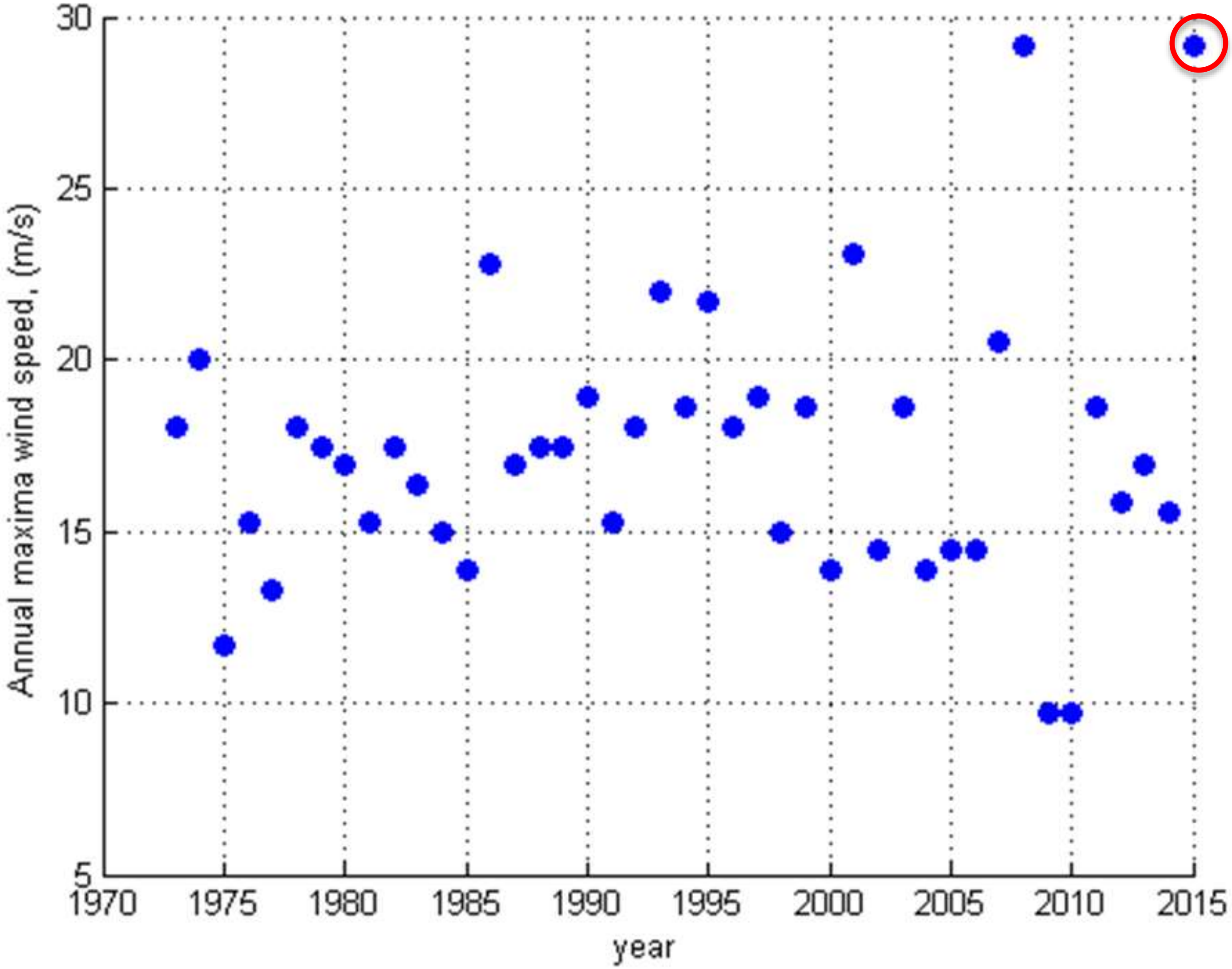


Annual maxima of wind speed at Pisa airport weather station

Wind speed – Pisa airport annual maxima elaboration

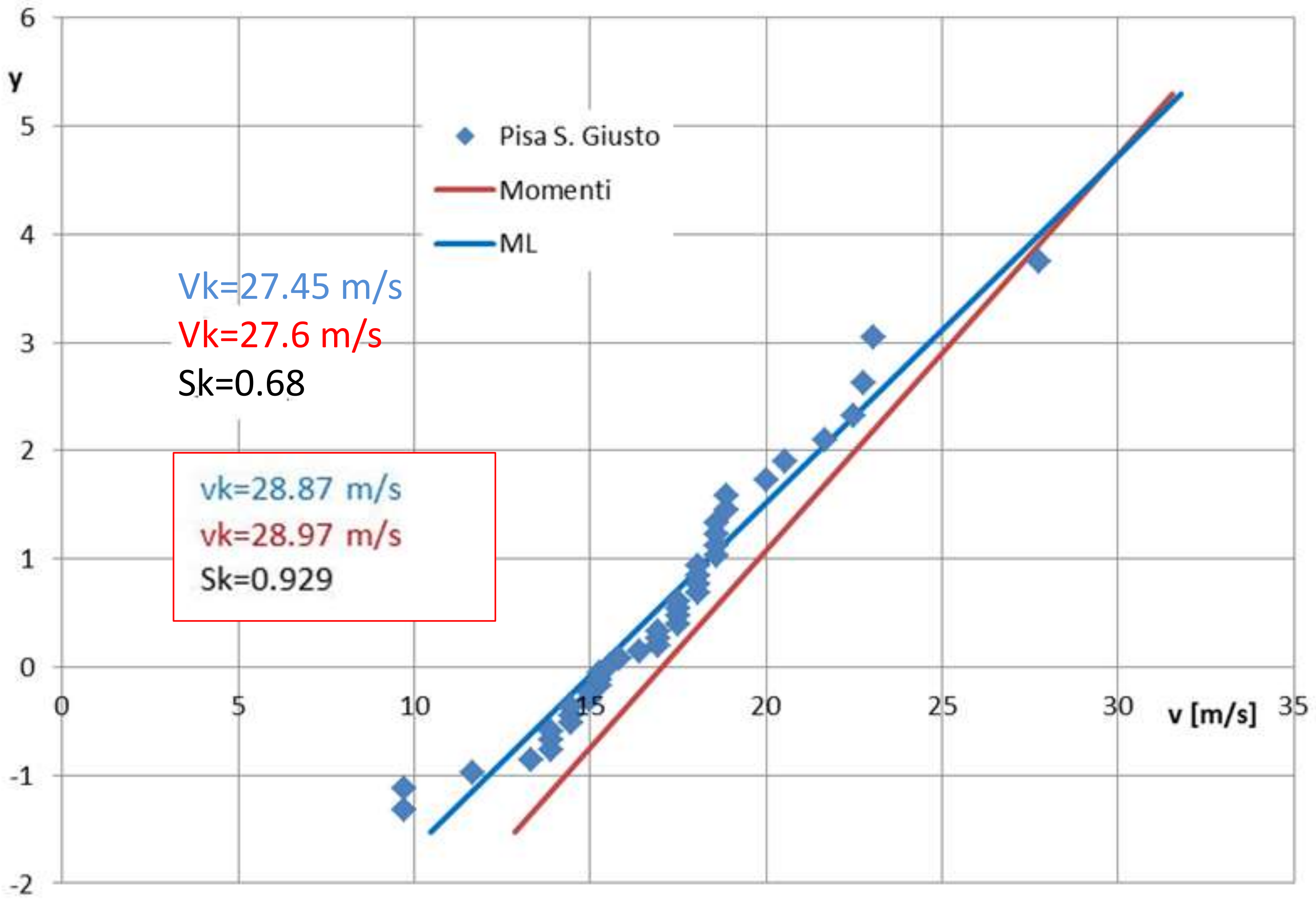


Wind actions



Annual maxima of wind speed at Pisa airport weather station

Wind speed – Pisa airport annual maxima elaboration



JCSS PROBABILISTIC MODEL CODE

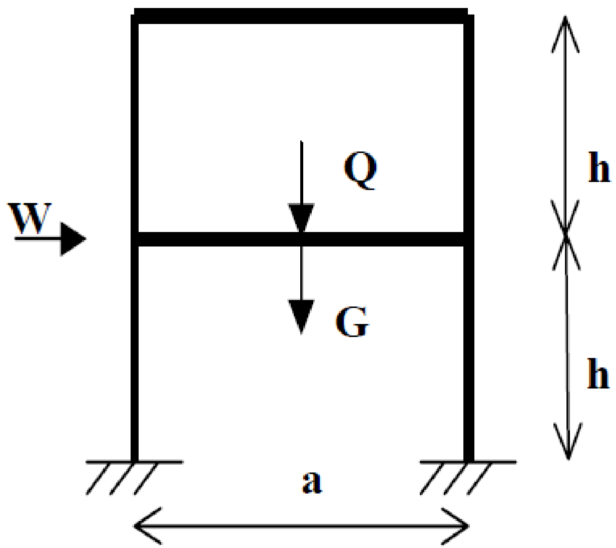


Figure 3.1. Two storey steel frame

EXAMPLE APPLICATIONS

Ton Vrouwenvelder

Milan Holicky

Jana Markova

$$R = m_R Z_p f_y$$

$$G = a\, b\, t\, \rho_c\, g$$

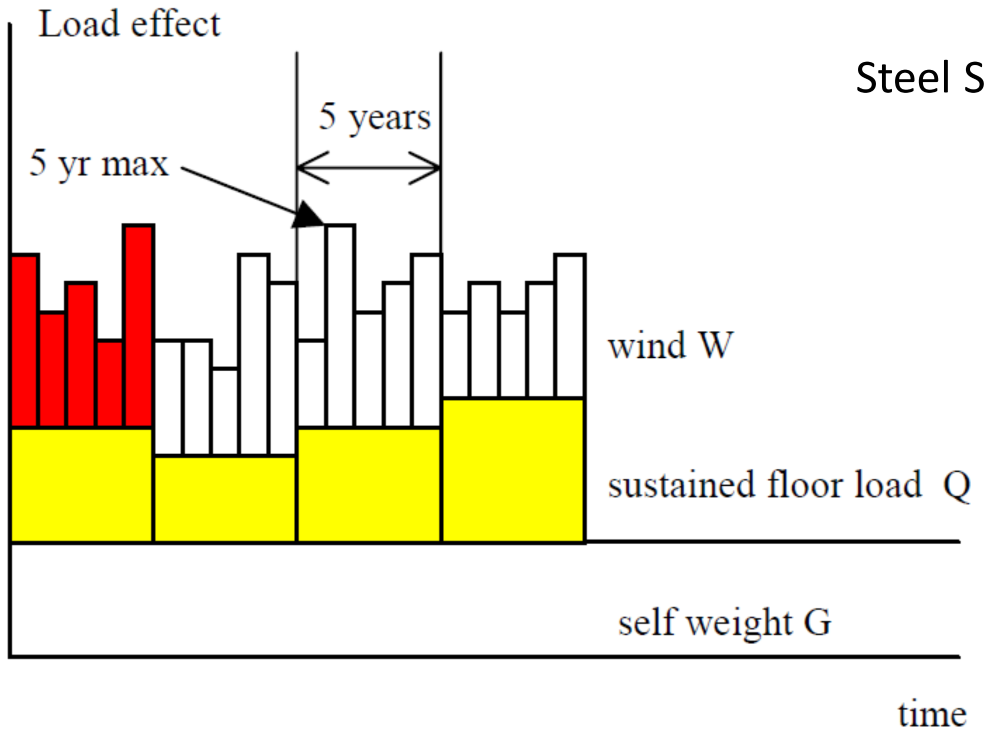
$$Q = a\, b\, (q_{long} + q_{short})$$

$$W = 2\, h\, b\, c_a\, c_g\, c_r\, (0.5\, m_q\, \rho_a\, U^2)$$

$$Z = R - 0.16\, m_E\, h\, (G + Q + W)$$

Table 3.1 Probabilistic models for the steel frame example (according to the JCSS Probabilistic Model Code 2001)

X	Designation	Distribution	Mean	V	λ
a	in plane column distance	Deterministic	6 m	-	
b	frame to frame distance	Deterministic	5 m	-	
h	storey height	Deterministic	3 m	-	
t	thickness concrete floor slab	Normal	0.20 m	0.03	
Z_p	plastic section modulus	Normal	0.0007m^3	0.02	
f_y	steel yield stress	Lognormal	300 MPa	0.07	
g	acceleration of gravity	Deterministic	10 m/s^2	-	
ρ_c	mass density concrete	Normal	2.4 ton/m^3	0.04	
q_{long}	long term live load (sustained)	Gamma	0.50 kN/m^2	1.15	0.2/year
q_{short}	short term live load (1 day)	Exponential	0.20 kN/m^2	1.60	1.0/year
ρ_a	mass density air	Deterministic	0.125kg/m^3	-	
c_a	aerodynamic shape factor	Normal	1.10	0.12	
c_g	gust factor	Normal	3.05	0.12	
c_r	roughness factor	Normal	0.58	0.15	
u	ref wind speed (8 hours)	Weibull	5 m/s	0.60	3.0/day
U	ref wind speed (one year)	Gumbel	30 m/s	0.10	1.0/year
m_q	model factor wind pressure	Normal	0.80	0.20	
m_R	model factor resistance	Normal	1.00	0.05	
m_E	model factor load effect	Normal	1.00	0.10	



