EN 1991 – Eurocode 1: Actions on structures
Part 1-3 General actions – Snow Loads

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Scope of the presentation

- Description of EN 1991-1-3 Eurocode 1: Part 1-3: Snow Loads
- Background research for snow maps for Europe, Accidental (exceptional) loads, Shape Coefficients, Combination Factors, etc.
- Examples

Background research

Many clauses of EN 1991-1-3 are based on the results of a research work, carried out between 1996 and 1999, under a contract specific to this Eurocode, to DGIII/D3 of the European Commission.

They were identified four main research items:

- study of the European ground snow loads map
- investigation and treatment of exceptional snow loads
- study of conversion factors from ground to roof loads
- definition of ULS and SLS combination factors for snow loads.

Background research

The research results are contained in two final reports.

COMMISSION OF THE EUROPEAN COMMUNITIES
DGIII - D3

SCIENTIFIC SUPPORT ACTIVITY IN THE FIELD OF STRUCTURAL STABILITY OF CIVIL ENGINEERING WORKS
SNOW LOADS

Contract n° 500269 dated December 16th 1996

FINAL REPORT

University of Pisa
Department of Structural Engineering
Prof. Luca Sanpaolesi

as Co-ordinator of the following Institutions:

1. BUILDING RESEARCH ESTABLISHMENT LTD, CONSTRUCTION DIVISION (UNITED KINGDOM)
2. CSTB, CENTRE DE RECHERCHE DE NANTES (FRANCE)
3. ECOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, (SWITZERLAND)
4. ISMES STRUCTURE ENGINEERING DEPARTMENT (ITALY)
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7. UNIVERSITY OF LEIPZIG, INSTITUTE OF CONCRETE DESIGN (GERMANY)
8. UNIVERSITY OF PISA, DEPARTMENT OF STRUCTURAL ENGINEERING (ITALY)

MARCH 1998

COMMISSION OF THE EUROPEAN COMMUNITIES
DGIII - D3

SCIENTIFIC SUPPORT ACTIVITY IN THE FIELD OF STRUCTURAL STABILITY OF CIVIL ENGINEERING WORKS
SNOW LOADS

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University of Pisa
Department of Structural Engineering
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SEPTEMBER 1999

http://www2.ing.unipi.it/dis/snowloads/

Contents of EN 1991-1-3

Section 1 - EN 1991-1-3 Field of application

EN 1991-1-3 provides guidance for the determination of the snow load to be used for the structural design of buildings and civil engineering works for sites at altitudes under 1500m.

In the case of altitudes above 1500m advice may be found in the appropriate **National Annex**.

Section 1 - EN 1991-1-3 Field of application

EN 1991-1-3 **does not give guidance** on the following specialist aspects of snow loading:

- “impact loads” due to snow sliding off or falling from a higher roof;
- additional wind loads resulting from changes in shape or size of the roof profile due to presence of snow or to the accretion of ice;
- loads in areas where snow is present all the year;
- loads due to ice;
- lateral loading due to snow (e.g. lateral loads due to dirfts);
- snow loads on bridges

Section 2 - Classification of actions

Actions due to snow are classified, in accordance with EN 1990, as:

- **Variable**: *action for which the variation in magnitude with time is neither negligible nor monotonic*
- **Fixed**: *action that has a fixed distribution and position over the structure….*
- **Static**: *action that does not cause significant acceleration of the structure or structural members*

Section 2 - Classification of actions

For particular conditions may be treated as **accidental actions:** *action, usually of short duration but of significant magnitude, that is unlikely to occur on a given structure during the design working life*

Exceptional snow load on the ground

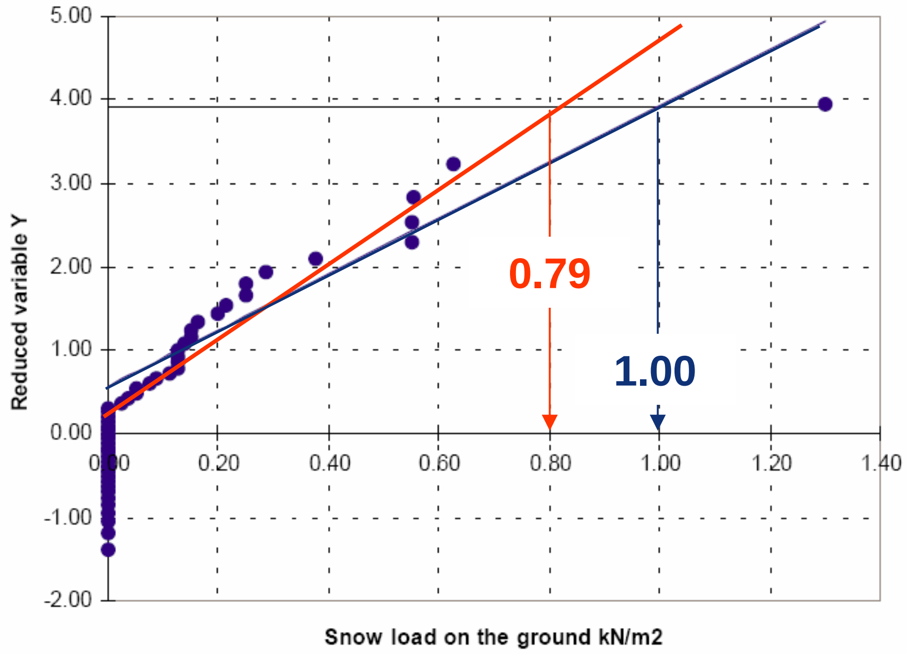
Exceptional snow drifts

Exceptional snow load on the ground

“load of the snow layer on the ground resulting from a snow fall which has an exceptionally infrequent likelihood of occurring”

Exceptional snow load on the ground

In some regions, particularly southern Europe, isolated very heavy snow falls have been observed resulting in snow loads which are significantly larger than those that normally occur. Including these snowfalls with the more regular snow events for the lengths of records available may significantly disturb the statistical processing of more regular snowfalls.



Gumbel probability paper: *Pistoia (IT)*

N° of recorded years = 51

N° of no snowy winters = 26

s_m = Max. snow Load = 1.30 kN/m^2

50yrs load incl. Max Load = 1.00 kN/m^2

s_k = 50yrs load excluded Max Load = 0.79 kN/m^2

$k = s_m/s_k$ = 1,65

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Exceptional snow load on the ground

The **National Annex** should specify the geographical locations where exceptional ground snow loads are likely to occur.

?

When the maximum ground snow load is to be considered as exceptional?

"If the ratio of the largest load value to the characteristic load determined without the inclusion of that value is greater than 1.5 then the largest value should be treated as an exceptional value"

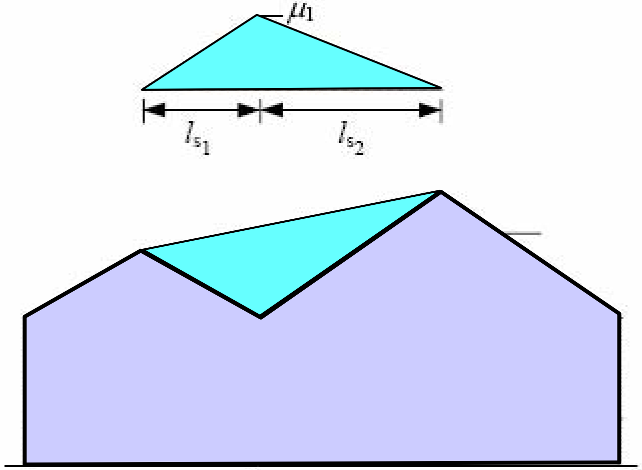
According to this definition over **2600** weather stations from 18 CEN countries (1997), in **159** they were registered exceptional ground snow loads.

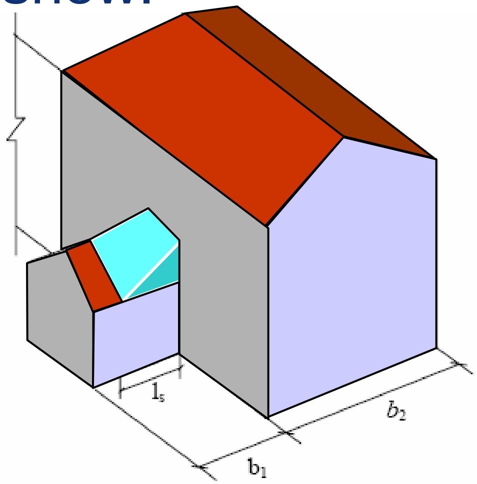
Definition of Exceptional snow drift

Exceptional snow drift

"load arrangement which describes the load of the snow layer on the roof resulting from a snow deposition pattern which has an exceptionally infrequent likelihood of occurring"

These load arrangements (treated in **Annex B** of EN 1991-1-3) may result from wind redistribution of snow deposited during single snow events. Localised snow concentrations may develop at obstructions and abrupt changes in height, leaving other areas of the roof virtually clear of snow.





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Section 3 - Design Situations

Different climatic conditions will give rise to different design situations. The four following possibilities are identified:

- **Case A**: normal case (non exceptional falls and drifts)
- **Case B1**: **exceptional falls** and non exceptional drifts
- **Case B2**: non exceptional falls and **exceptional drifts**
- **Case B3**: **exceptional falls and drifts**.

The national competent Authority may choose in the ***National Annex*** *the case applicable to particular locations for their own territory.*

Section 3 - Design Situations

Table A.1 Design Situations and load arrangements to be used for different locations

Normal	Exceptional conditions		
Case A	Case B1	Case B2	Case B3
No exceptional falls No exceptional drift	Exceptional falls No exceptional drift	No exceptional falls Exceptional drift	Exceptional falls Exceptional drift
3.2(1)	3.3(1)	3.3(2)	3.3(3)
Persistent/transient design situation [1] undrifted $\mu_i\ C_eC_t\ s_k$	*Persistent/transient design situation* [1] undrifted $\mu_i\ C_eC_t\ s_k$	*Persistent/transient design situation* [1] undrifted $\mu_i\ C_eC_t\ s_k$	*Persistent/transient design situation* [1] undrifted $\mu_i\ C_eC_t\ s_k$
	[4] drifted $\mu_i\ C_eC_t\ C_{esl}\ s_k$	in AnnexB)	[4] drifted $\mu_i\ s_k$ (for roof shapes in AnnexB)

Accidental: refers only to exceptional conditions

Persistent: Conditions of normal use

Transient: temporary conditions (e.g. execution or repair)

NOTE 1: Exceptional conditions are defined according to the National Annex.

NOTE 2: For cases B1 and B3 the National Annex may define design situations which apply for the particular local effects described in section 6.

Section 4 of EN 1991-1-3
Snow load on the ground

Section 4 - Snow load on the ground

The snow load on the roof is derived from the **snow load on the ground**, multiplying by appropriate conversion factors (shape, thermal and exposure coefficients).

Section 4 - Snow load on the ground

s_k is intended as the upper value of a random variable, for which a given statistical distribution function applies, with the annual probability of exceedence set to 0,02 (i.e. a probability of not being exceeded on the unfavourable side during a “reference period” of 50 years).

For locations where exceptional ground snow loads are recorded, these value must be excluded from the data sample of the random variable. The exceptional values may be considered outside the statistical methods.

The characteristic ground snow loads (s_k) are given by the **National Annex** for each CEN country.

Needs for harmonization – Development of European ground snow load map

- Inconsistencies at borders between existing national maps;
- Different procedures for measuring snow load (mainly ground snow data): snow depths + density conversion, water equivalent measures, direct load measures;
- Different approaches for statistical data analysis (Gumbel, Weibull, Log-normal distributions).

!

The research developed a consistent approach

Produced regional maps (*Annex C of EN 1991-1-3*)

- Snow load with Altitude relationship
- Zone numbers & altitude functions
- Geographical boundaries

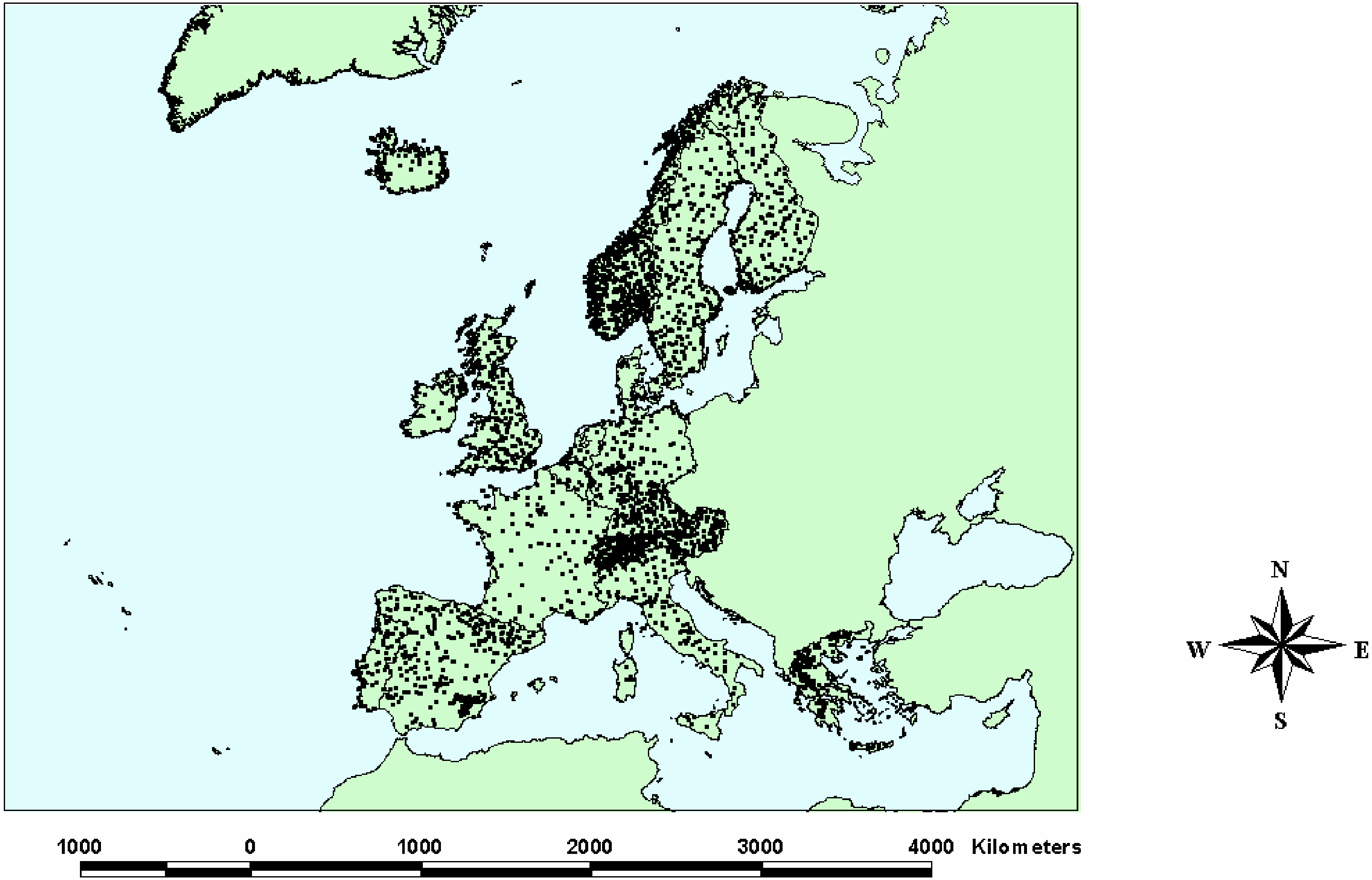
Section 4 - Snow load on the ground

For maps in **Annex C** of EN 1991-1-3 the following common approach has been followed:

- Statistical analysis of yearly maxima, using the **Gumbel Type I** CDF (best fitting in the majority of data points);
- **LSM** for the calculation of the best fitting regression curve;
- Both **zero and non zero values** have been analysed according to the "*mixed distribution approach*" ;
- Approximately **2600** weather stations consistently analysed;
- Regionalization of CEN area (18 countries 1997) into **10 climatic regions**;
- **Smoothing** of maps across borderlines between neighbouring climatic regions (buffer zones 100 km).