Steel S275 – V=0.07

$W_k/(G_k+Q_k)$
0
0.1
0.245
0.5
1
2
3
4
6
10

Cases considered for extreme wind velocity

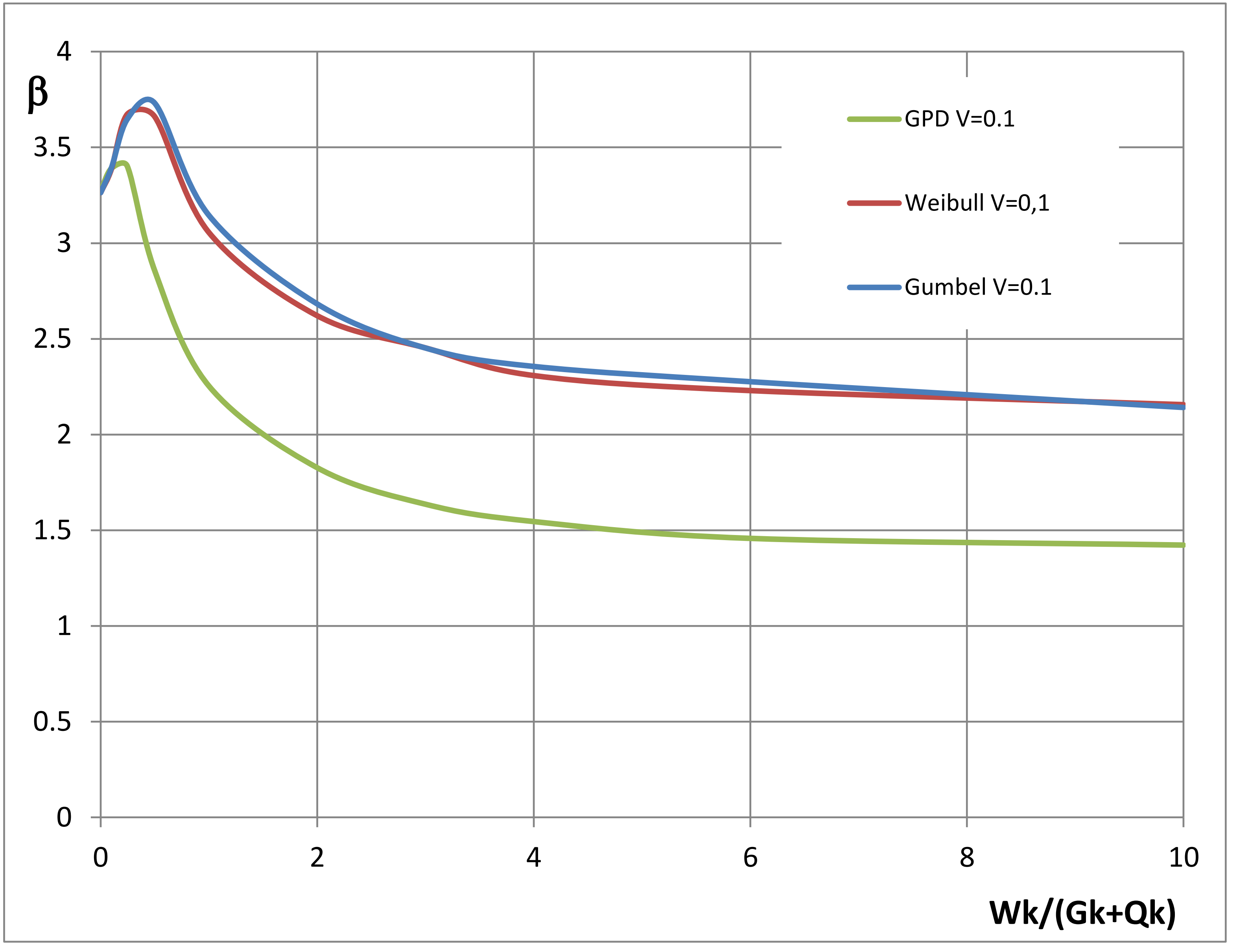
Gumbel distribution

3-parameters Weibull distribution

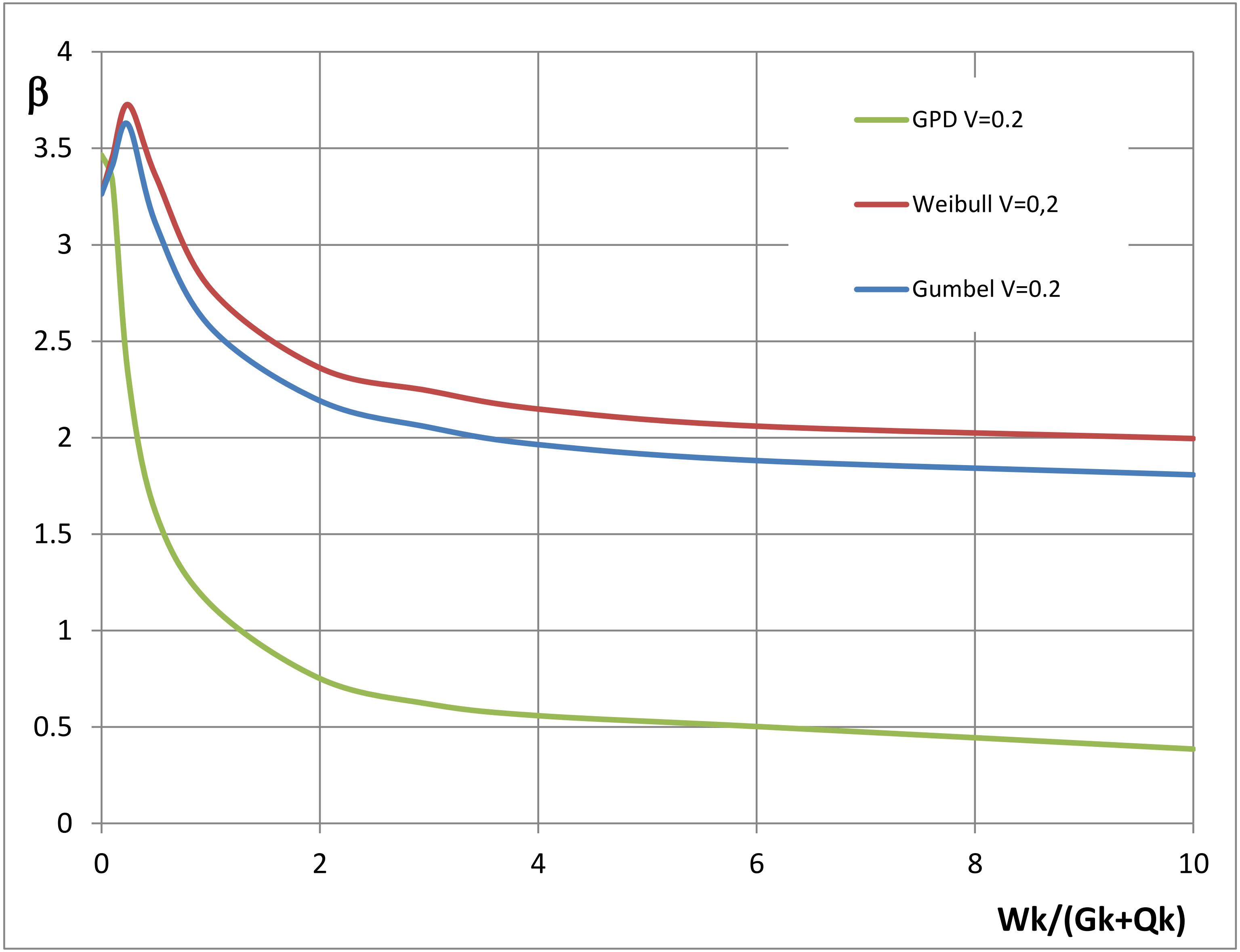
GPD

V=0.1

V=0.2



β-$W_k/(G_k+Q_k)$ diagrams for various extreme maxima distributions for wind (V=0.1)



β-$W_k/(G_k+Q_k)$ diagrams for various extreme maxima distributions for wind (V=0.2)

Reliability decreases when the wind action is very high

Reliability depends on the distribution assumed for extreme maxima

Wind pressure model is still an open question (each relevant coefficient needs to be discussion)

Fundamental combination (ULS)

$$\sum F_{\mathrm{d}} = \sum_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \gamma_{\mathrm{Q,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{\mathrm{0,j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}})$$

Eqn. 8.20 (formerly 6.10)

$$\sum F_{\mathrm{d}} = \begin{cases} \sum_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \gamma_{\mathrm{Q,1}} \psi_{\mathrm{0,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{\mathrm{0,j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}}) \\ \sum_{\mathrm{i}} \xi_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \gamma_{\mathrm{Q,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{\mathrm{0,j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}}) \end{cases}$$

Eqns. 8.21 a+b (formerly 6.10 a+b)

Fundamental combination (ULS)

$$\sum F_{\mathrm{d}} = \begin{cases} \sum_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \quad (\gamma_{\mathrm{P}} P_{\mathrm{k}}) \\ \sum_{\mathrm{i}} \xi_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \gamma_{\mathrm{Q,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{\mathrm{0,j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}}) \end{cases}$$

Eqns. 8.22 a+b (formerly 6.10 a+b mod)

$$\sum F_{\mathrm{d}} = \sum_{\mathrm{i}} \gamma_{\mathrm{G1,i}} G_{\mathrm{1k,i}} + \sum_{\mathrm{i}} \gamma_{\mathrm{G2,i}} G_{\mathrm{2k,i}} + \gamma_{\mathrm{Q,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{\mathrm{0,j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}})$$

PT proposal (rejected)

Rand. Var.	Variable	distr	μ	COV	$F(x_k)$
θ_R	MU Concrete	LogN	1.00	0.20	$F(\mu_X)$
	MU Steel		1.00	0.10	
	MU Timber		1.00	0.15	
	MU Masonry			Input Jäger	
	MU Soil		/	/	
X	Concrete compressive strength	LogN	1.00	0.17	0.05
	Structural steel yielding strength		1.00	0.07	
	Re-bar yield strength		1.00	0.06	
	Solid timber bending strength		1.00	0.25	
	Glulam timber bending strength		1.00	0.15	
	Masonry compression			Input Jäger	
	Masonry shear			Input Jäger	
	Soil internal friction		1.00	0.09	
	Soil drained cohesion		1.00	0.47	
	Soil undrained shear strength		1.00	0.38	
	Timber bending MOE		1.00	0.13	
	Masonry MOE			Input Jäger	
	Steel bending MOE		1.00	0.02	
	Concrete compression MOE		1.00	To be completed	
G_S	Concrete	Norm	1.00	0.05	0.50
	Steel		1.00	0.04	
	Timber		1.00	0.10	
	Masonry			Input Jäger	
	Soil		1.00	0.10	

Rand. Var.	Variable	distr	μ	COV	$F(x_k)$
G_P	Permanent load	Norm	1.00	0.10	0.50
G_P^*	Permanent load (large COV)	Norm	1.00	0.20	0.95
θ_Q	MU Wind	LogN	To be completed	0.35	0.78 for Cpe, Mean values for others
	MU Snow 1	LogN	1.00	0.20 - 0.30	Mu+sigma for Cr[a], mean values for others
	MU Snow 1			0.35	mean
	MU Imposed	LogN	1.00	0.10	Mean value
Q (1yr)	Wind pressure	Gumbel	1.00	0.25	0.98
	Snow on ground	Gumbel	1.00	0.40	0.98
	Imposed	Gumbel (LogN)	1.00	To be completed	0.98

Model uncertainty - LogNormal

Two cases:

Mean value 0.35 and 0.51 for wind – 0.20 and 0.28 for snow

$$\alpha_G = \frac{g_{sk}}{g_{sk} + g_{Pk}}$$

$$\alpha_G = \frac{1}{3}; 0.6; 0.8; 1.0$$

$$\alpha_Q = \frac{q_k}{g_{sk} + g_{Pk} + q_k}$$

$$\alpha_Q = 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8$$

Design equation according to:

Eq. 8.20 (6.10)

γ_G	γ_Q
1.35	1.5

Eq. 8.21 a+b (6.10 a+b)

γ_G	γ_Q	ξ	$\psi_{0,1}$	$\psi_{0,2}$
1.35	1.5	0.85	0.6	0.7

Eq. 8.20 prop

γ_{G1}	γ_{G2}	γ_{Qw}	γ_{Qs}
1.203	1.213	1.529	1.711

Eq. 8.20 a+b prop

γ_{G1}	γ_{G2}	γ_{Qw}	γ_{Qs}	ξ	$\psi_{0,1}$	$\psi_{0,2}$
1.221	1.229	1.516	1.675	0.85	0.6	0.7

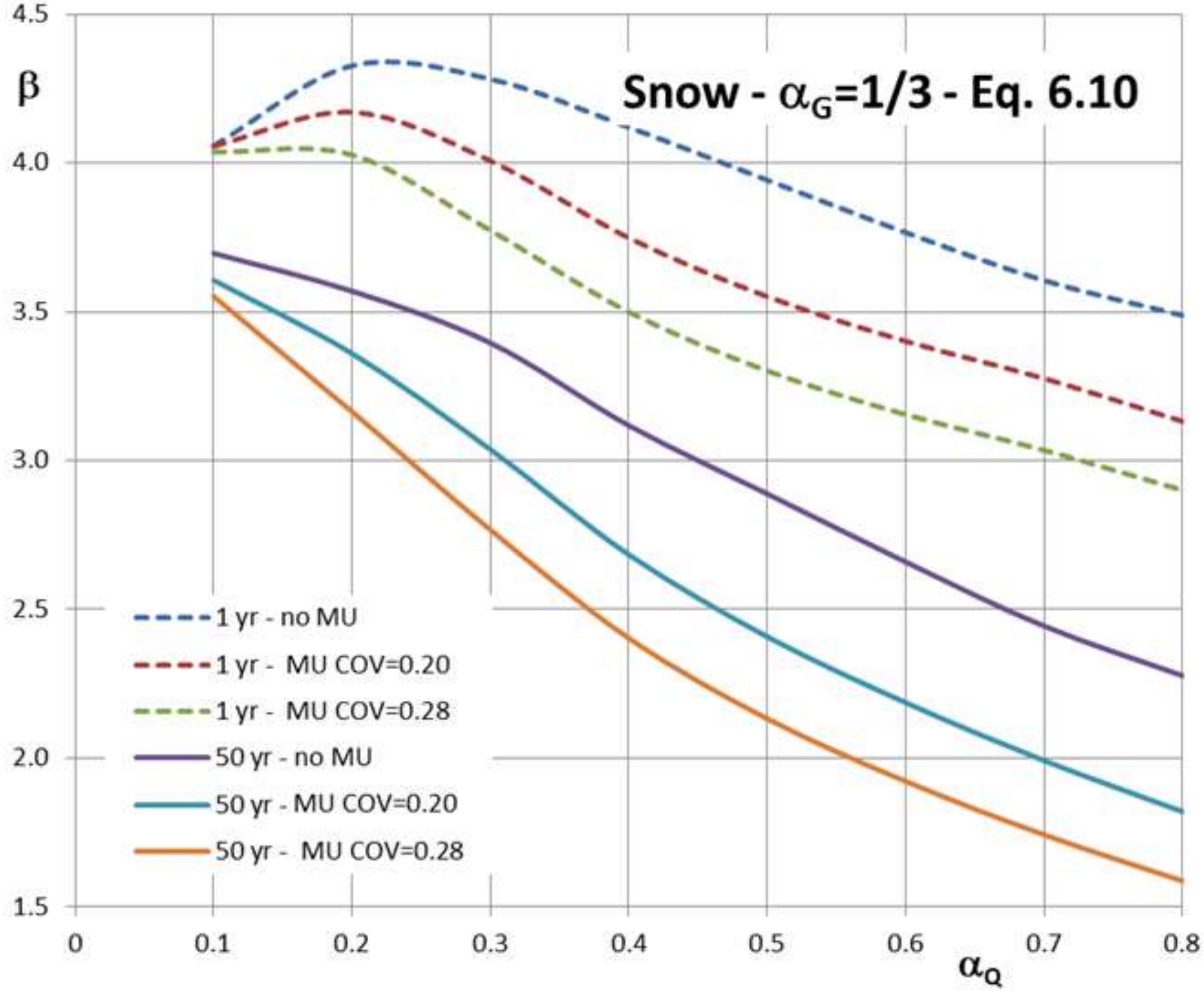
Probability of failure is evaluated for two cases:

1 year and 50 years

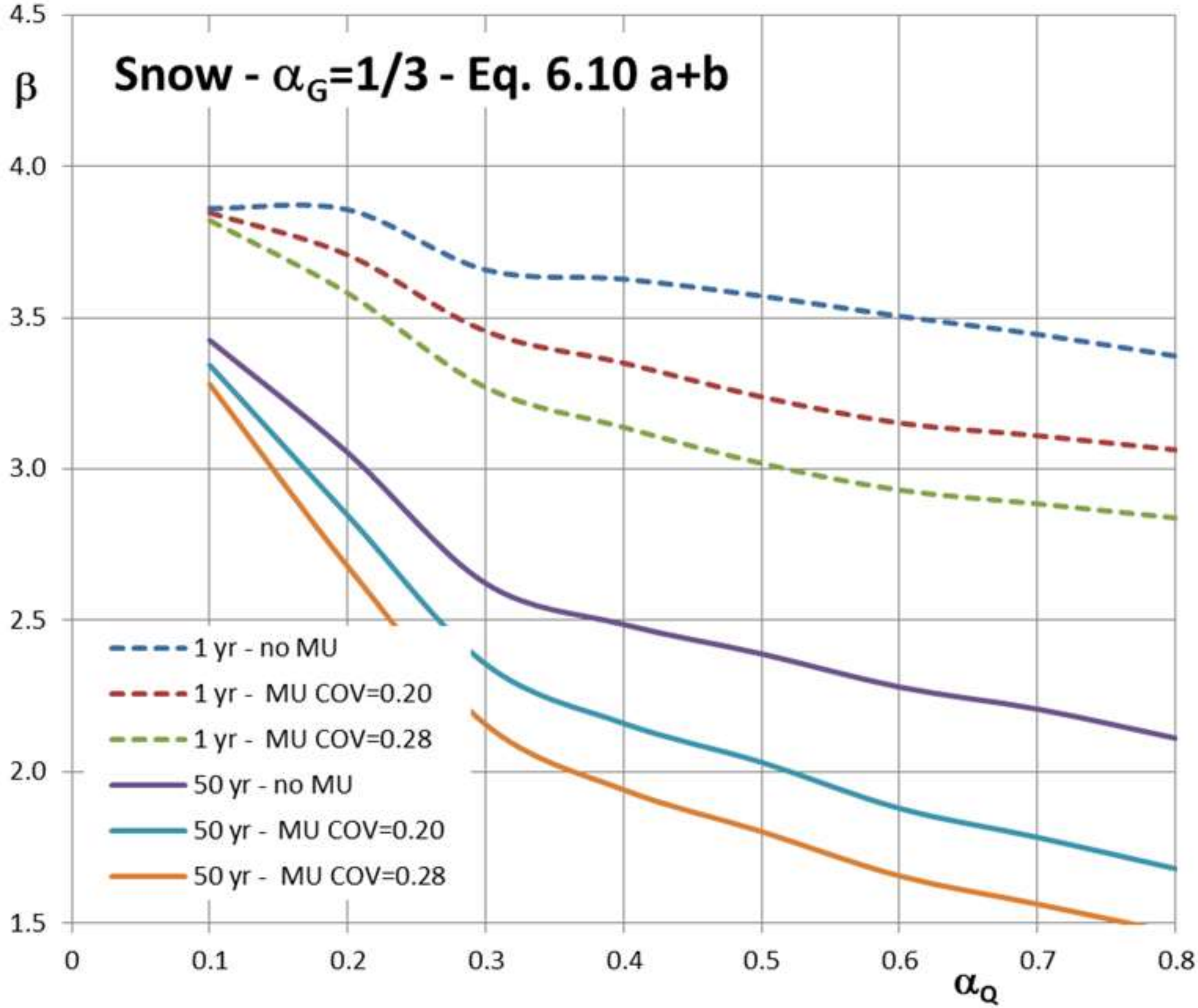
Steel

Concrete

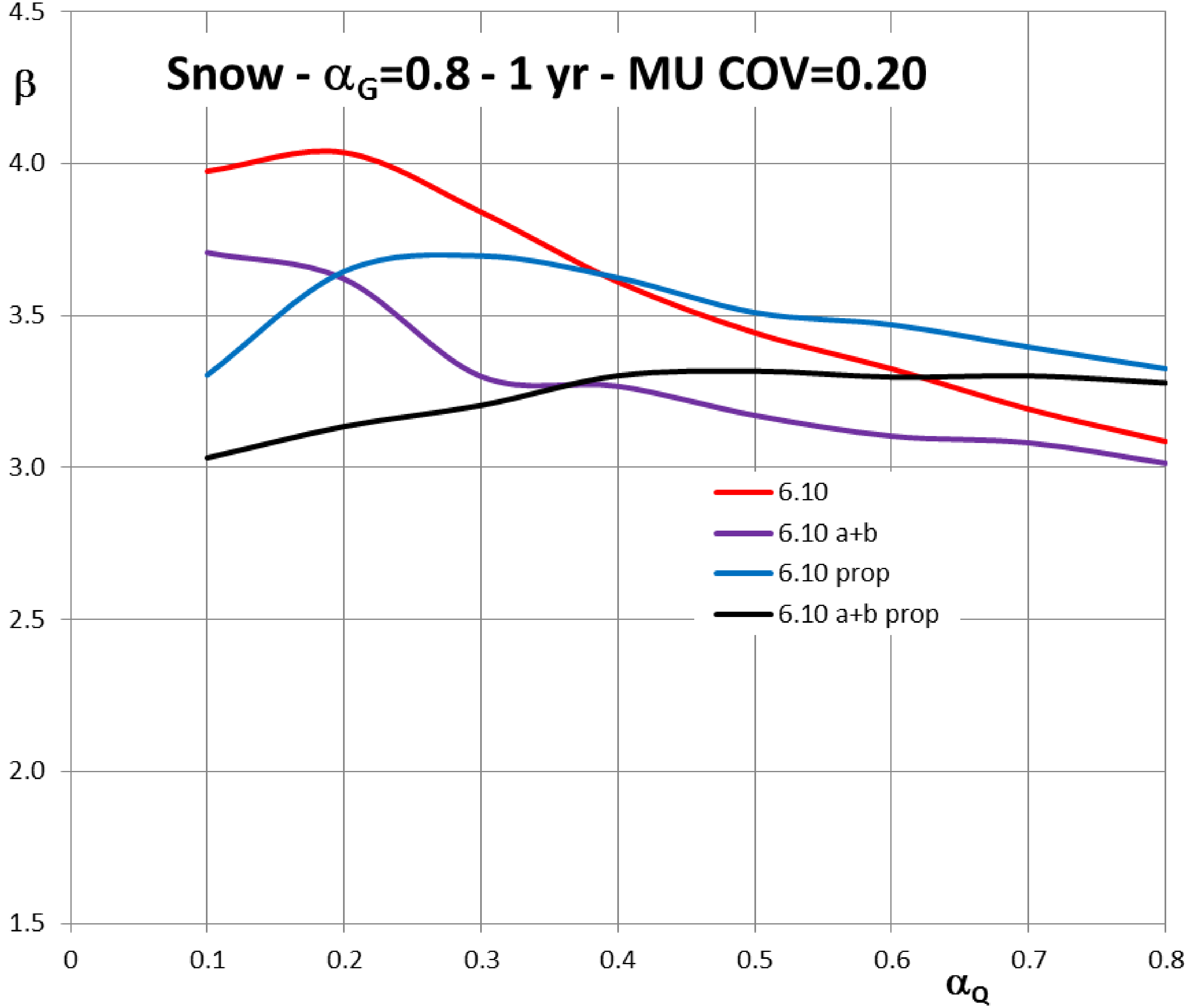
Glulam



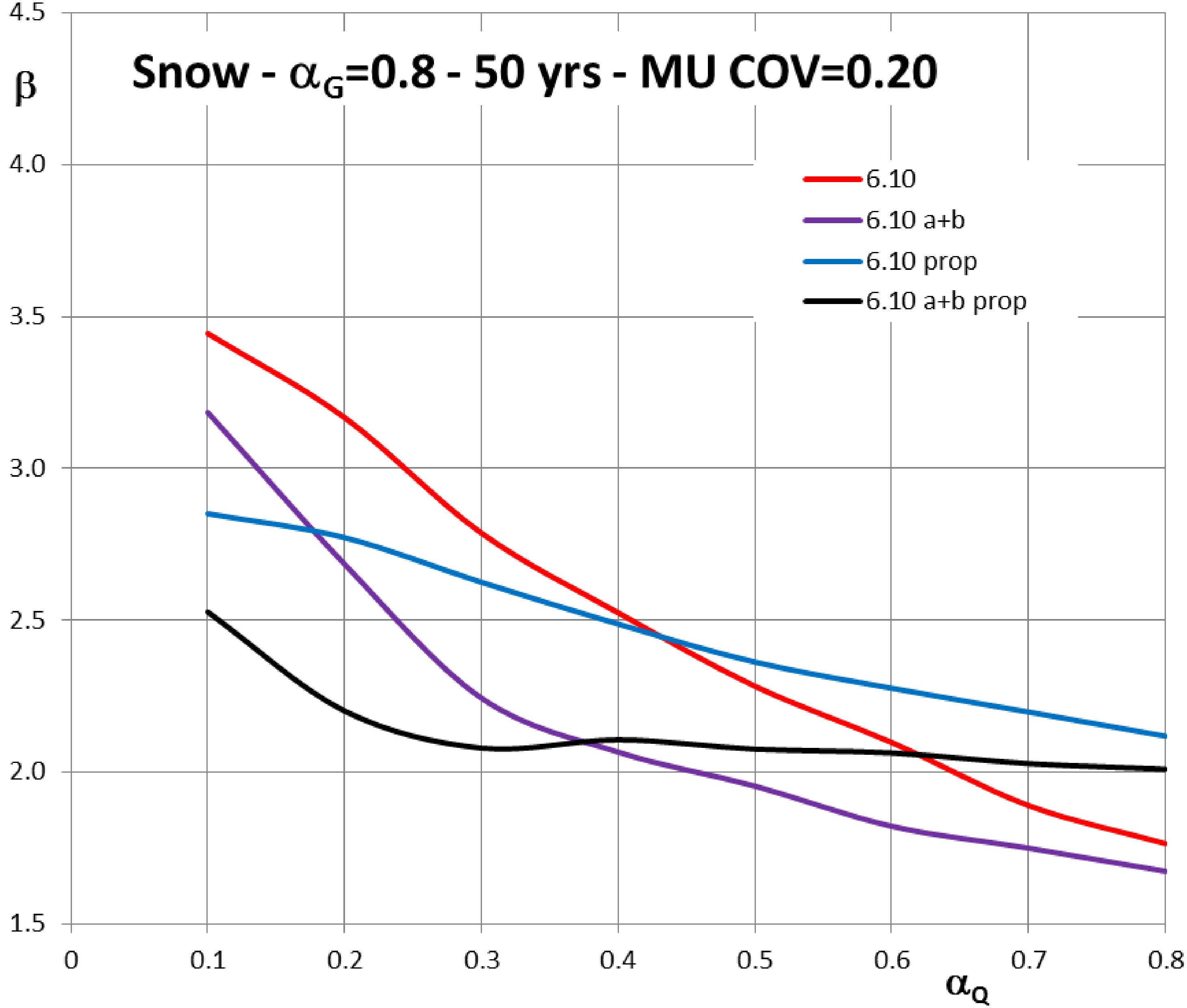
Steel – Snow – Eq. 6.10



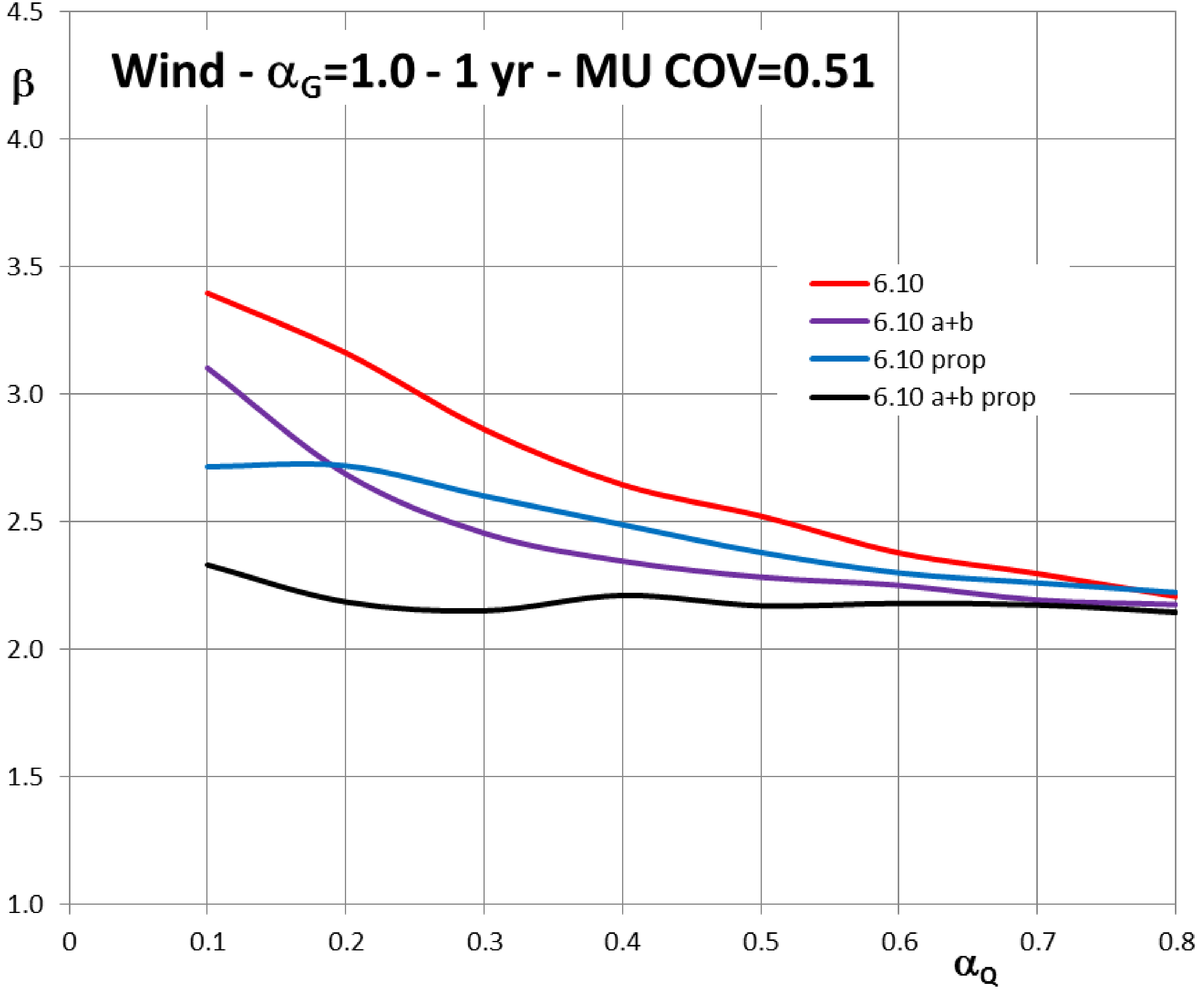
Steel – Snow – Eq. 6.10 a+b



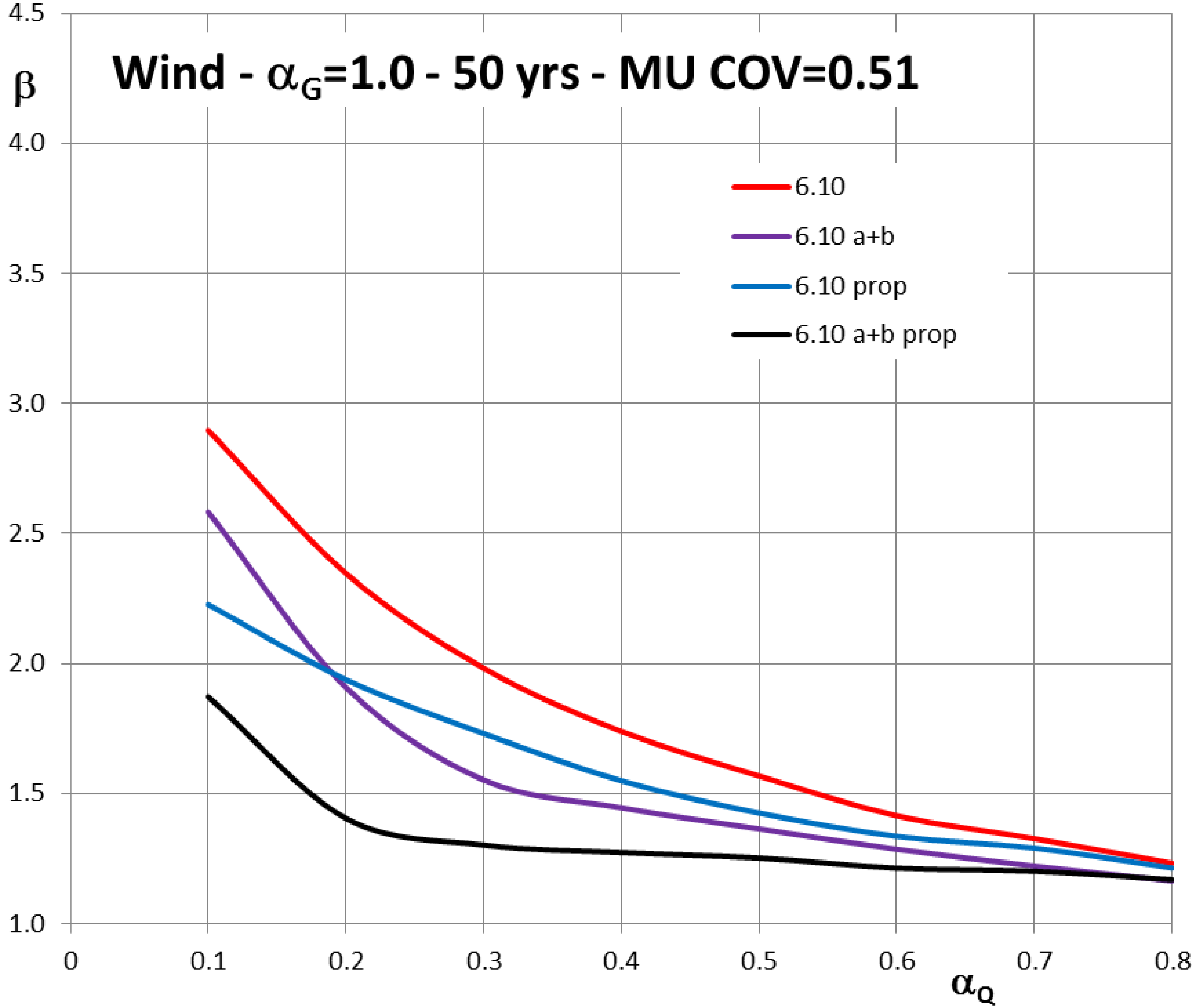
Steel – Snow – MU COV=0.20



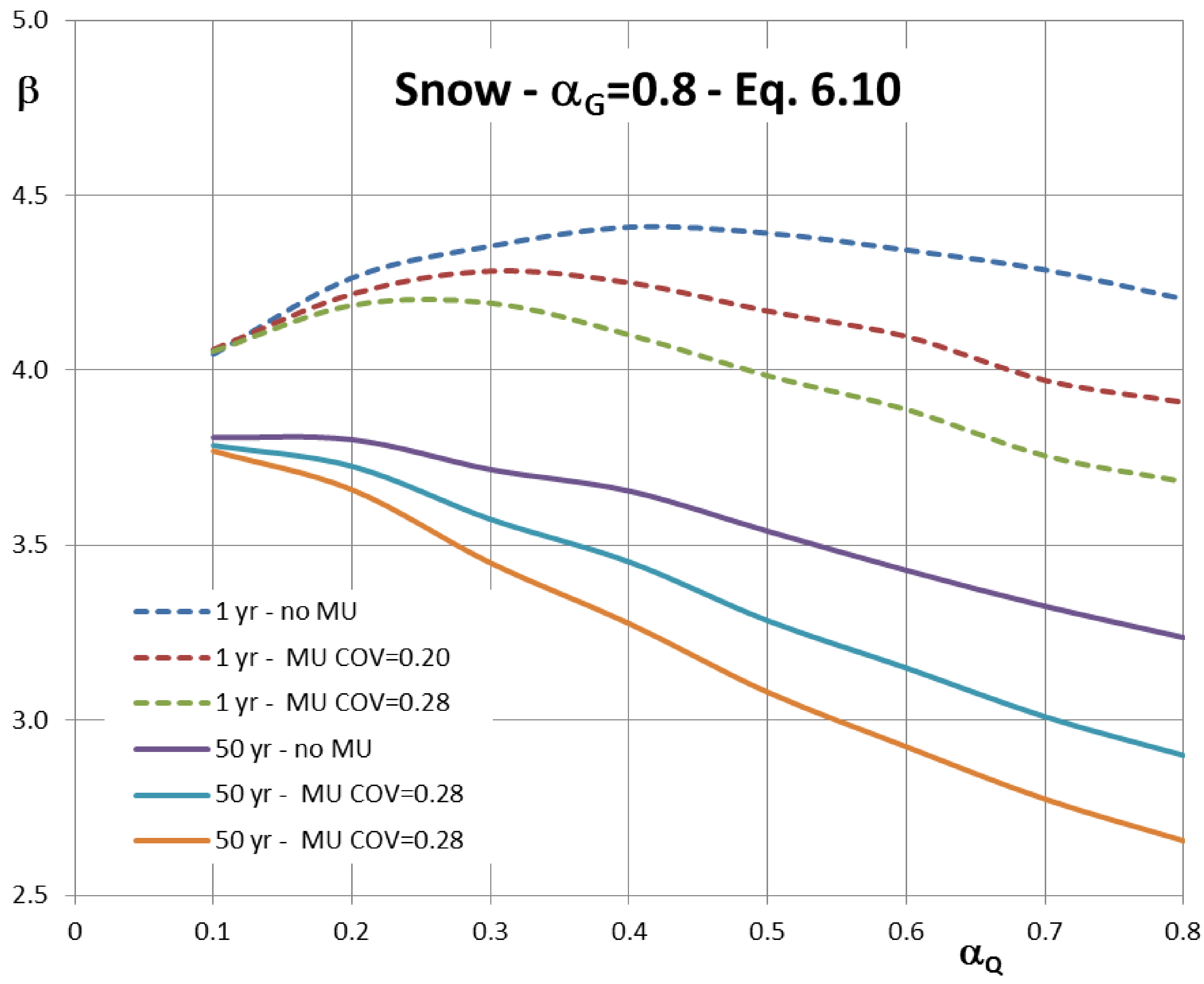
Steel – Snow –MU COV 0.20