Section 4 - Snow load on the ground

Data Points



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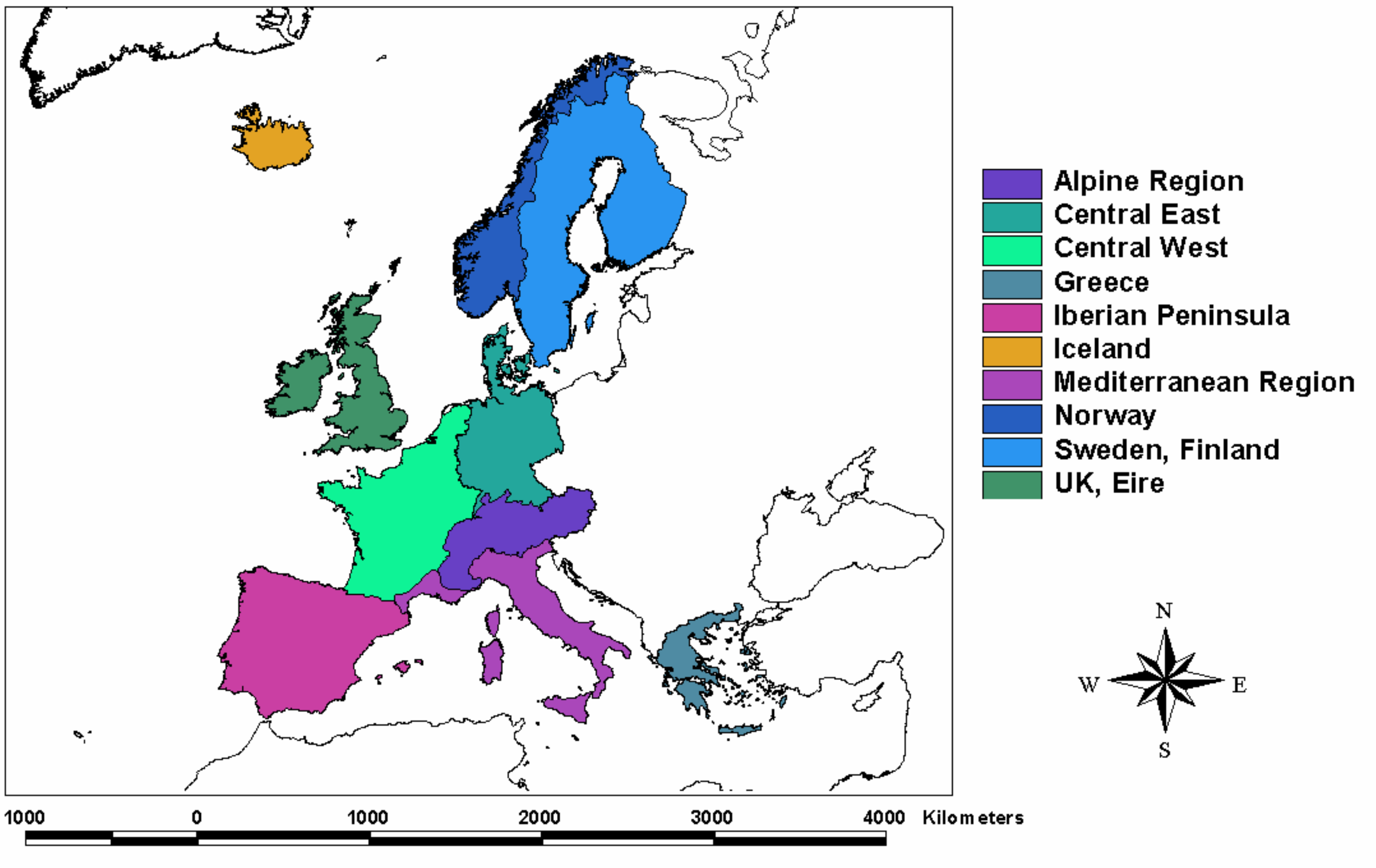
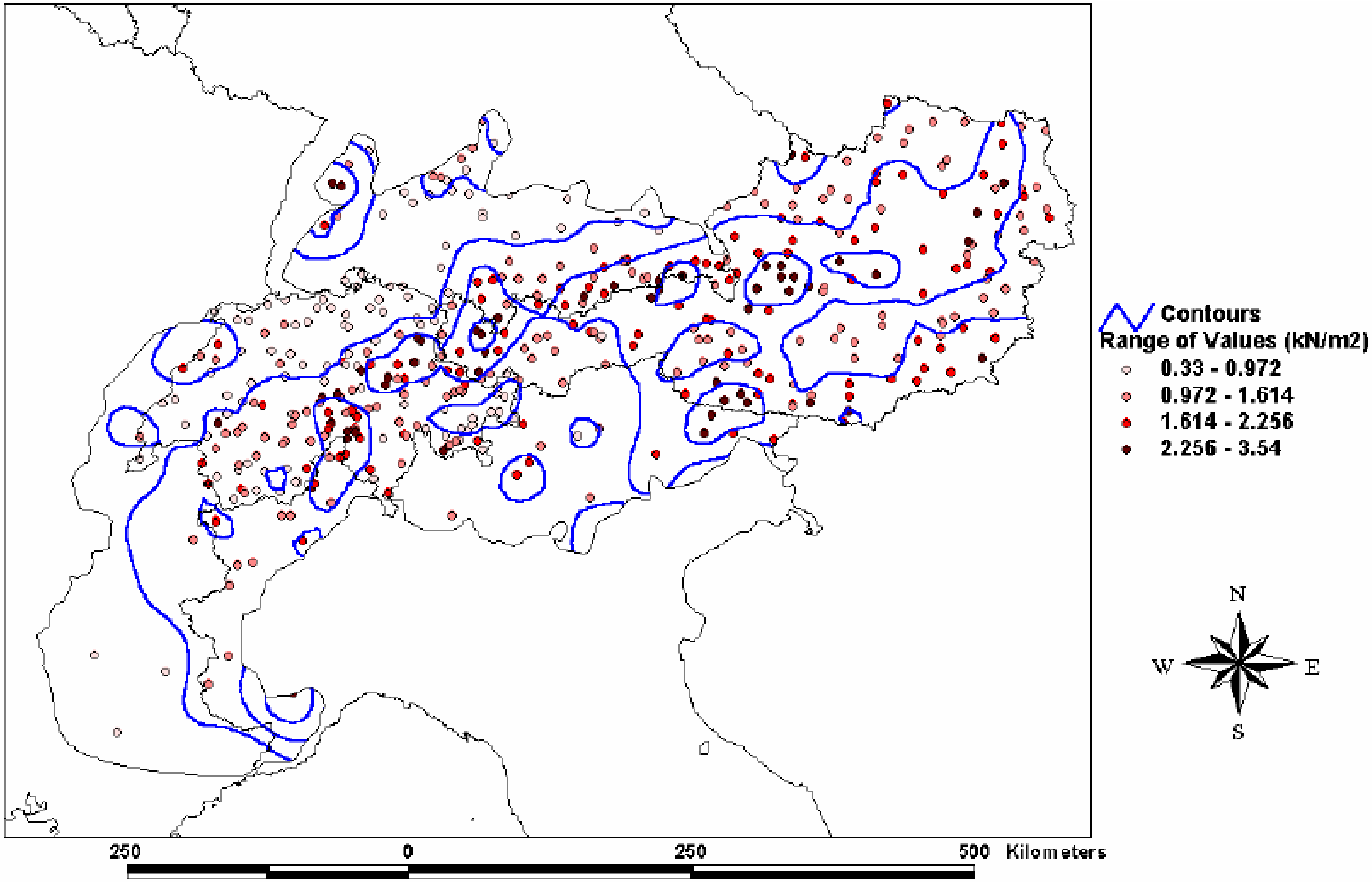
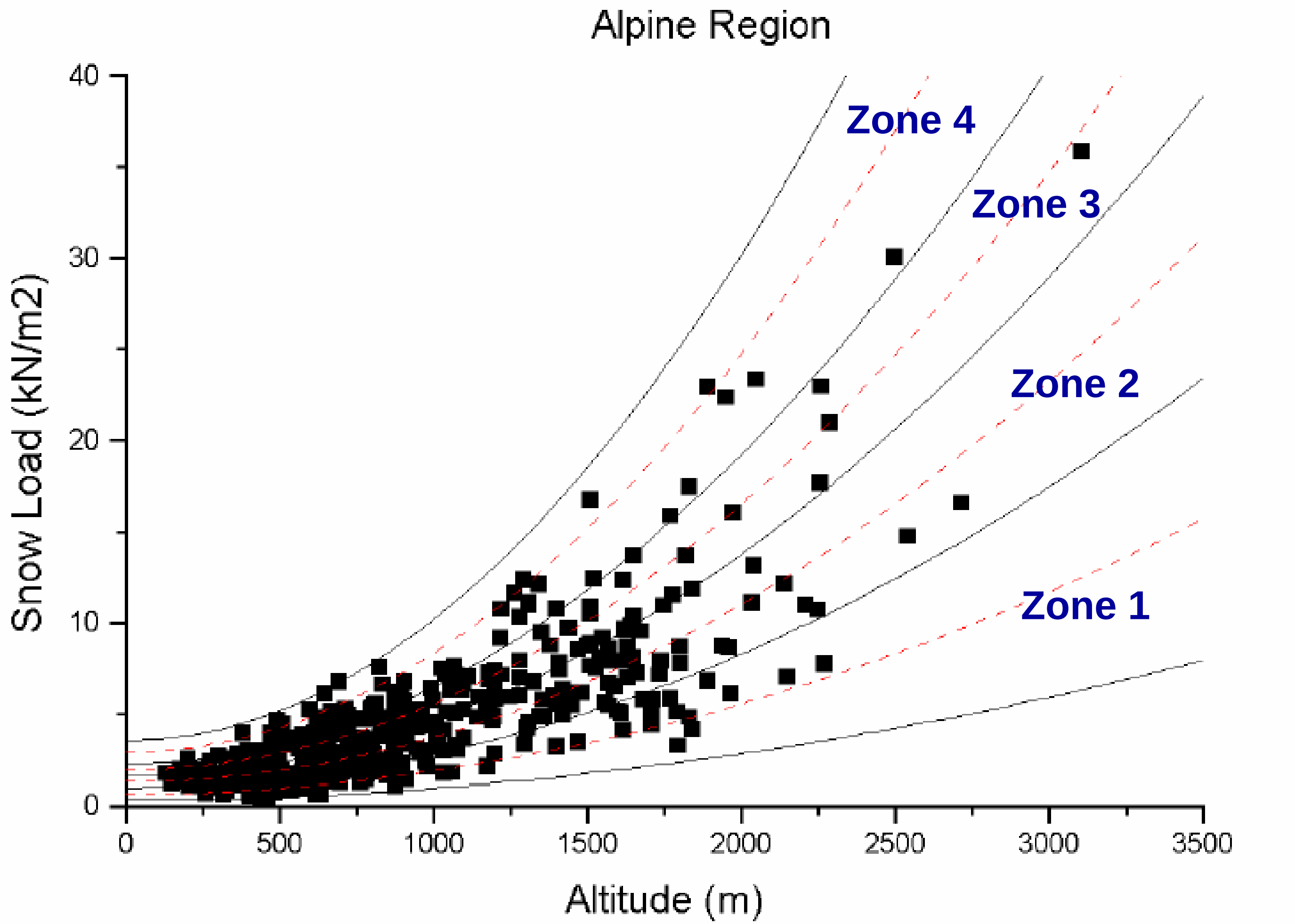
10 European regions, with homogeneous climatic features



Alpine Region – Snow load at sea level (France, Italy, Austria, Germany and Switzerland)



Section 4 - Snow load on the ground



$$s_k = (0{,}642Z + 0{,}009)\left[1 + \left(\frac{A}{728}\right)^2\right]$$

z = Zone number given on the map
A = site altitude above Sea Level [m]

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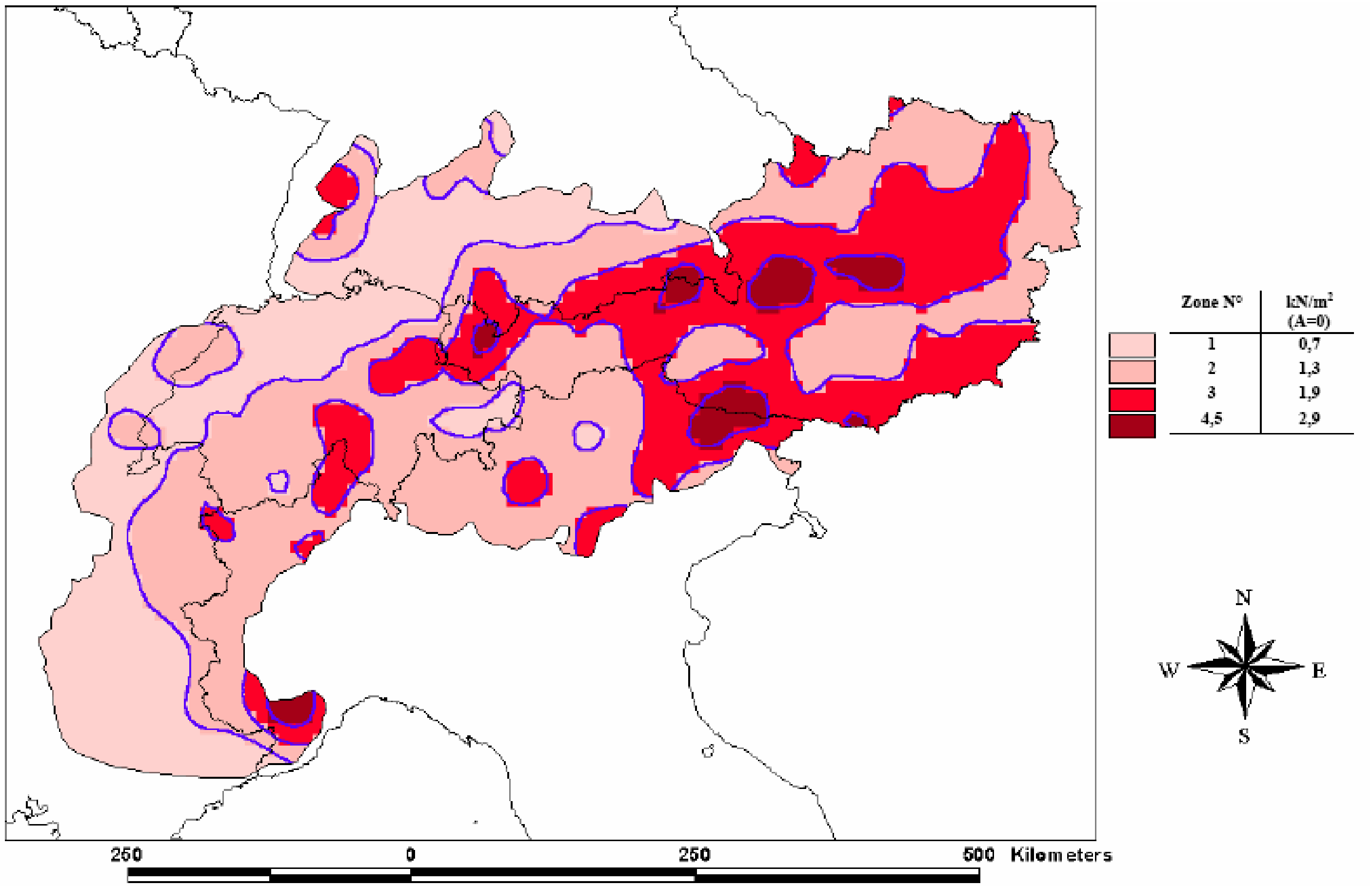
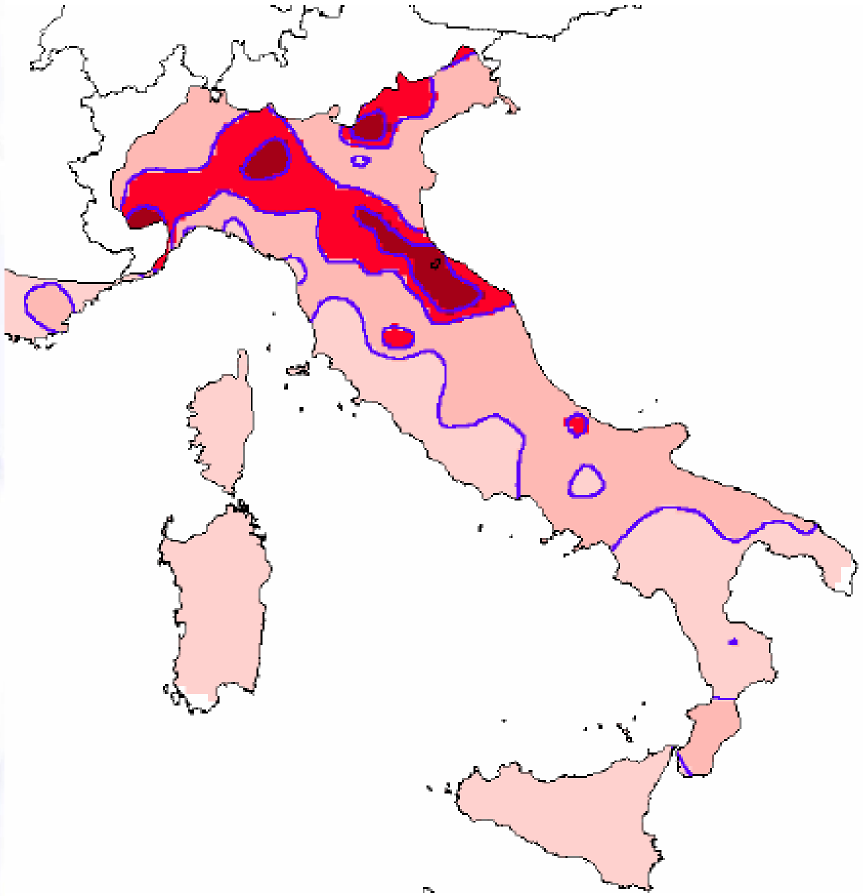
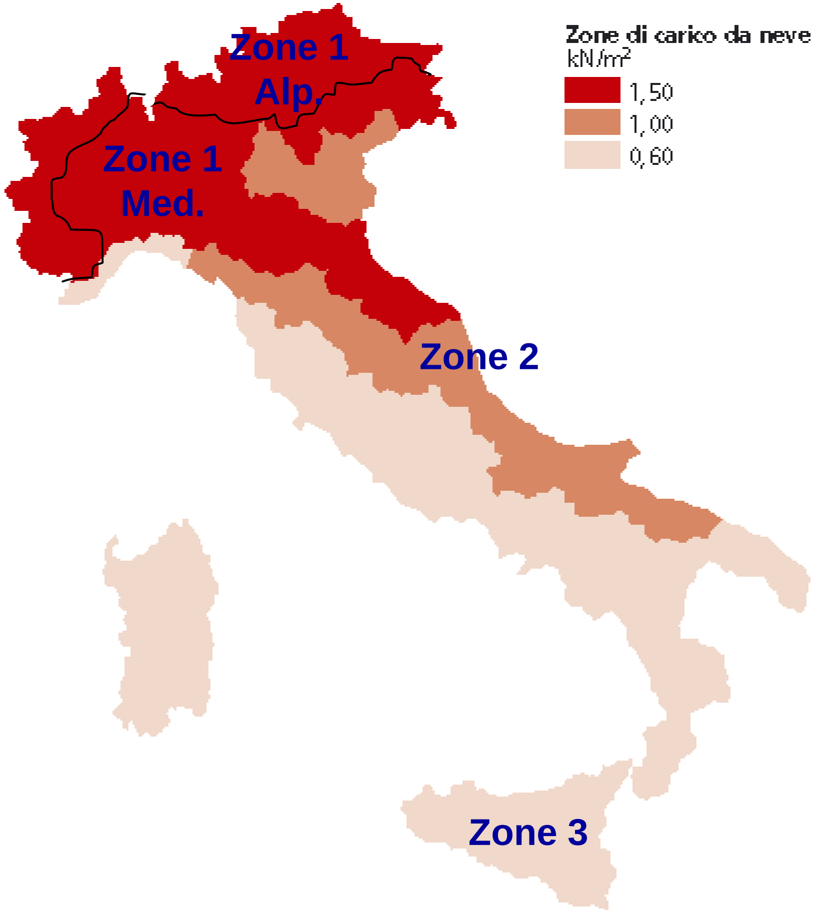
Alpine Region – Snow load at sea level