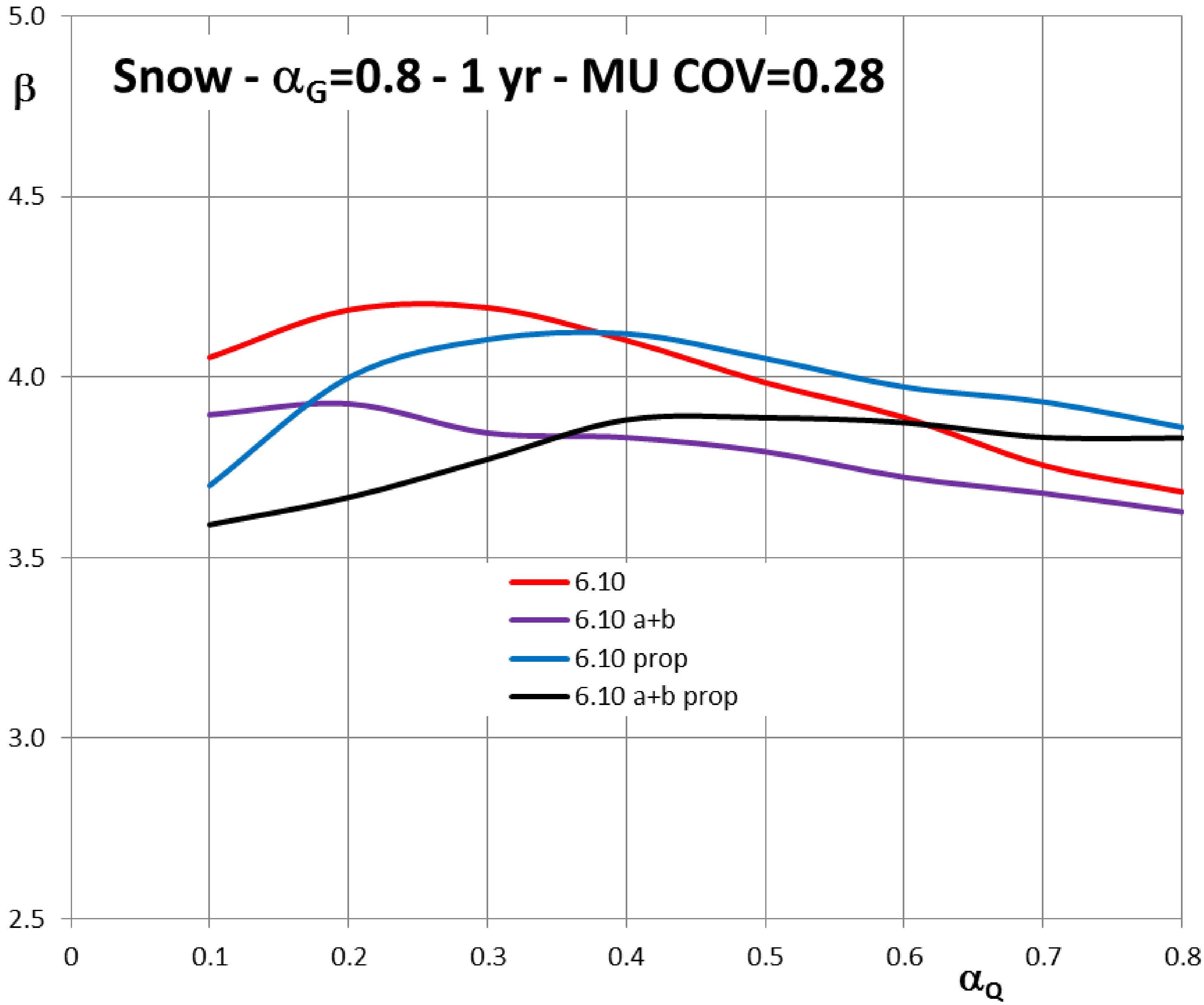
Steel – Snow – MU COV=0.51



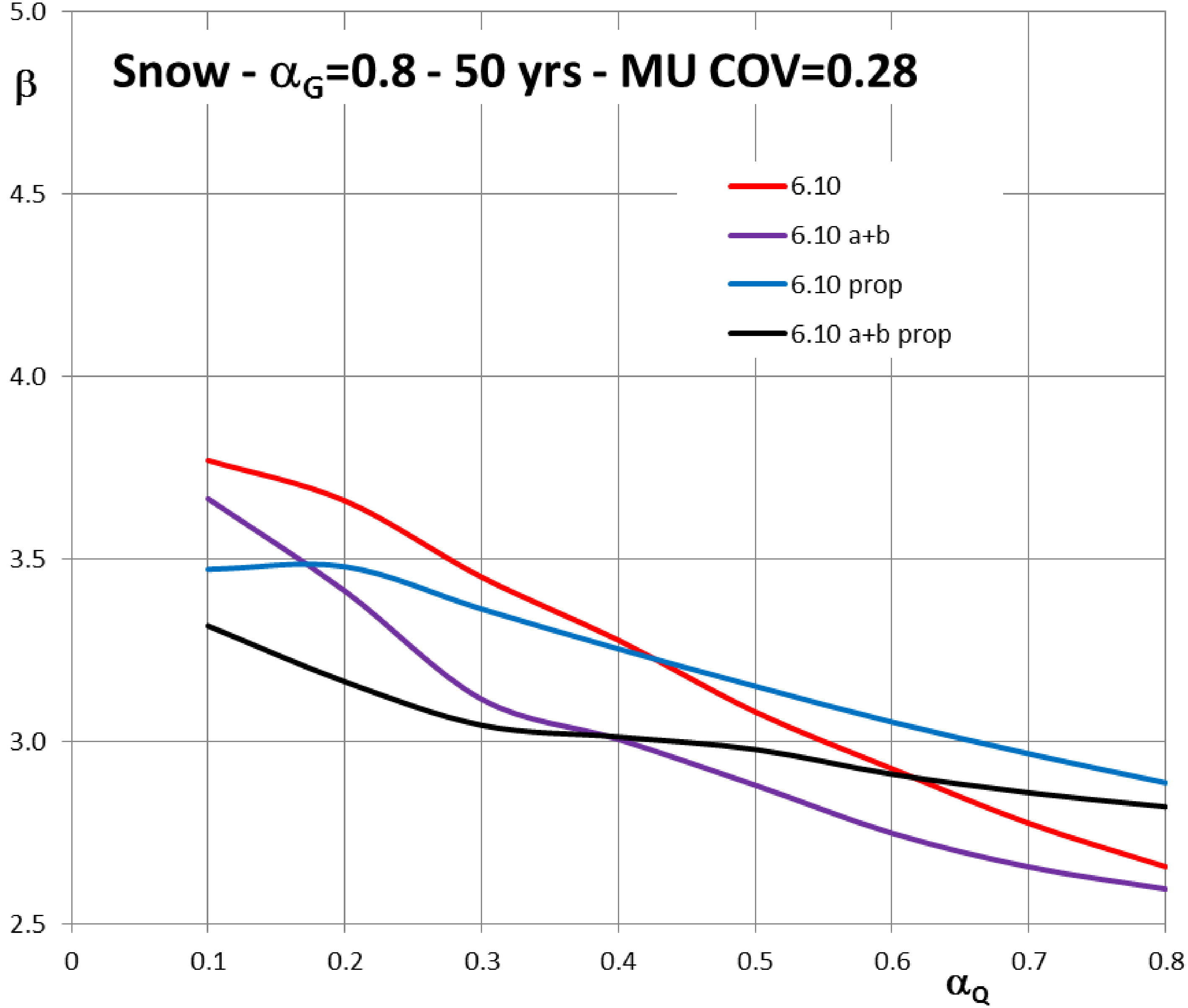
Steel – Snow –MU COV 0.51



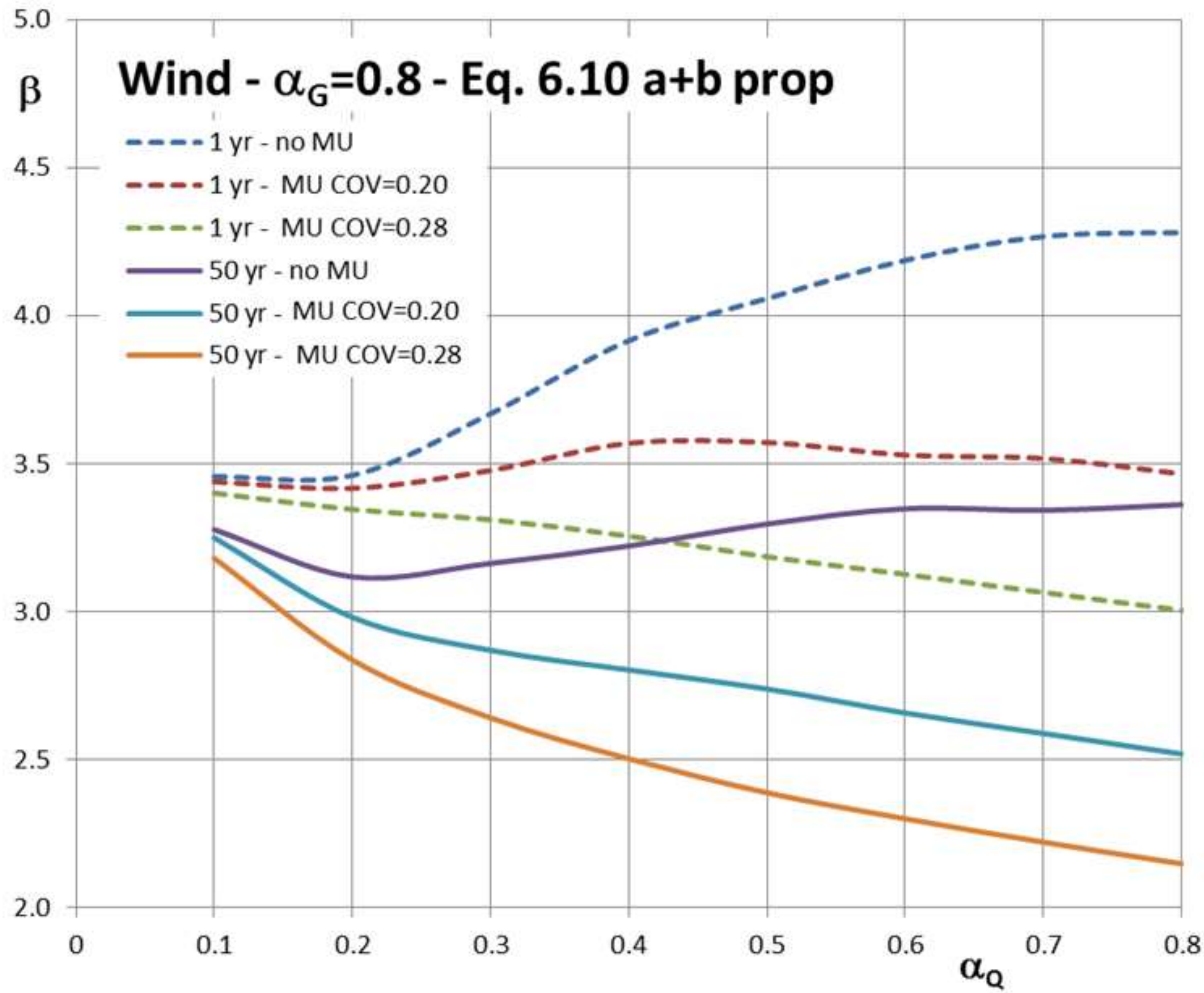
Snow - α_G=0.8 - Eq. 6.10
β
5.0
4.5
4.0
3.5
3.0
2.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
α_Q
1 yr - no MU
1 yr - MU COV=0.20
1 yr - MU COV=0.28
50 yr - no MU
50 yr - MU COV=0.28
50 yr - MU COV=0.28