Section 4 - Snow load on the ground





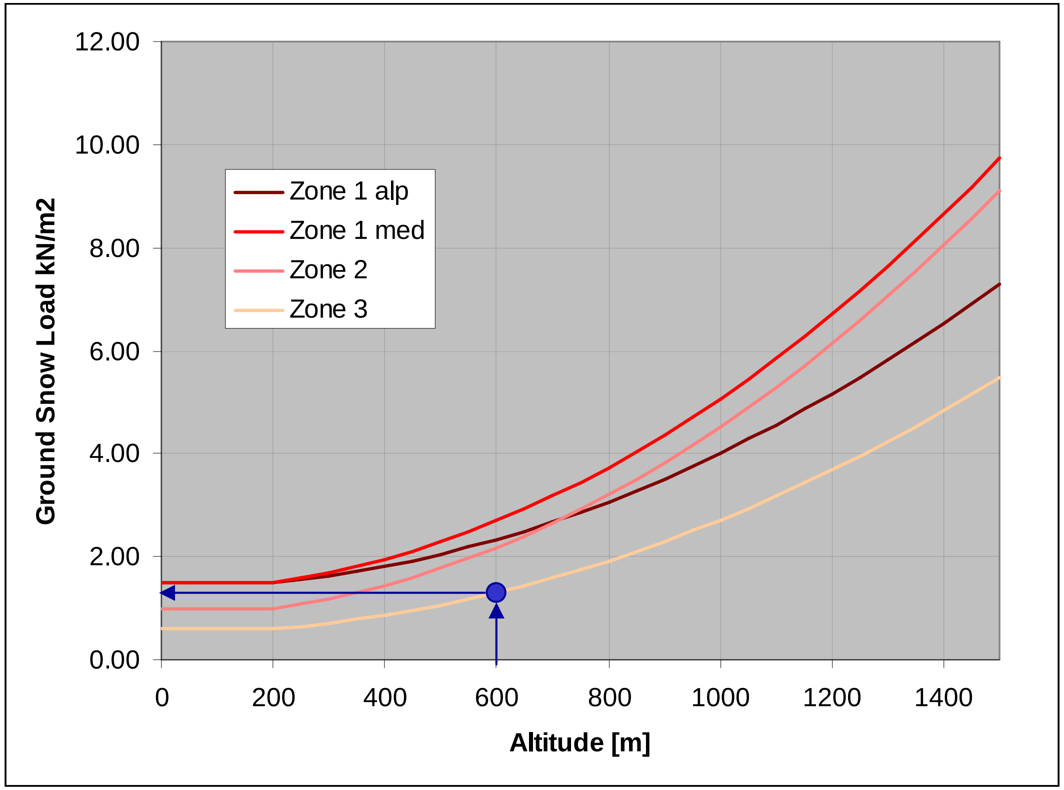
Map for Mediterranean region
Annex C EN 1991-1-3
(geographical boundaries)

Italian National Annex
(administrative boundaries)

Section 4 - Snow load on the ground - Example

Italian ground Snow load Map:

- 4 different zones (3 Med. + 1 Alpine)
- Administrative boundaries (110 provinces)
- 4 Altitude correlation functions



Example of calculation of ground snow load at a given location:

Inputs:
- **zone** n. 3
- **altitude** = 600m a.s.l.

s_k **= 1,30 kN/m²**

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Other representative values of ground snow loads

Combination value ψ_0 s_k

$$\sum_{j\geq 1}\gamma_{G,j}G_{k,j}"+"\gamma_P P"+"\gamma_{Q,1}Q_{k,1}"+"\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i}$$

Eq. 6.10

EN 1990

The combination factor ψ_0 is applied to the snow load effect when the dominating load effect is due to some other external load, such as wind.

Based upon the available data ψ_0 values were calculated through the Borges-Castanheta method.

Other representative values of ground snow loads

Frequent value ψ_1 s_k

The frequent value $\psi_1 s_k$ is chosen so that the time it is exceeded is 0,10 of the reference period.

$$\sum_{j\geq 1} G_{k,j} "+" P "+" \psi_{1,1} Q_{k,1} "+" \sum_{i>1} \psi_{2,i} Q_{k,i}$$

Eq. 6.15b

EN 1990

Quasi-permanent value ψ_2 s_k

The quasi-permanent value $\psi_2 s_k$ (used for the calculation of long-term effects) is usually chosen so that the proportion of the time it is exceeded is 0,50 of the reference period.

$$\sum_{j\geq 1} G_{k,j} "+" P "+" \sum_{i>1} \psi_{2,i} Q_{k,i}$$

Eq. 6.16b

EN 1990

ψ_1 and ψ_2 values were calculated from **daily data series** available at **59 weather stations** representative of all 10 different climatic regions.

Other representative values of ground snow loads

Table 4.1 Recommended values of coefficients ψ_0, ψ_1 and ψ_2 for different locations for buildings.

Regions	ψ_0	ψ_1	ψ_2
Finland Iceland Norway Sweden	0,70	0,50	0,20
Reminder of other CEN member states, for sites located at altitude H > 1000 m above sea level	0,70	0,50	0,20
Reminder of other CEN member states, for sites located at altitude H ≤ 1000 m above sea level	0,50	0,20	0,00

Treatment of exceptional loads on the ground

Maps given in National Annexes are determined without taking into account “exceptional falls”

?

How to determine design values for accidental ground snow loads?

For locations where exceptional loads may occur (National Annex), the ground snow load may be treated as accidental action with the value:

$$s_{Ad} = C_{esl}\, s_k$$

Where:

C_{esl} (set by the National Annex) - recommended value = 2,0

s_k = characteristic ground snow load at the site considered

$$\sum_{j\geq 1} G_{k,j} \text{"+"} P \text{"+"} A_d \text{"+"} (\psi_{1,1} \text{ or } \psi_{2,1}) Q_{k,1} \text{"+"} \sum_{i>1} \psi_{2,i} Q_{k,i}$$

Eq. 6.11b

EN 1990

Section 5 of EN 1991-1-3
Snow load on roofs

Section 5 - Snow load on roofs

The snow the snow layers on a roof can have many different shapes depending on roof's characteristics:

- its shape;
- its thermal properties;
- the roughness of its surface;
- the amount of heat generated under the roof;
- the proximity of nearby buildings;
- the surrounding terrain;
- the local meteorological climate, in particular its windiness, temperature variations, and likelihood of precipitation (either as rain or as snow).

Snow load on roofs – Load arrangements

In absence of wind, or with very low wind velocities (<2 m/s) snow deposits on the roof in a balanced way and generally a uniform cover is formed

UNDRIFTED LOAD ARRANGEMENT

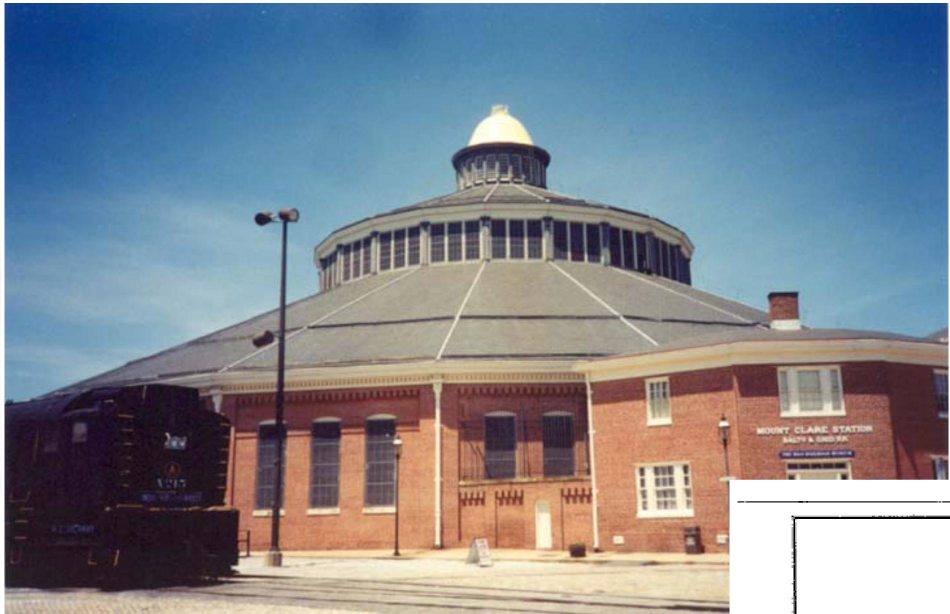
Snow load on roofs – Load arrangements

For situations where the wind velocity increases above 4 ÷ 5 m/s snow particles can be picked up from the snow cover and re-deposited on the lee sides, or on lower roofs in the lee side, or behind obstructions on the roof.

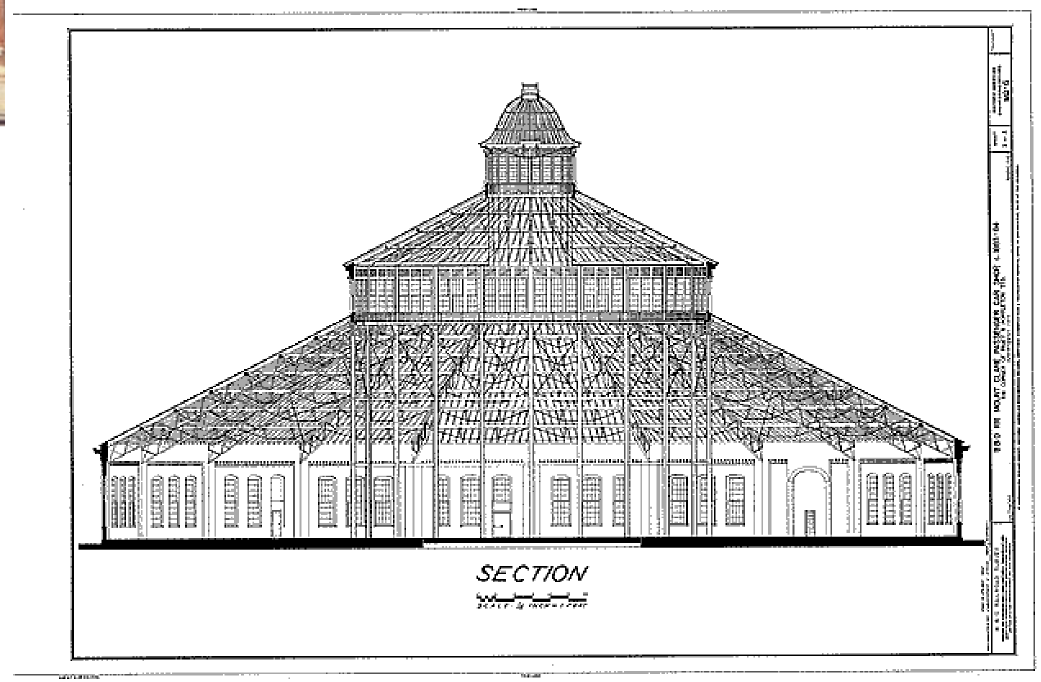
DRIFTED SNOW LOAD ARRANGEMENT

Model in wind tunnel for multi - pitched roof
wind velocity > 5 m/s

Snow load on roofs – Collapse due to drifting (1)



Baltimore & Ohio
Railroad Museum (MD - U.S.)



Snow load on roofs – Collapse due to drifting (1)

17th February 2003 – Collapse due to heavy snow storm unbalanced load on half roof

Snow load on roofs – Collapse due to drifting (2)

Collapse of a silo roof due to unbalanced snow deposition pattern

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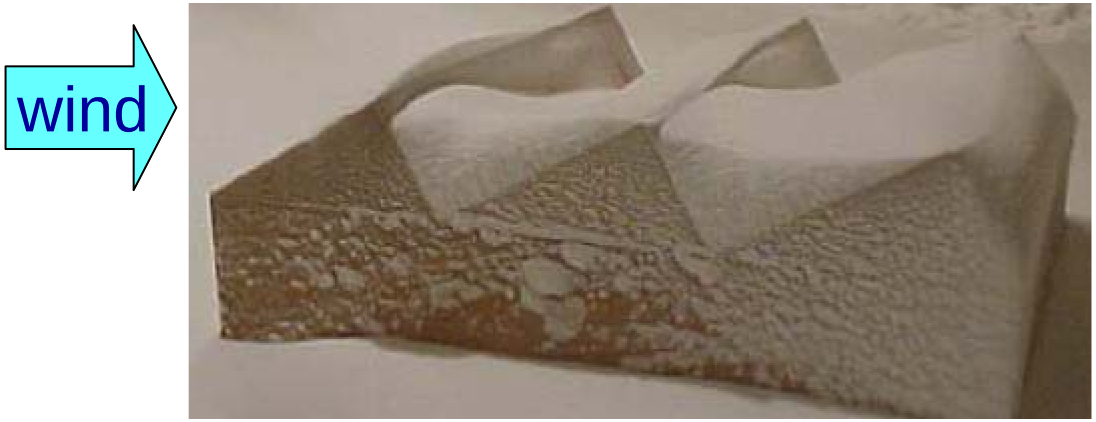
EXCEPTIONAL DRIFTS

In **maritime climates** (e.g. UK and Eire), where snow usually melts and clears between the individual weather systems and where moderate to high wind speeds occur during the individual weather system, the amount of the drifted load is considered to be of a high magnitude compared to the ground snow load, and the drifted snow is considered an exceptional load and treated as an **accidental load** using the accidental design situation (**Annex B of EN 1991-1-3**).



Model in wind tunnel for multi - pitched roof
wind velocity > 5 m/s

Snow load on roofs

Snow load on the roof (*s*) is determined converting the *characteristic ground snow load* into an **undrifted** or **drifted roof load** for *persistent/transient* and, where required by the National Annex, *accidental* design situations by the use of:

- an appropriate shape coefficient which depends on the shape of the roof;
- considering the influence of thermal effects from inside the building and the terrain around the building.

Snow load on roofs – Load arrangements

For the **persistent / transient** design situations i.e. no exceptional snow falls or drifts:

$$s = \mu_i \; C_e \; C_t \; s_k \qquad \text{(5.1 } \textit{EN 1991-1-3}\text{)}$$

For the **accidental** design situations, where **exceptional ground snow load** is the accidental action:

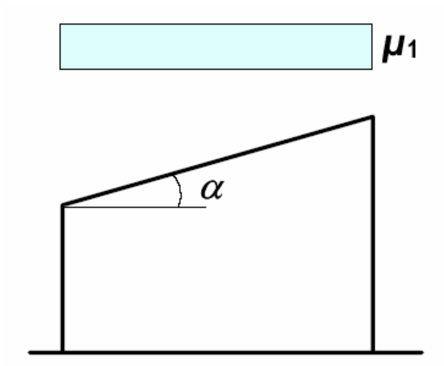
$$s = \mu_i \; C_e \; C_t \; s_{Ad} \qquad \text{(5.2 } \textit{EN 1991-1-3}\text{)}$$

For the **accidental** design situations where **exceptional snow drift** is the accidental action and where Annex B applies:

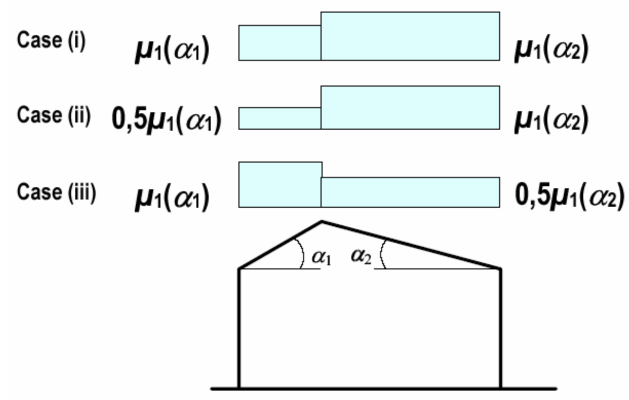
$$s = \mu_i \, s_k \qquad \textit{(5.3 EN 1991-1-3)}$$

Snow load on roofs – Shape coefficients

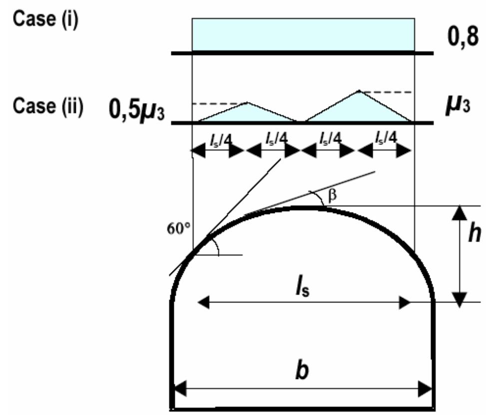
EN 1991-1-3 gives shape coefficients for the following types of roofs (*non exceptional drifted cases*):