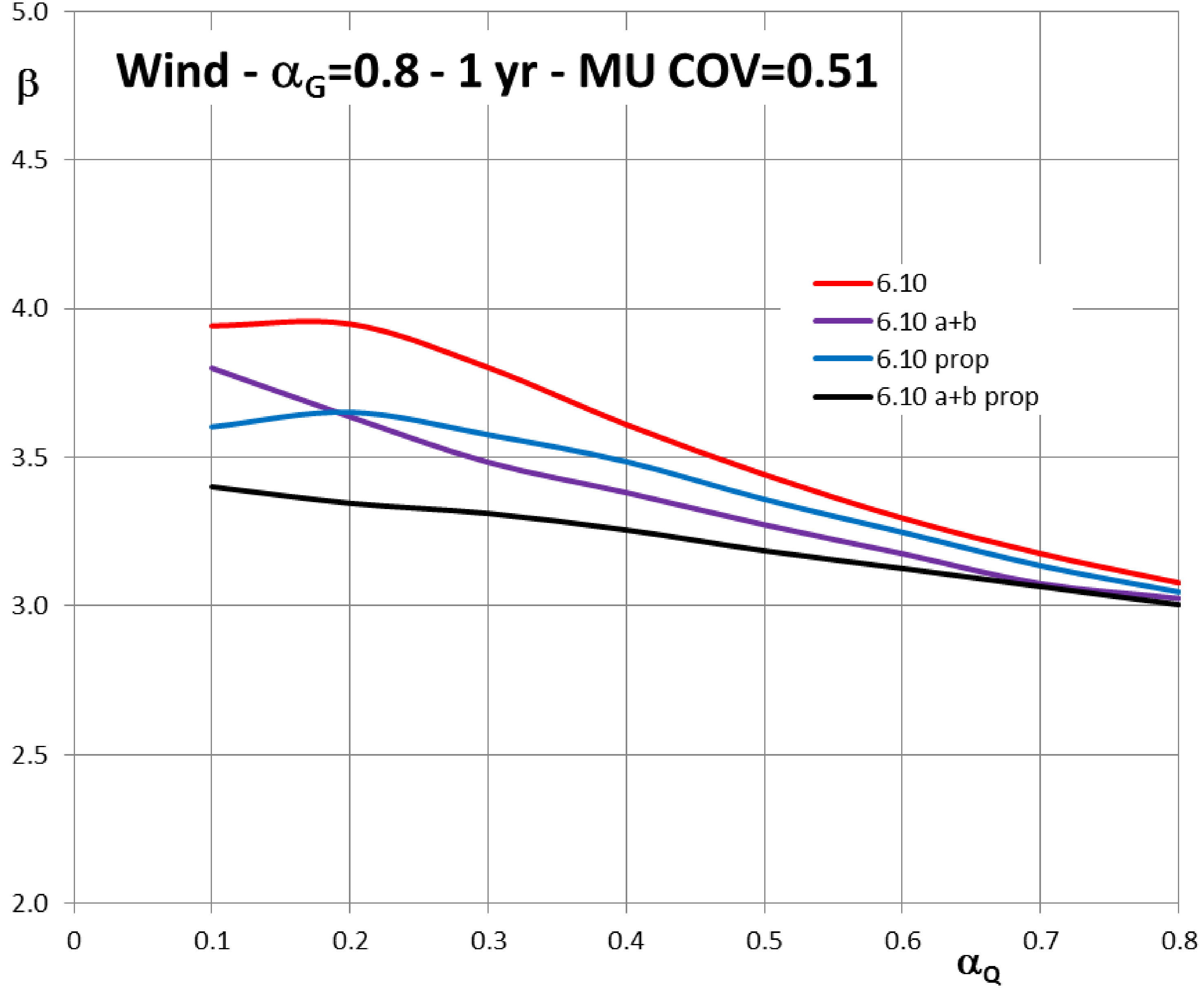
Concrete – Snow –MU COV=0.28



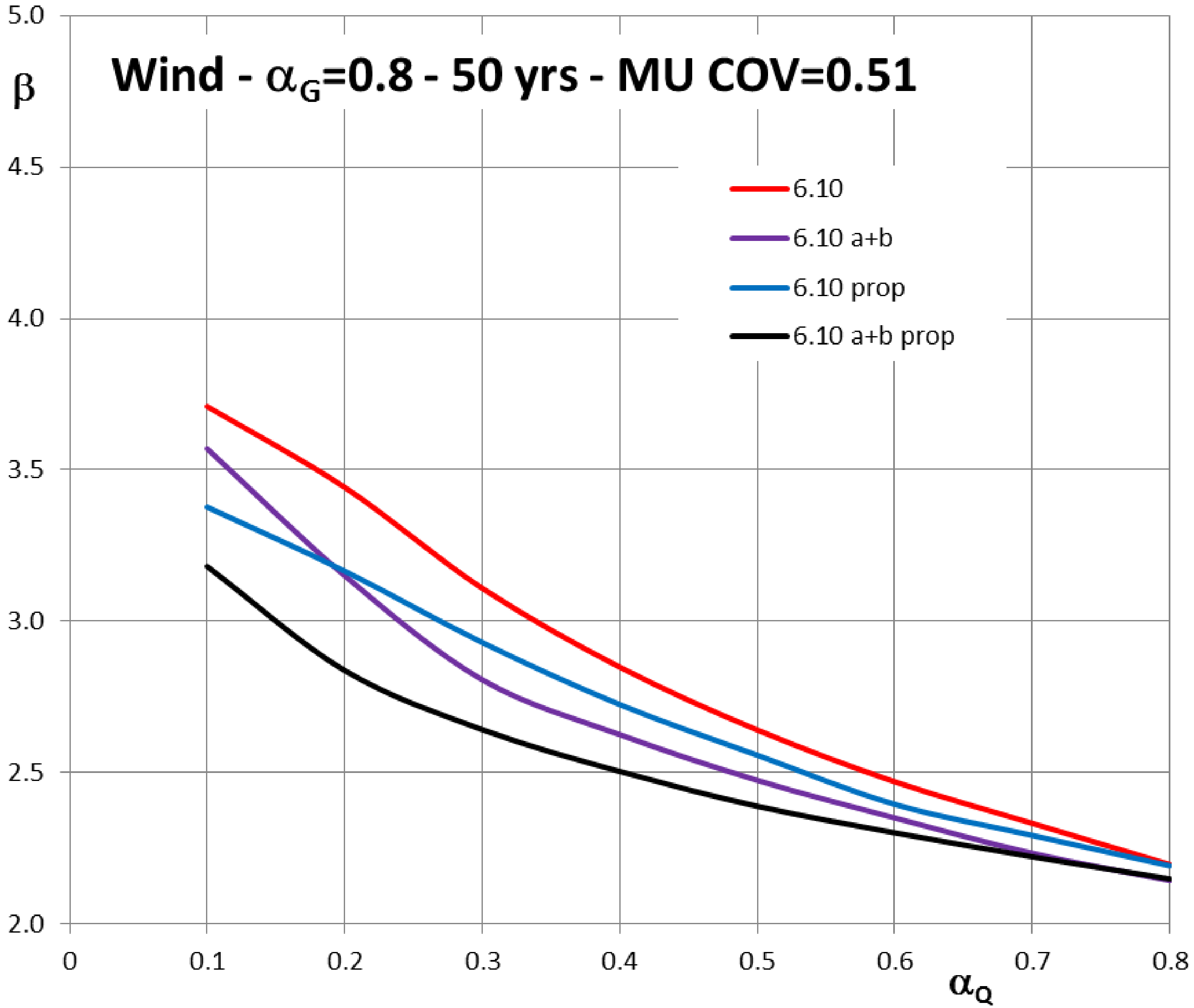
Concrete – Snow –MU COV 0.28



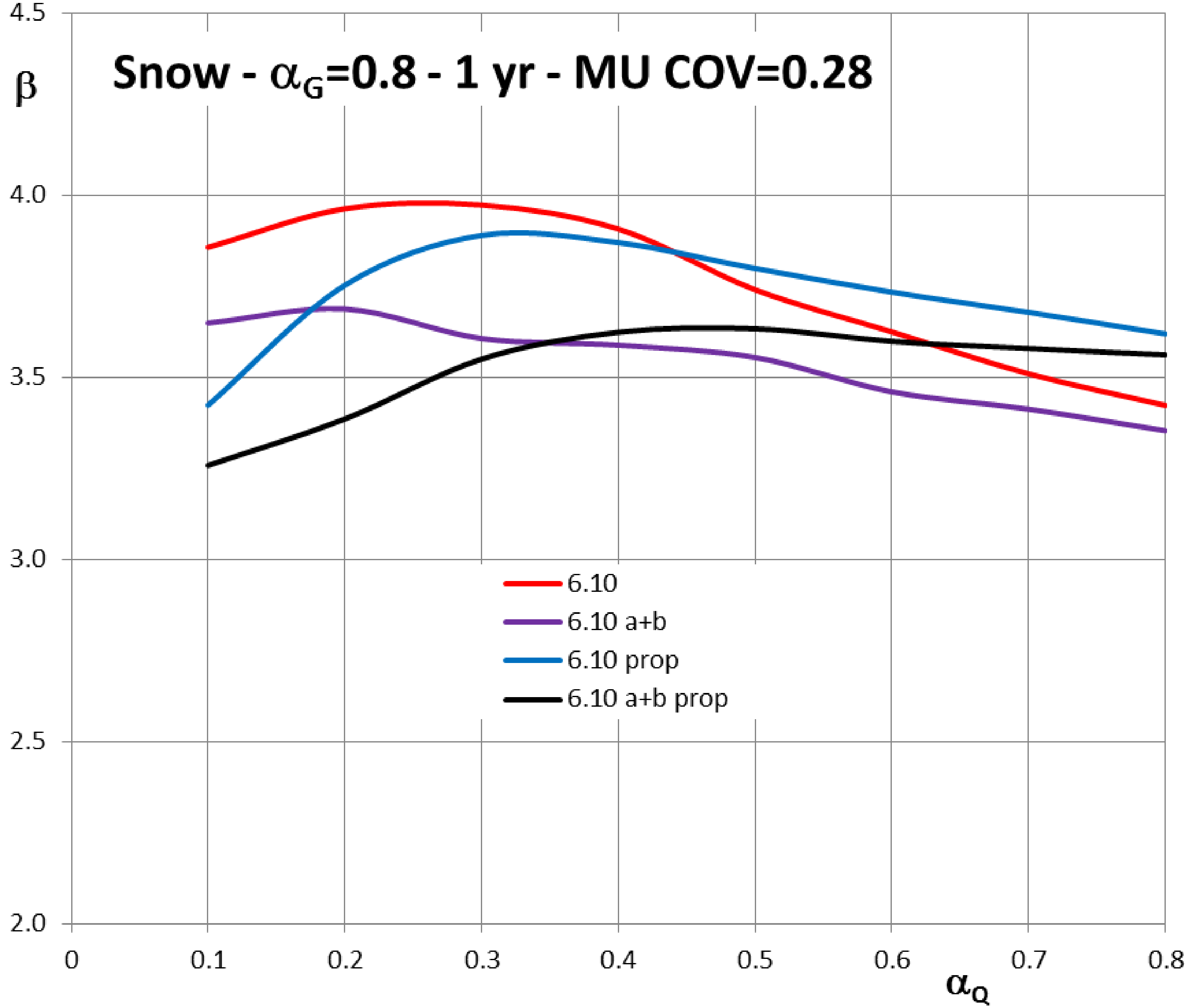
Concrete – Wind – Eq. 6.10 a+b prop



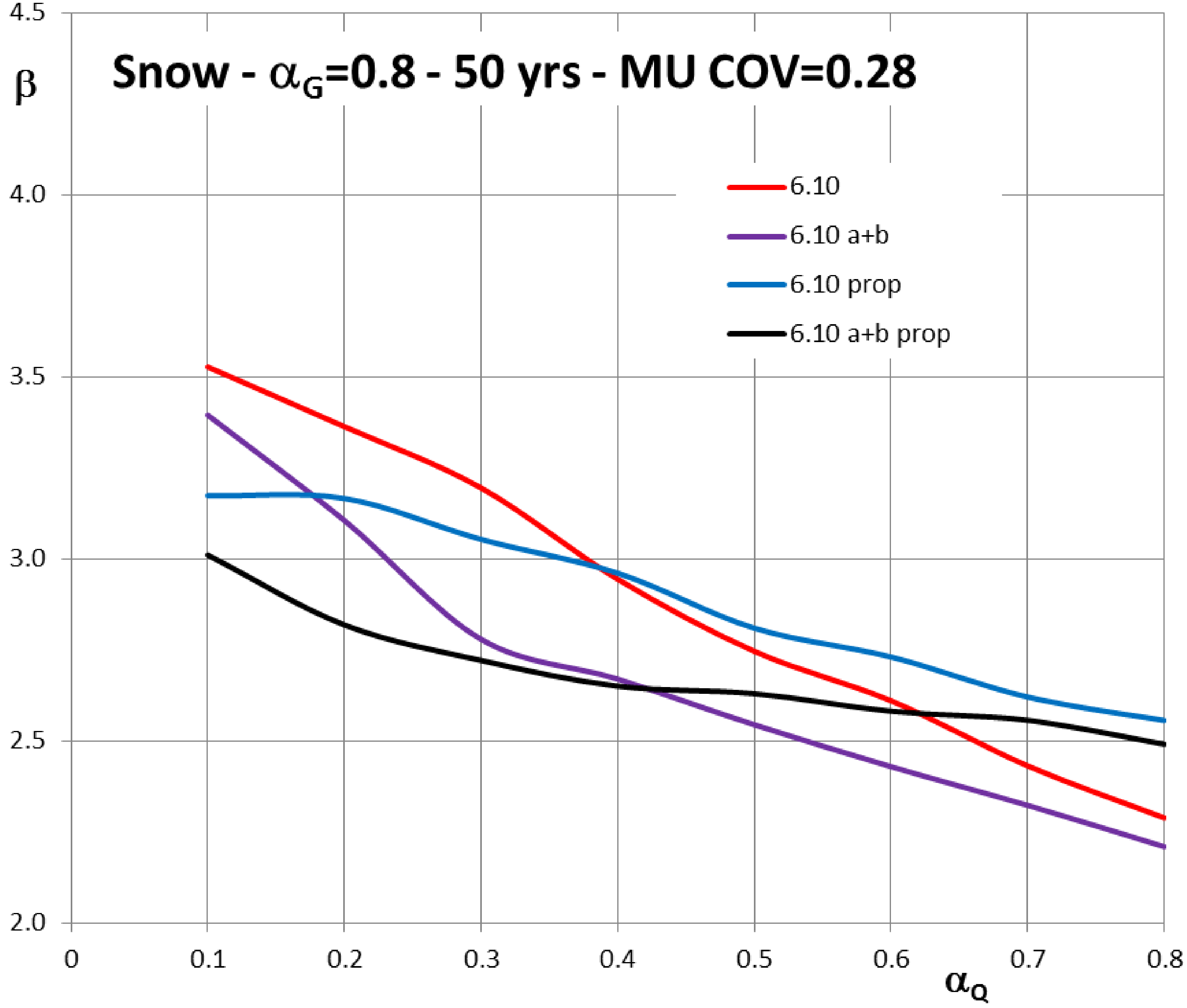
Concrete – Wind – MU COV=0.51



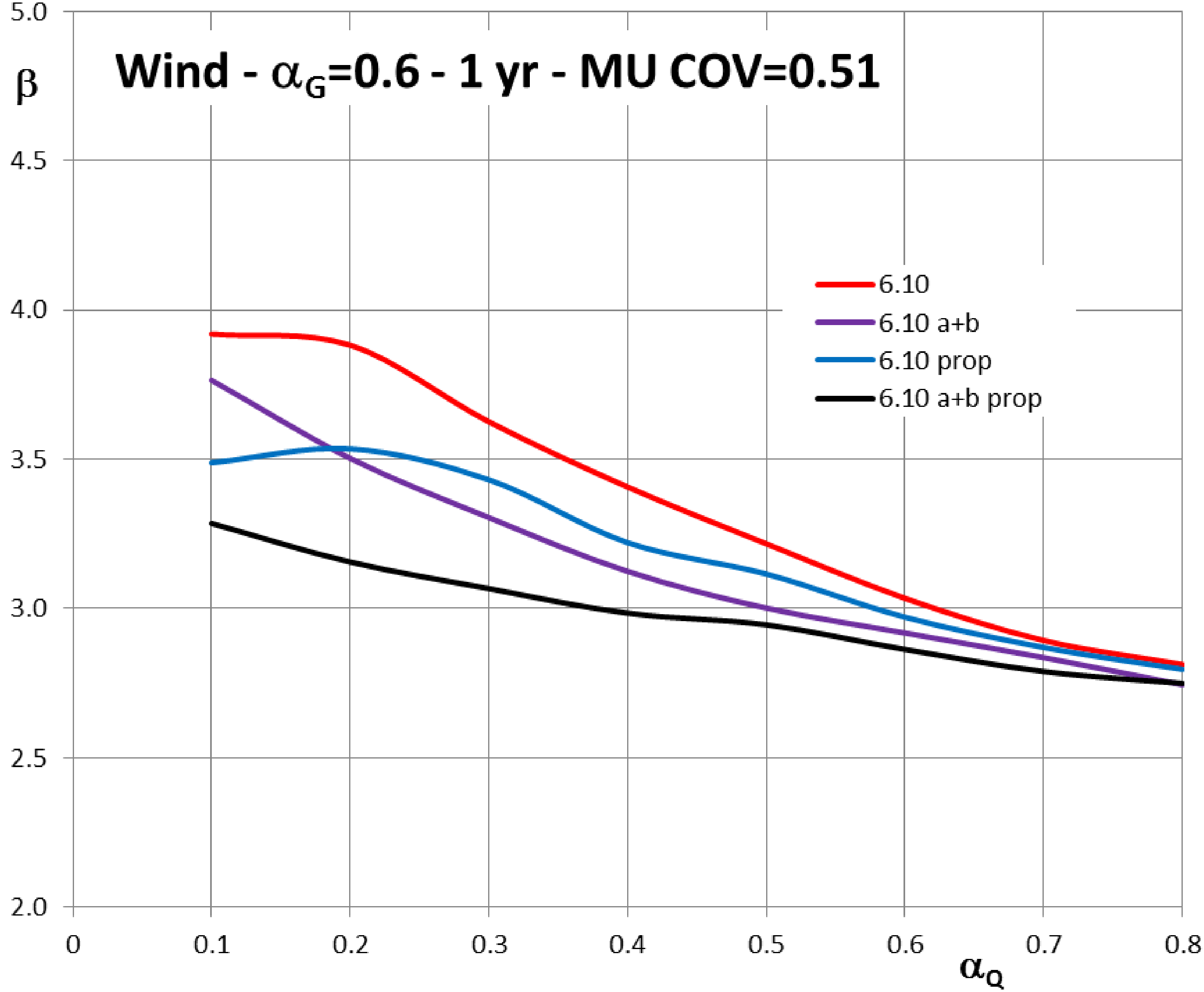
Concrete – Wind – MU COV=0.51



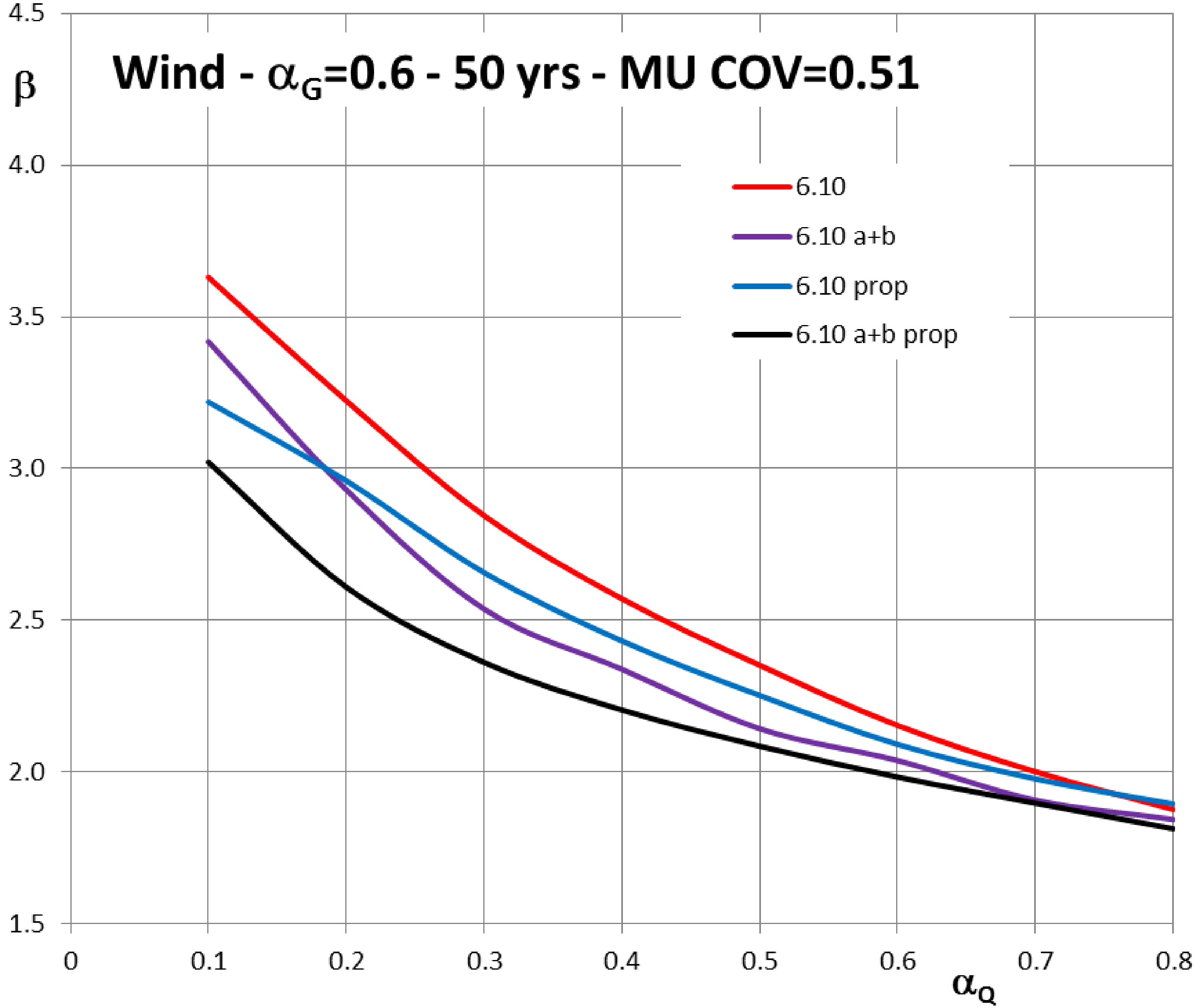
Glulam – Snow –MU COV=0.28



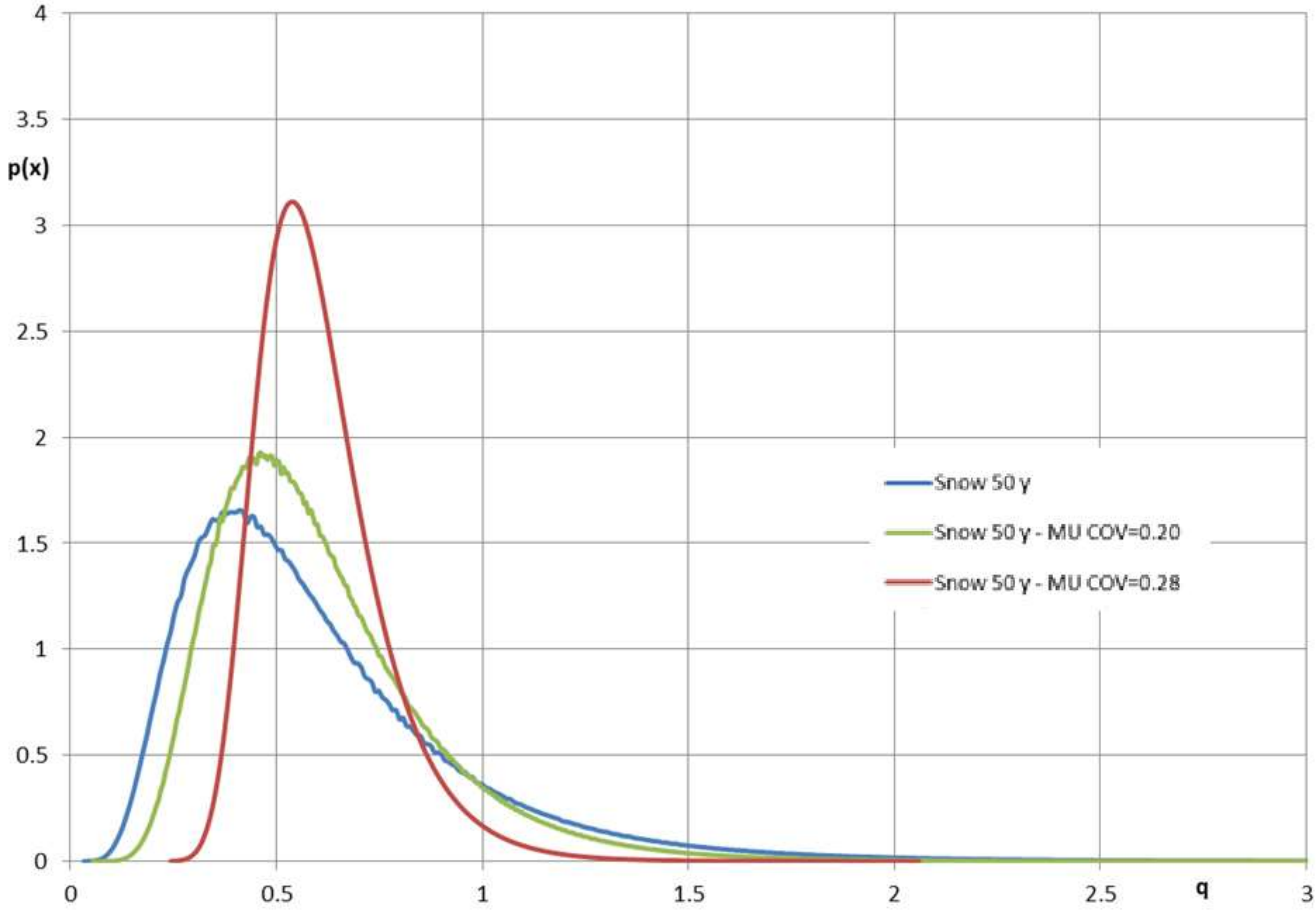
Concrete – Snow –MU COV 0.28



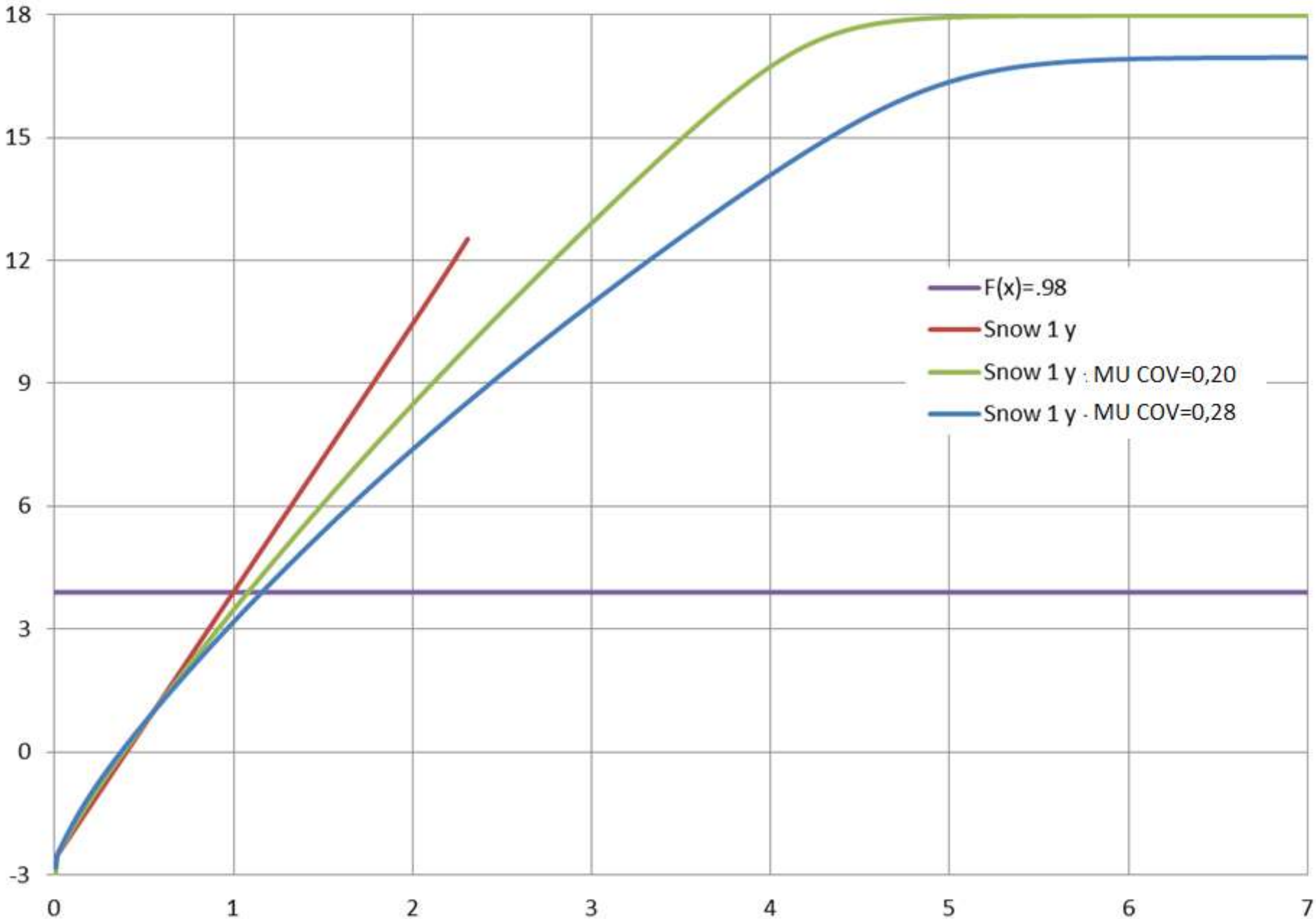
Glulam – Wind – MU COV=0.51



Glulam – Wind – MU COV=0.51

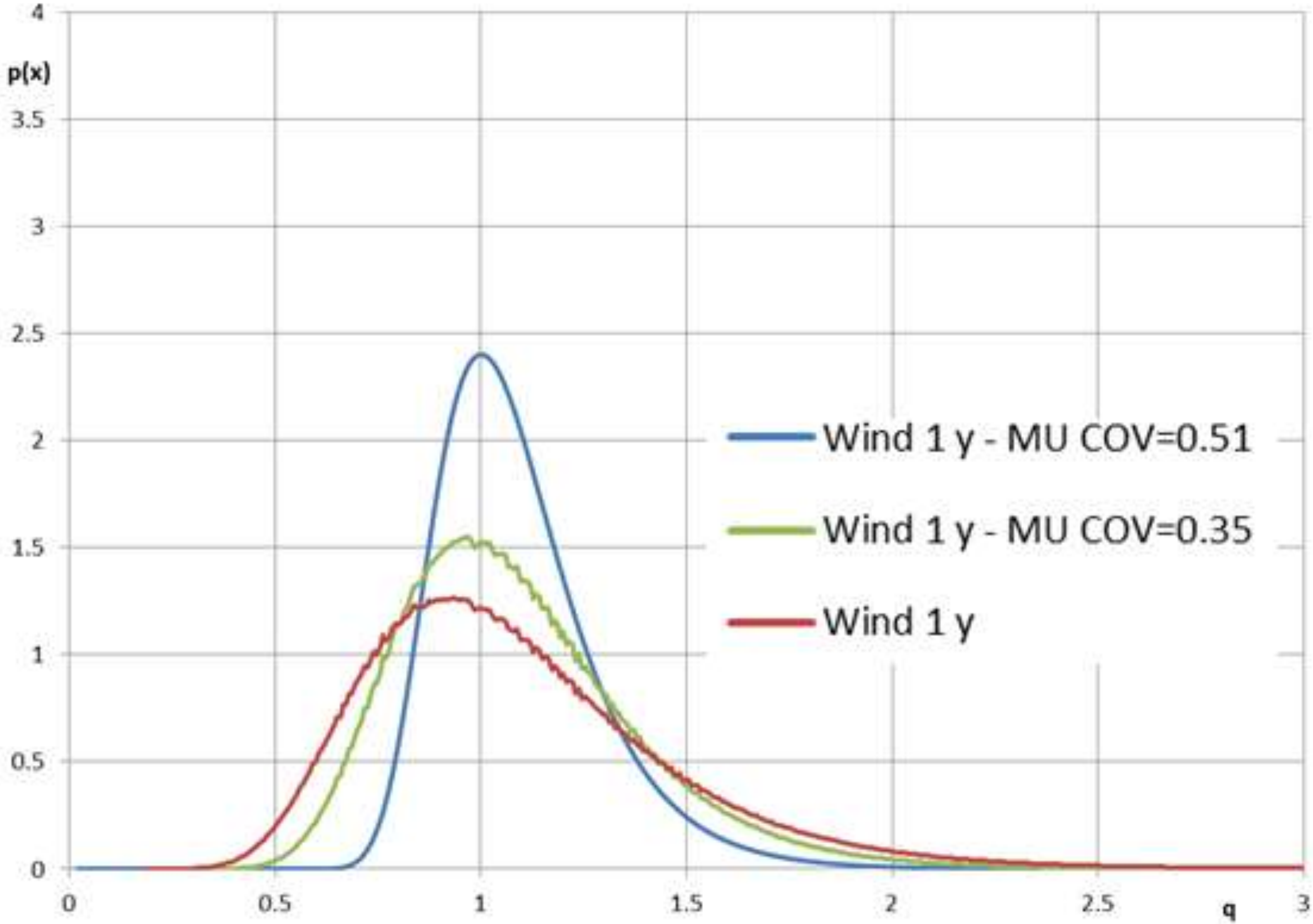


Snow – Resulting pdfs

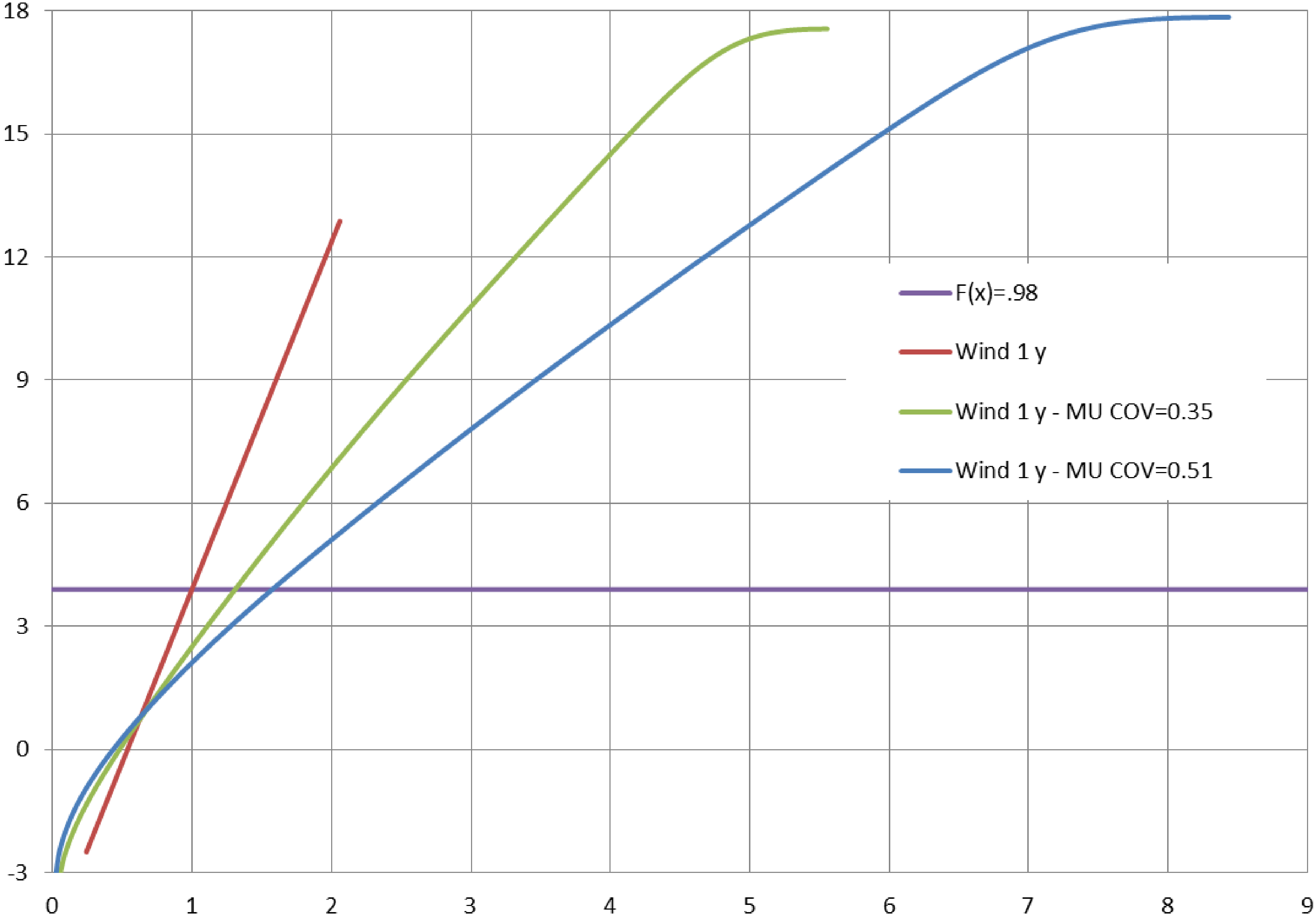


18
15
12
9
6
3
0
-3
0
1
2
3
4
5
6
7
F(x)=.98
Snow 1 y
Snow 1 y . MU COV=0,20
Snow 1 y . MU COV=0,28

Snow – CDFs



Wind − Resulting pdfs



Wind – Resulting CDFs

Design equation

(eq. 8.20 of prEN1990:2019)

$$\frac{p\,r_k}{\gamma_M} = (1-\alpha_Q)\gamma_G g_k + \alpha_Q \gamma_Q q_k \qquad (1)$$

$\gamma_M = 1.00$ (steel);

$\gamma_G = 1.35$

$\gamma_Q = 1.50$

p is a suitable parameter granting that (1) is satisfied

α_Q is a parameter expressing the relative weigth of variable and permanent actions

Probability of failure

$$P_f = P\left(p\,\theta_R r - \left(\left(1-\alpha_Q\right)g + \alpha_Q\theta_Q q\right) < 0\right)$$

Hypotheses

Random variable		Distr. type	Mean (μ)	COV	Charact. Fractile (value)	Charact. Value
Resistance model unc. (steel)	Θ_R	Logn.	1.00	0.05	(μ)	$\theta_{R,k}$
Mat. property (steel yielding strength)	R	Logn.	1.00	0.07	$\mu-2\sigma$	r_k
Permanent load	G	Normal	1.00	0.1	0.50	g_k
Variable Load model unc.	Θ_Q	Logn.	1.00	0.30	($\mu+\sigma$)	$\theta_{Q,k}$
Variable Load (yearly extreme)	Q	Gumbel	1.00	0.40	0.98	q_k

Considered cases

- 1 year reference period considering permanent actions and wind actions including variable load model uncertainty θ_Q;
- 1 year reference period considering permanent actions and wind actions excluding θ_Q;
- 50 years reference period considering permanent actions and wind actions including variable load model uncertainty θ_Q;
- 50 years reference period considering permanent actions and wind actions excluding θ_Q.

$$P_f = P\left(p\,\theta_R r - \left((1-\alpha_Q)g + \alpha_Q \theta_Q q\right) < 0\right)$$

Reference values of β_t and P_{ft}

Reference value of β_t and P_{ft} have been determined referring to the following conditions:

$$\min \sum w_i (\beta_i - \beta_t)^2 \qquad (3)$$

$$\min \sum \sum w_{i,j} \left(\beta_{i,j} - \beta_{tj}\right)^2$$

$$\min \sum w_i \left(P_{fi} - P_{ft}\right)^2 \qquad (5)$$

Different distribution of weights have been considered

Case 1: (basic case)

$$\alpha_Q = 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80$$

subcase 1.1 like case 1 (most refined coverage)

$$\alpha_Q = 0.20, 0.25, 0.30, 0.35, ..0.70, 075, 0.80$$

Case 2: (basic case shifted by -0.1)

$$\alpha_Q = 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70$$

Case 3: (higher influence of permanent loads)

$$\alpha_Q = 0.05, 0.15, 0.25, 0.35, 0.45, 0.55$$

subcase 3.1 like case 3 (most refined coverage)

$$\alpha_Q = 0.05, 0.10, 0.15, \dots, 0.50, 0.55$$

Case 4: (basic case shifted by +0.05)

$$\alpha_Q = 0.25, 0.35, 0.45, 0.55, 0.65, 0.75, 0.85$$

Case 5: like case 3, $\alpha_Q = 0.05, 0.15, 0.25, 0.35, 0.45, 0.55$, with linearly decreasing weighs (relative weights are 3 for $\alpha_Q = 0.05$; 2.5 for $\alpha_Q = 0.15$; 2.0 for $\alpha_Q = 0.25$; 1.5 for $\alpha_Q = 0.35$; 1.0 for $\alpha_Q = 0.45$; 0.5 for $\alpha_Q = 0.55$).