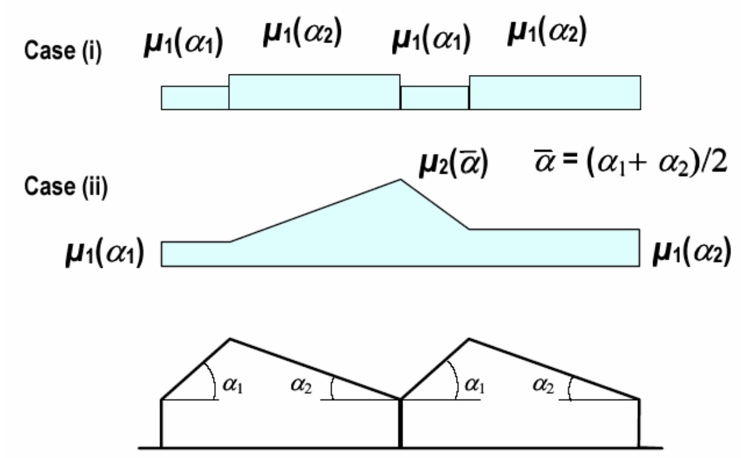
Monopitch



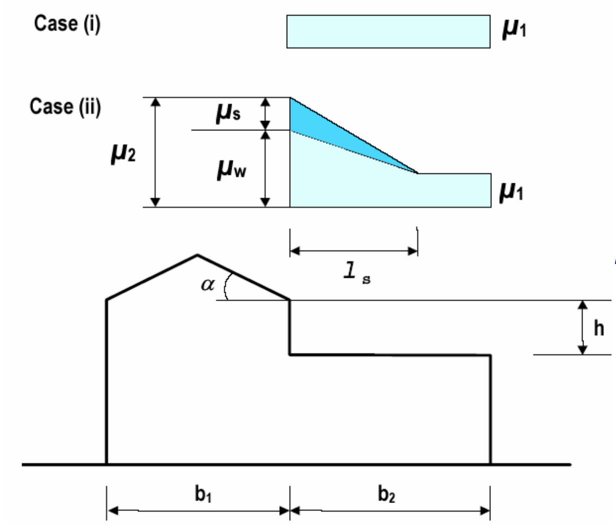
Pitched



Cylindrical



Multi-span



Roofs abutting and close to taller construction works

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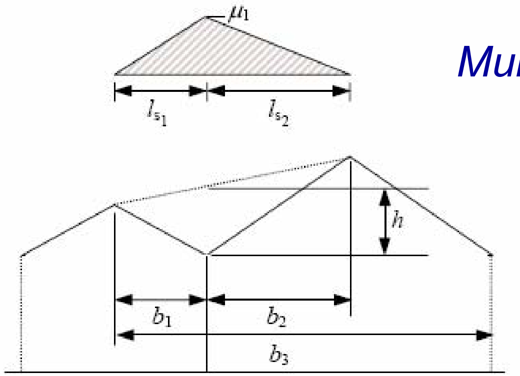
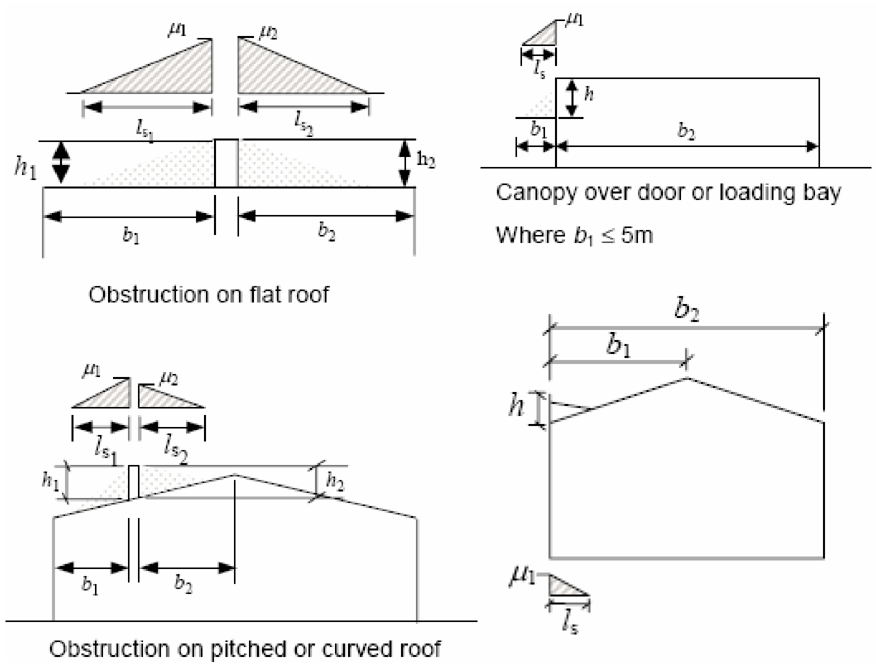
Snow load on roofs – Shape coefficients

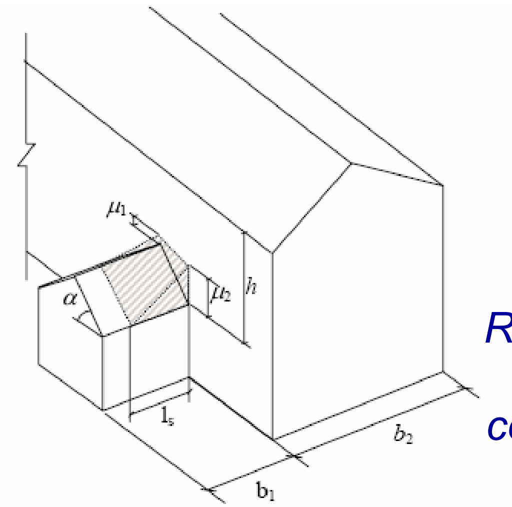
Annex B of EN 1991-1-3 gives shape coefficients for the following types of roofs (*exceptional drifted cases*):



Multi-span



Drifting at projections, obstructions and parapets



Roofs abutting and close to taller construction works

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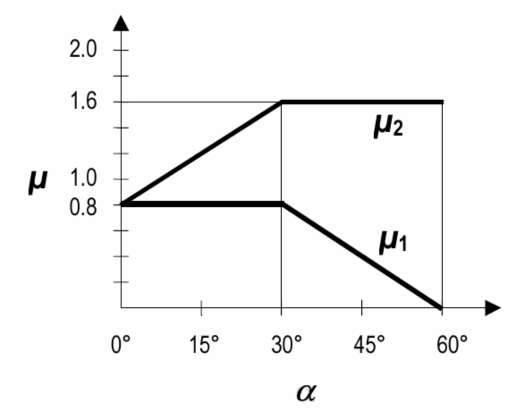
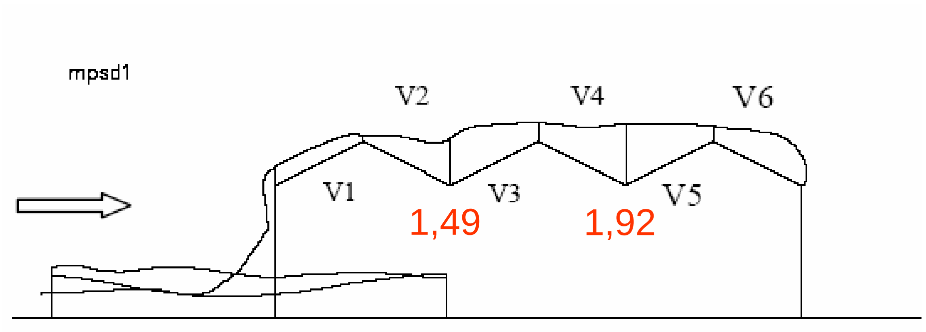
Snow load on roofs – Shape coefficients

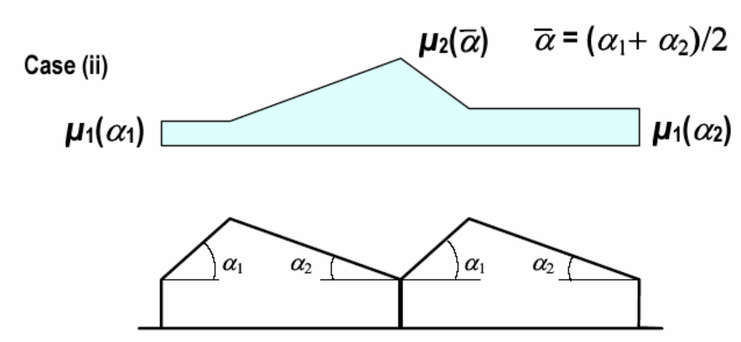
Values for shape coefficients μ_i given in EN 1991-1-3 are calibrated on a wide experimental campaign, both in situ and in wind tunnel.



Angle of pitch of roof α	$0° \le \alpha \le 30°$	$30° < \alpha < 60°$	$\alpha \ge 60°$
μ_1	0,8	$0,8(60 - \alpha)/30$	0,0
μ_2	$0,8 + 0,8\ \alpha/30$	1,6	--



Average = 1,67



Multi-span drifted case

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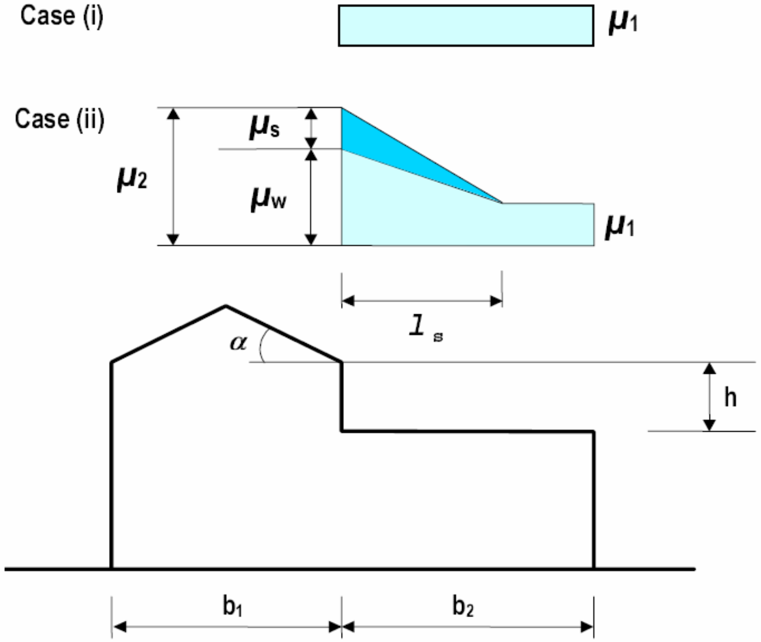
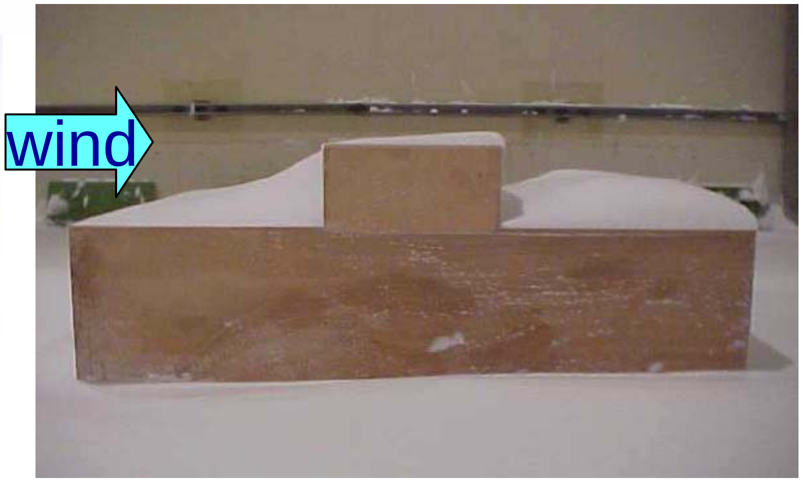
Snow load on roofs – Shape coefficients

Roof abutting and close to taller construction works





μ_s is for snow falling from the higher roof (α>15°)

μ_w is the snow shape coefficient due to wind:

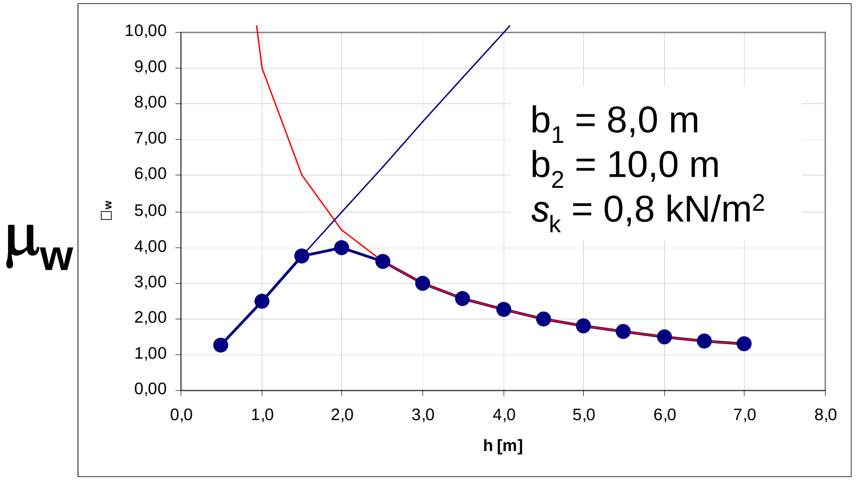
$$\mu_w = (b_1+b_2)/2h < \gamma\, h / s_k$$

$$\gamma = 2 \text{ kN/m}^3$$

$$0.8 < \mu_w < 4$$

$$l_s = 2h$$

$$5\text{m} < l_s < 15\text{m}$$



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Snow load on roofs – Exposure coefficient

A coefficient (C_e) defining the reduction or increase of snow load on a roof of an unheated building, as a fraction of the characteristic snow load on the ground.