Case 1 - 1 year reference period - Permanent load + wind without model uncertainty

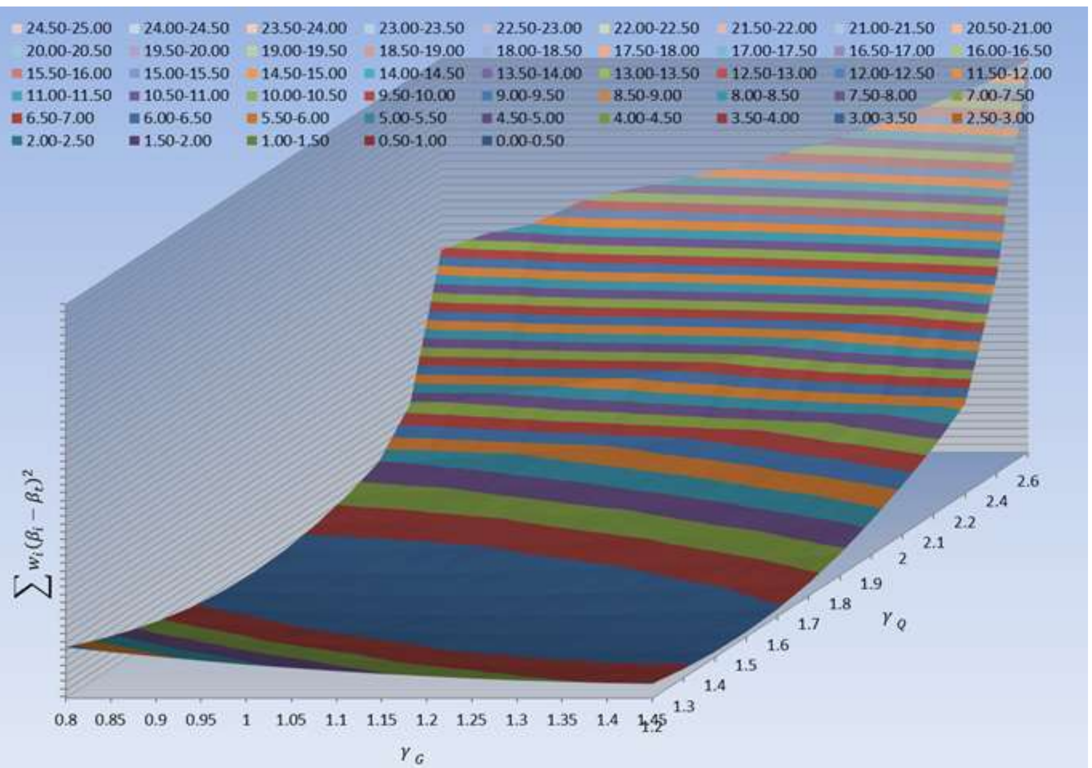
Weight factors

	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
w	0	0	0	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0
α_Q	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9

Target values

β_t	4.998
P_{ft}	1.077E-06

$$\gamma_G = 1.03 \qquad \gamma_Q = 1.67$$



γ_G=1.03 γ_Q=1.67			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	1.154E-02	2.27	0.00	6.809E-07	4.83
0.05	5.016E-04	3.29	0.05	3.165E-08	5.41
0.10	2.238E-05	4.08	0.10	4.914E-09	5.73
0.15	3.234E-06	4.51	0.15	4.870E-09	5.74
0.20	1.263E-06	4.71	0.20	8.097E-09	5.65
0.25	6.996E-07	4.83	0.25	1.474E-08	5.54
0.30	4.756E-07	4.90	0.30	3.255E-08	5.40
0.35	3.250E-07	4.98	0.35	6.703E-08	5.27
0.40	3.213E-07	4.98	0.40	1.277E-07	5.15
0.45	2.738E-07	5.01	0.45	2.248E-07	5.05
0.50	2.437E-07	5.03	0.50	3.681E-07	4.95
0.55	2.298E-07	5.04	0.55	6.643E-07	4.84
0.60	1.944E-07	5.07	0.60	9.529E-07	4.76
0.65	2.143E-07	5.06	0.65	1.506E-06	4.67
0.70	2.164E-07	5.05	0.70	2.245E-06	4.59
0.75	2.025E-07	5.07	0.75	3.185E-06	4.51
0.80	2.109E-07	5.06	0.80	3.804E-06	4.48
0.85	2.067E-07	5.06	0.85	5.002E-06	4.42
0.90	1.913E-07	5.08	0.90	6.359E-06	4.36
0.95	2.010E-07	5.07	0.95	8.805E-06	4.29

Case 1 - 1 year reference period - Permanent load + wind without model uncertainty

Weight factors

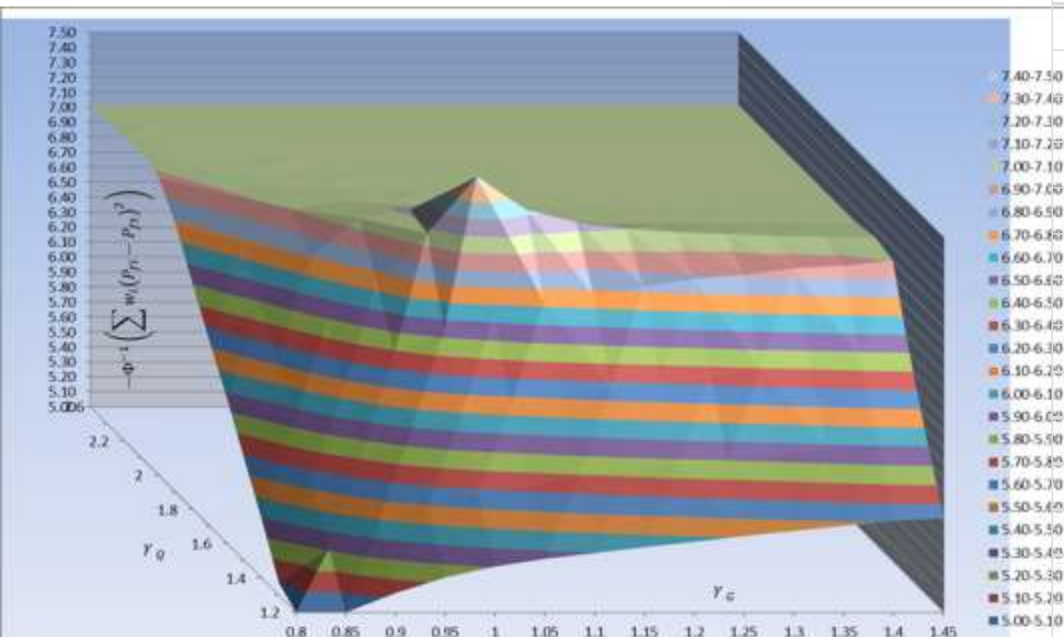
	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
w	0	0	0	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0
α_Q	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9

Target values

β_t	4.998
P_{ft}	1.077E-06

$$\gamma_G = 1.05 \qquad \gamma_Q = 1.61$$

3D Plot of $-\Phi^{-1}\left(\sum w_i\left(P_{fi} - P_{ft}\right)^2\right)$



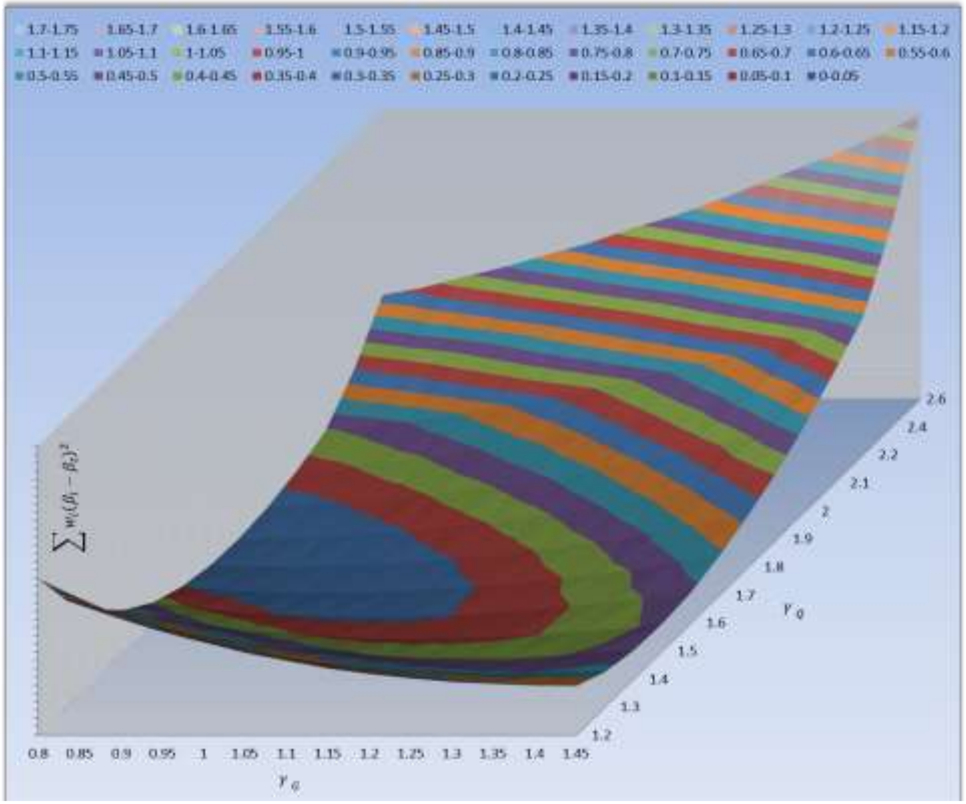
γ_G=1.05 γ_Q=1.61			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	3.644E-03	2.68	0.00	6.809E-07	4.83
0.05	1.644E-04	3.59	0.05	3.165E-08	5.41
0.10	1.022E-05	4.26	0.10	4.914E-09	5.73
0.15	2.284E-06	4.58	0.15	4.870E-09	5.74
0.20	1.239E-06	4.71	0.20	8.097E-09	5.65
0.25	8.496E-07	4.79	0.25	1.474E-08	5.54
0.30	7.538E-07	4.81	0.30	3.255E-08	5.40
0.35	7.034E-07	4.82	0.35	6.703E-08	5.27
0.40	8.125E-07	4.80	0.40	1.277E-07	5.15
0.45	8.368E-07	4.79	0.45	2.248E-07	5.05
0.50	7.788E-07	4.80	0.50	3.681E-07	4.95
0.55	9.119E-07	4.77	0.55	6.643E-07	4.84
0.60	9.808E-07	4.76	0.60	9.529E-07	4.76
0.65	9.799E-07	4.76	0.65	1.506E-06	4.67
0.70	1.071E-06	4.74	0.70	2.245E-06	4.59
0.75	1.280E-06	4.70	0.75	3.185E-06	4.51
0.80	1.252E-06	4.71	0.80	3.804E-06	4.48
0.85	1.351E-06	4.69	0.85	5.002E-06	4.42
0.90	1.397E-06	4.69	0.90	6.359E-06	4.36
0.95	1.608E-06	4.66	0.95	8.805E-06	4.29

Case 1 - 1 year reference period - Permanent load + wind with model uncertainty

Target values

β_t	3.610
P_{ft}	2.638E-04

$\gamma_G = 0.88$ $\gamma_Q = 1.81$



γ_G=0.88 γ_Q=1.81			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	7.324E-02	1.45	0.00	6.809E-07	4.83
0.05	4.495E-03	2.61	0.05	5.318E-08	5.32
0.10	3.641E-04	3.38	0.10	2.343E-07	5.04
0.15	1.514E-04	3.61	0.15	2.233E-06	4.59
0.20	1.244E-04	3.66	0.20	9.024E-06	4.29
0.25	1.236E-04	3.67	0.25	2.435E-05	4.06
0.30	1.295E-04	3.65	0.30	4.892E-05	3.90
0.35	1.377E-04	3.64	0.35	8.397E-05	3.76
0.40	1.471E-04	3.62	0.40	1.265E-04	3.66
0.45	1.570E-04	3.60	0.45	1.809E-04	3.57
0.50	1.578E-04	3.60	0.50	2.325E-04	3.50
0.55	1.682E-04	3.59	0.55	2.865E-04	3.44
0.60	1.691E-04	3.58	0.60	3.579E-04	3.38
0.65	1.702E-04	3.58	0.65	4.063E-04	3.35
0.70	1.805E-04	3.57	0.70	4.672E-04	3.31
0.75	1.814E-04	3.57	0.75	5.426E-04	3.27
0.80	1.822E-04	3.56	0.80	6.046E-04	3.24
0.85	1.831E-04	3.56	0.85	6.468E-04	3.22
0.90	1.932E-04	3.55	0.90	7.323E-04	3.18
0.95	1.939E-04	3.55	0.95	7.951E-04	3.16

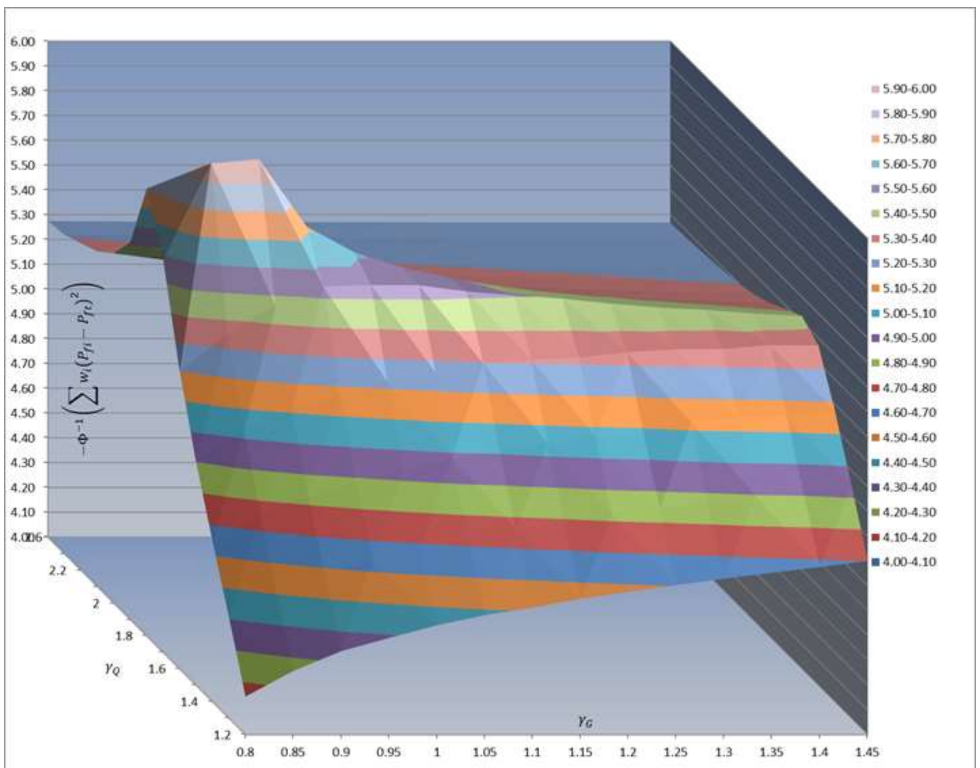
Case 1 - 1 year reference period - Permanent load + wind with model uncertainty

Target values

β_t	3.610
P_{ft}	2.638E-04

$$\gamma_G = 0.88 \qquad \gamma_Q = 1.70$$

3D Plot of $-\Phi^{-1}\left(\sum w_i\left(P_{fi}-P_{ft}\right)^2\right)$



γ_G=0.88 γ_Q=1.70			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	7.324E-02	1.45	0.00	6.809E-07	4.83
0.05	5.524E-03	2.54	0.05	5.318E-08	5.32
0.10	5.428E-04	3.27	0.10	2.343E-07	5.04
0.15	2.241E-04	3.51	0.15	2.233E-06	4.59
0.20	2.068E-04	3.53	0.20	9.024E-06	4.29
0.25	1.972E-04	3.54	0.25	2.435E-05	4.06
0.30	2.188E-04	3.52	0.30	4.892E-05	3.90
0.35	2.170E-04	3.52	0.35	8.397E-05	3.76
0.40	2.343E-04	3.50	0.40	1.265E-04	3.66
0.45	2.395E-04	3.49	0.45	1.809E-04	3.57
0.50	2.612E-04	3.47	0.50	2.325E-04	3.50
0.55	2.695E-04	3.46	0.55	2.865E-04	3.44
0.60	2.640E-04	3.47	0.60	3.579E-04	3.38
0.65	2.741E-04	3.46	0.65	4.063E-04	3.35
0.70	2.848E-04	3.45	0.70	4.672E-04	3.31
0.75	2.960E-04	3.44	0.75	5.426E-04	3.27
0.80	2.928E-04	3.44	0.80	6.046E-04	3.24
0.85	3.047E-04	3.43	0.85	6.468E-04	3.22
0.90	3.021E-04	3.43	0.90	7.323E-04	3.18
0.95	3.147E-04	3.42	0.95	7.951E-04	3.16

Case 1 - 50 year reference period - Permanent load + wind without model uncertainty

Weight factors

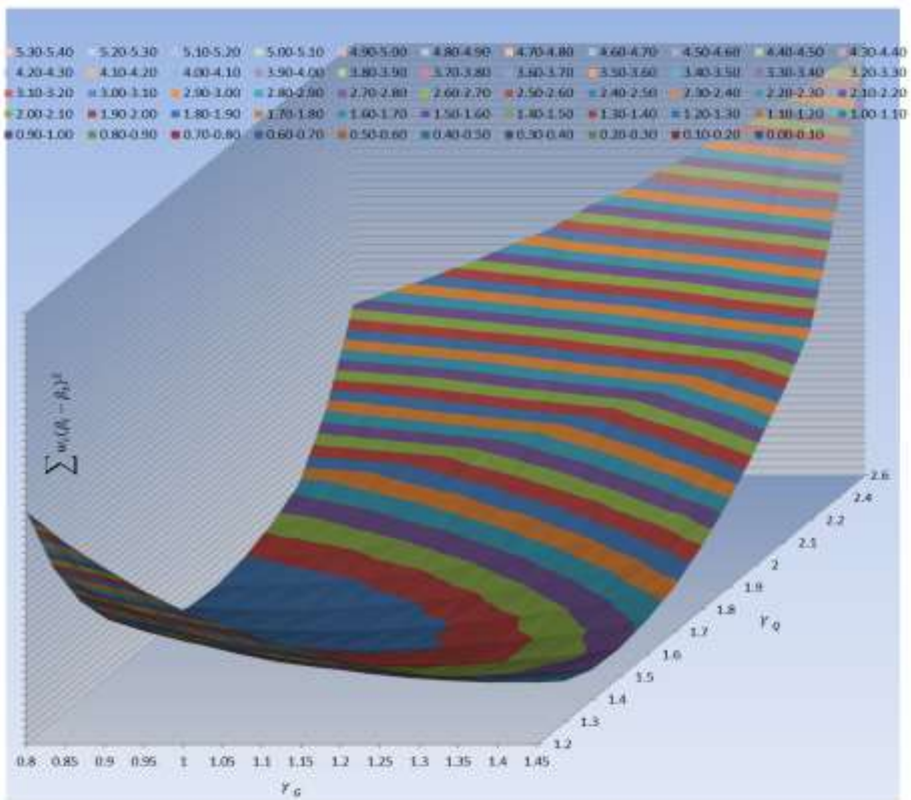
	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
w	0	0	0	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0
α_Q	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9

Target values

β_t 3.521

P_{ft} 5.464E-04

$\gamma_G = 0.91$ $\gamma_Q = 1.80$



γ_G=0.91 γ_Q=1.80			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	7.324E-02	1.45	0.00	6.809E-07	4.83
0.05	1.329E-02	2.22	0.05	2.348E-07	5.04
0.10	2.328E-03	2.83	0.10	2.732E-07	5.01
0.15	6.082E-04	3.24	0.15	1.113E-06	4.73
0.20	3.092E-04	3.42	0.20	4.480E-06	4.44
0.25	2.278E-04	3.51	0.25	1.410E-05	4.19
0.30	2.035E-04	3.54	0.30	3.681E-05	3.96
0.35	1.836E-04	3.56	0.35	8.001E-05	3.77
0.40	1.799E-04	3.57	0.40	1.488E-04	3.62
0.45	1.881E-04	3.56	0.45	2.439E-04	3.49
0.50	1.913E-04	3.55	0.50	3.599E-04	3.38
0.55	1.902E-04	3.55	0.55	4.855E-04	3.30
0.60	2.005E-04	3.54	0.60	6.512E-04	3.22
0.65	2.073E-04	3.53	0.65	8.683E-04	3.13
0.70	2.109E-04	3.53	0.70	1.076E-03	3.07
0.75	2.118E-04	3.52	0.75	1.249E-03	3.02
0.80	2.103E-04	3.53	0.80	1.547E-03	2.96
0.85	2.215E-04	3.51	0.85	1.691E-03	2.93
0.90	2.160E-04	3.52	0.90	1.971E-03	2.88
0.95	2.234E-04	3.51	0.95	2.298E-03	2.83

Case 1 - 50 year reference period - Permanent load + wind without model uncertainty

Weight factors

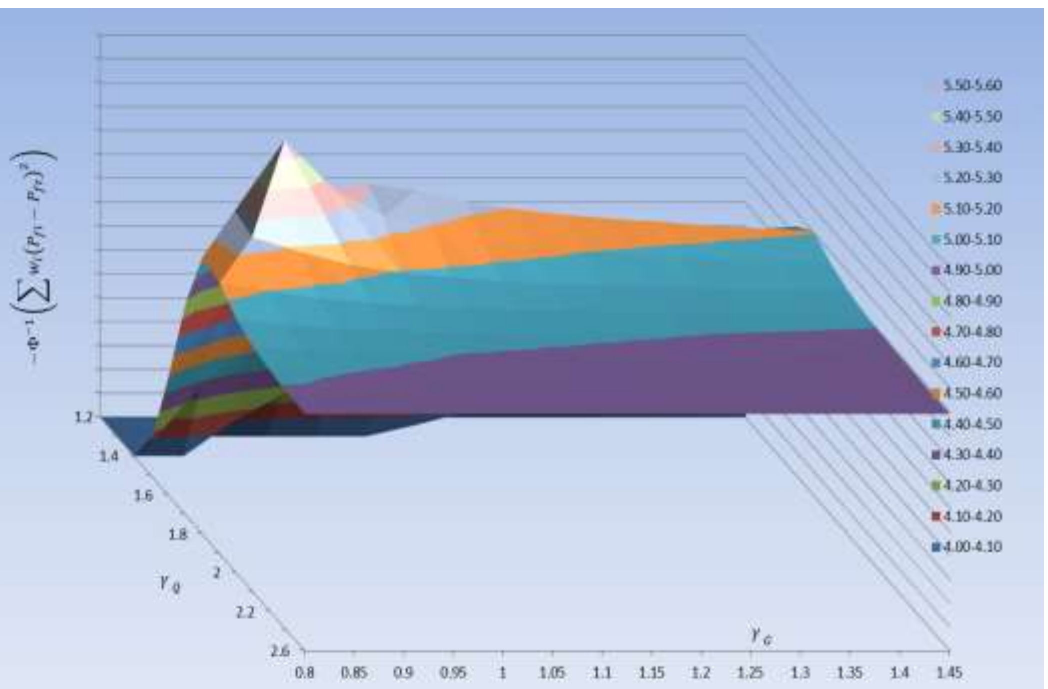
	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
w	0	0	0	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0.1428571	0	0
α_Q	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9

Target values

β_t	3.521
P_{ft}	5.464E-04

$$\gamma_G = 0.90 \qquad \gamma_Q = 1.70$$

3D Plot of $-\Phi^{-1}\left(\sum w_i\left(P_{fi} - P_{ft}\right)^2\right)$



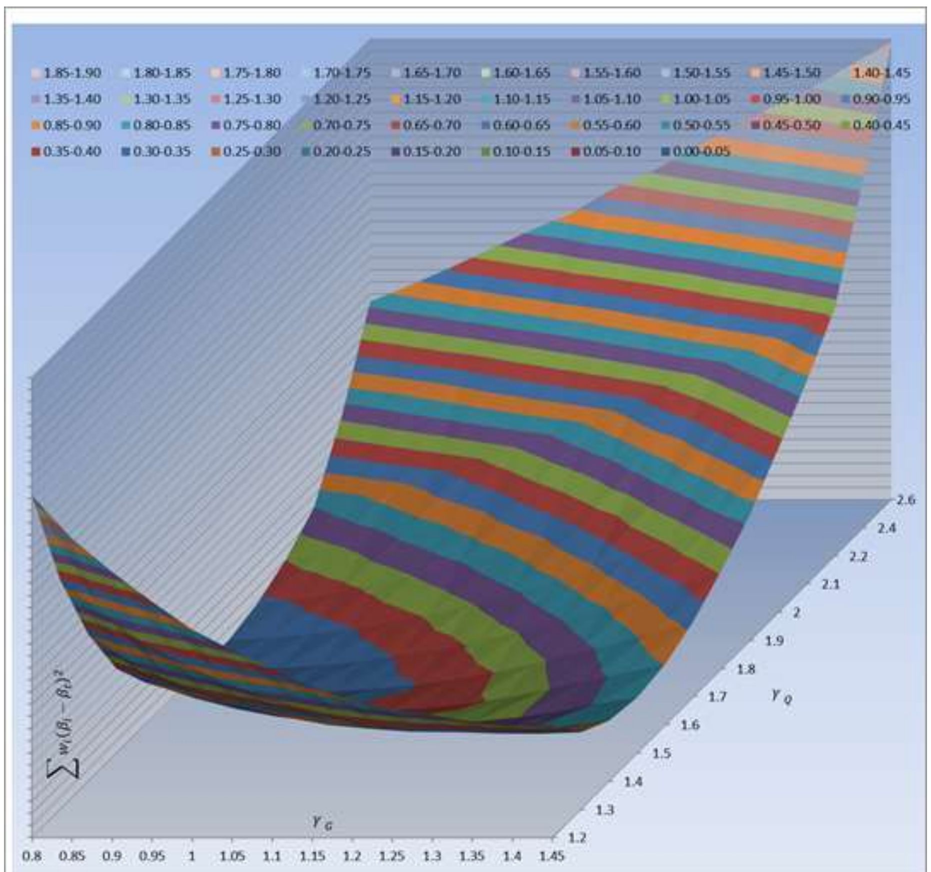
γ_G=0.90 γ_Q=1.70			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	7.324E-02	1.45	0.00	6.809E-07	4.83
0.05	1.754E-02	2.11	0.05	2.348E-07	5.04
0.10	3.793E-03	2.67	0.10	2.732E-07	5.01
0.15	1.241E-03	3.03	0.15	1.113E-06	4.73
0.20	6.633E-04	3.21	0.20	4.480E-06	4.44
0.25	4.579E-04	3.32	0.25	1.410E-05	4.19
0.30	4.382E-04	3.33	0.30	3.681E-05	3.96
0.35	3.887E-04	3.36	0.35	8.001E-05	3.77
0.40	4.153E-04	3.34	0.40	1.488E-04	3.62
0.45	4.007E-04	3.35	0.45	2.439E-04	3.49
0.50	4.144E-04	3.34	0.50	3.599E-04	3.38
0.55	4.216E-04	3.34	0.55	4.855E-04	3.30
0.60	4.232E-04	3.34	0.60	6.512E-04	3.22
0.65	4.514E-04	3.32	0.65	8.683E-04	3.13
0.70	4.431E-04	3.32	0.70	1.076E-03	3.07
0.75	4.620E-04	3.31	0.75	1.249E-03	3.02
0.80	4.771E-04	3.30	0.80	1.547E-03	2.96
0.85	4.887E-04	3.30	0.85	1.691E-03	2.93
0.90	4.972E-04	3.29	0.90	1.971E-03	2.88
0.95	5.029E-04	3.29	0.95	2.298E-03	2.83

Case 1 - 50 year reference period - Permanent load + wind with model uncertainty

Target values

β_t	2.451
P_{ft}	1.071E-02

$\gamma_G = 0.87$ $\gamma_Q = 1.83$



γ_G=0.87 γ_Q=1.83			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	2.912E-01	0.55	0.00	3.435E-04	3.39
0.05	1.687E-02	2.12	0.05	9.135E-07	4.77
0.10	7.004E-03	2.46	0.10	1.913E-05	4.12
0.15	5.370E-03	2.55	0.15	1.507E-04	3.61
0.20	5.118E-03	2.57	0.20	5.878E-04	3.24
0.25	5.485E-03	2.54	0.25	1.414E-03	2.99
0.30	6.132E-03	2.50	0.30	2.526E-03	2.80
0.35	6.212E-03	2.50	0.35	4.180E-03	2.64
0.40	6.873E-03	2.46	0.40	5.812E-03	2.52
0.45	7.040E-03	2.46	0.45	7.734E-03	2.42
0.50	7.075E-03	2.45	0.50	1.035E-02	2.31
0.55	7.370E-03	2.44	0.55	1.211E-02	2.25
0.60	7.884E-03	2.41	0.60	1.399E-02	2.20
0.65	8.096E-03	2.40	0.65	1.683E-02	2.12
0.70	7.966E-03	2.41	0.70	1.857E-02	2.08
0.75	8.446E-03	2.39	0.75	2.109E-02	2.03
0.80	8.540E-03	2.38	0.80	2.314E-02	1.99
0.85	8.725E-03	2.38	0.85	2.452E-02	1.97
0.90	8.487E-03	2.39	0.90	2.645E-02	1.94
0.95	8.812E-03	2.37	0.95	2.898E-02	1.90

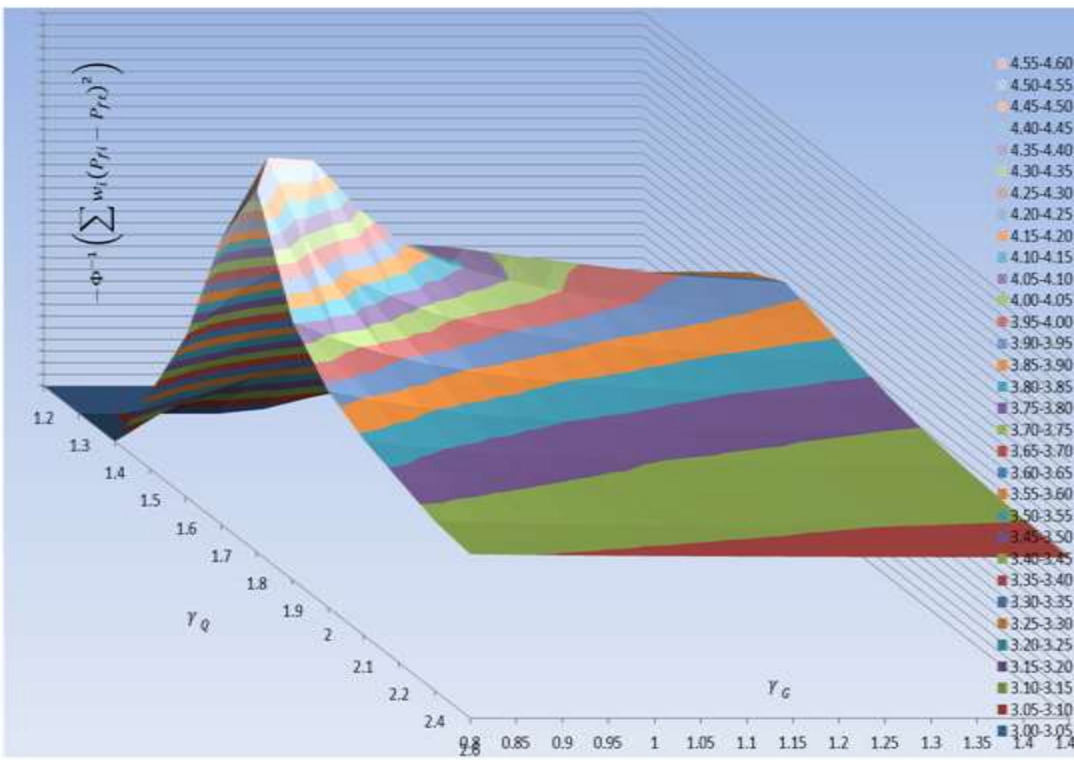
Case 1 - 50 year reference period - Permanent load + wind with model uncertainty

Target values

β_t	2.451
P_{ft}	1.071E-02

$\gamma_G = 0.87$ $\gamma_Q = 1.72$

3D Plot of $-\Phi^{-1}\left(\sum w_i\left(P_{fi} - P_{ft}\right)^2\right)$



γ_G=0.87 γ_Q=1.72			γ_G=1.35 γ_Q=1.5		
α_Q	P_f	β	α_Q	P_f	β
0.00	2.912E-01	0.55	0.00	3.435E-04	3.39
0.05	2.028E-02	2.05	0.05	9.135E-07	4.77
0.10	9.841E-03	2.33	0.10	1.913E-05	4.12
0.15	7.822E-03	2.42	0.15	1.507E-04	3.61
0.20	7.855E-03	2.42	0.20	5.878E-04	3.24
0.25	8.287E-03	2.40	0.25	1.414E-03	2.99
0.30	9.289E-03	2.35	0.30	2.526E-03	2.80
0.35	9.564E-03	2.34	0.35	4.180E-03	2.64
0.40	1.010E-02	2.32	0.40	5.812E-03	2.52
0.45	1.067E-02	2.30	0.45	7.734E-03	2.42
0.50	1.110E-02	2.29	0.50	1.035E-02	2.31
0.55	1.125E-02	2.28	0.55	1.211E-02	2.25
0.60	1.176E-02	2.26	0.60	1.399E-02	2.20
0.65	1.185E-02	2.26	0.65	1.683E-02	2.12
0.70	1.217E-02	2.25	0.70	1.857E-02	2.08
0.75	1.271E-02	2.24	0.75	2.109E-02	2.03
0.80	1.268E-02	2.24	0.80	2.314E-02	1.99
0.85	1.280E-02	2.23	0.85	2.452E-02	1.97
0.90	1.305E-02	2.22	0.90	2.645E-02	1.94
0.95	1.342E-02	2.21	0.95	2.898E-02	1.90

Summary of the sensitivity study (50 years reference)

			Wind with model uncertainty 50 years reference period			Wind without model uncertainty 50 years reference period		
				$\gamma_{G,new}$	$\gamma_{Q,new}$		$\gamma_{G,new}$	$\gamma_{Q,new}$
Case 1		β_t	2.451	0.87	1.83	3.521	0.91	1.80
		P_{ft}	1.07E-02	0.87	1.72	5.46E-04	0.90	1.70
	Subcase 1.1	β_t						
		P_{ft}						
Case 2		β_t	2.755	0.90	2.01	3.814	1.01	1.89
		P_{ft}	7.41E-03	0.90	1.80	3.25E-04	1.01	1.73
Case 3		β_t	3.114	0.99	2.16	4.086	1.12	1.93
		P_{ft}	4.26E-03	0.96	1.90	1.38E-04	1.11	1.72
	Subcase 3.1	β_t				4.085	1.10	1.90
		P_{ft}				1.25E-04	1.11	1.72
Case 4		β_t	2.346	0.78	1.80	3.405	0.94	1.72
		P_{ft}	1.26E-02	0.85	1.70	6.62E-04	0.85	1.70
Case 5		β_t	3.289	0.99	2.36	4.392	1.19	1.88
		P_{ft}	4.47E-03	0.95	1.90	6.08E-05	1.15	1.79

Summary of the sensitivity study (1 year reference)

			Wind with model uncertainty 1 year reference period			Wind without model uncertainty 1 year reference period		
				$\gamma_{G,new}$	$\gamma_{Q,new}$		$\gamma_{G,new}$	$\gamma_{Q,new}$
Case 1		β_t	3.610	0.88	1.81	4.998	1.03	1.67
		P_{ft}	2.64E-04	0.88	1.70	1.08E-06	1.05	1.61
	Subcase 1.1	β_t	3.594	0.87	1.83			
		P_{ft}	2.59E-04	0.88	1.71			
Case 2		β_t	3.868	0.94	1.98	5.177	1.15	1.68
		P_{ft}	1.78E-04	0.96	1.74	5.34E-07	1.16	1.62
Case 3		β_t	4.123	1.06	2.10	5.307	1.27	1.62
		P_{ft}	9.64E-05	1.06	1.81	1.68E-07	1.30	1.61
	Subcase 3.1	β_t						
		P_{ft}						
Case 4		β_t	3.524	0.76	1.80	4.9	1.11	1.63
		P_{ft}	3.10E-04	0.85	1.70	1.52E-06	1.00	1.61
Case 5		β_t	4.426	1.16	2.28	5.431	1.30	1.60
		P_{ft}	4.81E-05	1.06	2.01	7.56E-08	1.31	1.63

Conclusions

Target reliability and then the solution is strongly influenced on the considered cases and on the model uncertainty;

shifting the considered α_Q window results vary (even taking into account different number of subintervals can have some effect)

for the same case, partial factors γ_Q "calibrated" referring to β and partial factors calibrated referring to P_f can differ up to 0.3 - 0.4, while γ_G factors look very close due to small COV and no model uncertainty ;

In general, γ_Q values calibrated referring to P_f are smaller and less sensitive to model uncertainty than those calibrated with respect β

The $-\Phi^{-1}\left(\sum w_i\left(P_{fi}-P_{ft}\right)^2\right)$ surfaces are characterized by extensive plateau indicating that the region of optimal solutions in terms of probability of failure is much more wide than crudely indicated by the maximum;

Conclusions

Considering one variable action characterized by high COV and high model uncertainty and one permanent action characterized by small COV could lead to capricious results: in effect, surprisingly, increasing the relevance (case 3) or the relative weights (case 5) of permanent loads results in a moderate increase of γ_G and in a much more evident increase of γ_Q;

Since the calibration tends to uniform the calculated reliability, it increases the reliability in the region where α_Q is high and it reduces the reliability in the region where α_Q is low. But, comparing the figures before and after the calibration, it is evident that the decrease of the reliability in region where permanent actions dominates could be unacceptable. In addition, it should be considered that permanent actions are always present and that structures sensitive to them cannot rely on hidden safety.

Conclusions

Hidden safety resources are often invoked to justify the apparent reduced reliability of structures whose design is dominated by variable actions (characterized by high COV). Disregarding hidden safety could affect effective reliability in high α_Q, but, at present, hidden safety cannot be quantified.

From the engineering point of view, tackling the calibration of partial factors as a pure mathematical challenge could lead to manifestly bizarre results.
As already discussed, in many cases it results $\gamma_G < 1$, especially when model uncertainty dominates; clearly, such finding cannot be accepted.

The procedure, if not accompanied by sound engineering judgement, could lead in a very wrong direction: paradoxically, the effect of an increase of the uncertainty is not only, as expected, an increase of γ_Q, but also a parallel, even relatively more pronounced, decrease of γ_G.

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