The choice for C_e should consider the future development around the site.

C_e should be taken as 1,0 unless otherwise specified for different topographies.

The **National Annex** may give the values of C_e for different topographies, recommended values are given.

Snow load on roofs – Exposure coefficient

***Windswept topography*, where (C_e = 0,8)** are flat unobstructed areas exposed on all sides without, or little shelter afforded by terrain, higher construction works or trees.

***Normal topography*, where (C_e = 1,0)** areas where there is no significant removal of snow by wind on construction work, because of terrain, other construction works or trees.

***Sheltered topography*, where (C_e = 1,2)** areas in which the construction work being considered is considerably lower than the surrounding terrain or surrounded by high trees and/or surrounded by higher construction works.

Snow load on roofs – Thermal coefficient

The thermal coefficient C_t is used to account for the reduction of snow loads on roofs with high thermal transmittance (> 1 W/m^{2}K), in particular for some glass covered roofs, because of melting caused by heat loss.

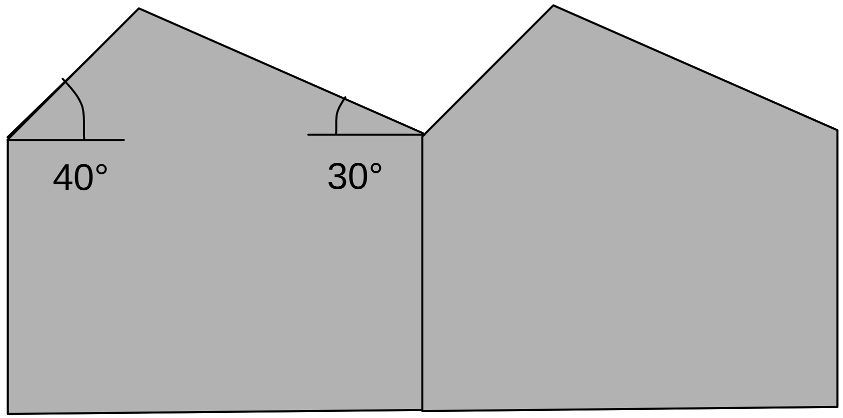
For all other cases: C_t = 1,0

Further guidance may be obtained from ISO 4355

Multi-span roof in Sweden

Properties of Building

Location: Sweden – Snow load **zone 2** – **300m** asl
Building surroundings – normal – Ce = 1,0
Effective heat insulation applied to roof – Ct = 1,0

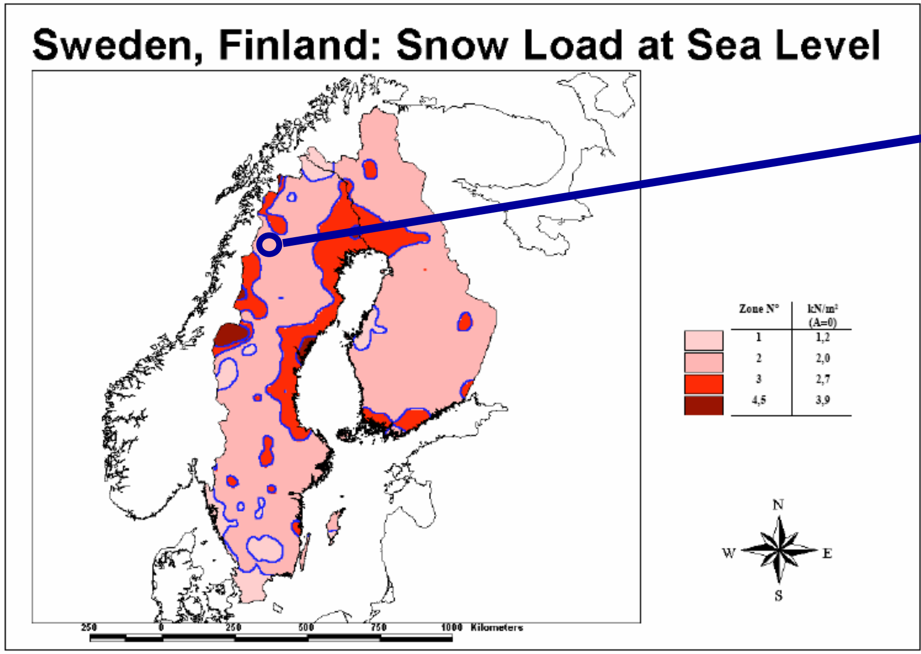


Snow load on roofs – Example (2)

Altitude relationship for Sweden:

$$s_k = 0{,}790Z + 0{,}375 + \frac{A}{336}$$

where: *Z* is the Zone Number & A is the altitude



Zone 2
A = 300 m

Characteristic ground snow load at the site:

s_k = 0,790 x 2 + 0,375 + 300/336 = **2,85** kN/m^2

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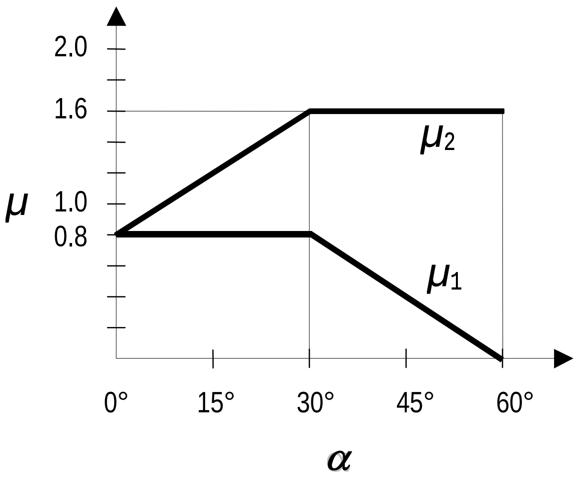
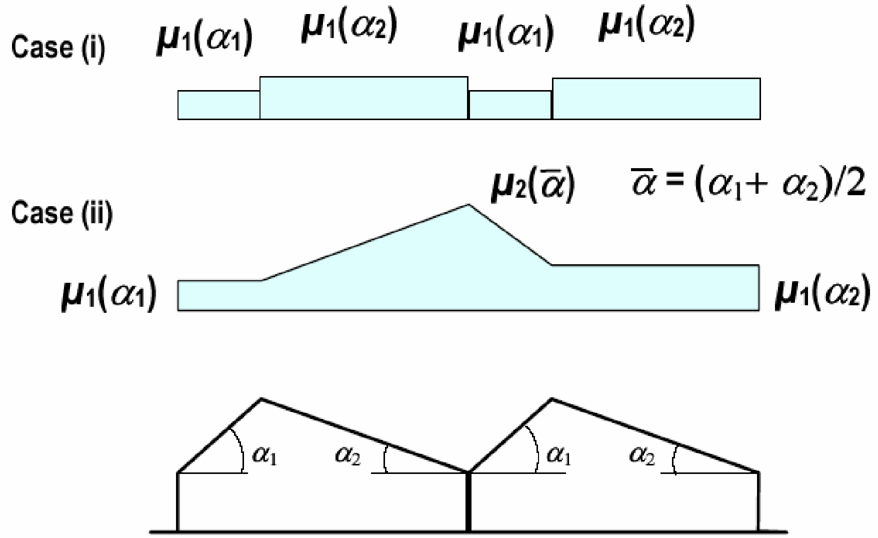
Snow load on roofs – Example (3)

Determination of shape coefficients:

Undrifted load arrangement: Case (i) μ_1
Drifted load arrangement: Case (ii) μ_1, μ_2





$$\alpha_1 = 40° \qquad \mu_1(\alpha_1) = 0{,}53$$

$$\alpha_2 = 30° \qquad \mu_1(\alpha_2) = 0{,}80$$

$$\overline{\alpha} = \frac{\alpha_1 + \alpha_2}{2} = 35° \quad \mu_2(\overline{\alpha}) = 1{,}60$$

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Snow load on roofs – Example (4)

s_k = 2,85 kN/m^2

$s = C_t\ C_e\ \mu_i\ s_k$

$$\alpha_1 = 40° \qquad \mu_1(\alpha_1) = 0{,}53$$

$$\alpha_2 = 30° \qquad \mu_1(\alpha_2) = 0{,}80$$

$$\bar{\alpha} = \frac{\alpha_1 + \alpha_2}{2} = 35° \quad \mu_2(\bar{\alpha}) = 1{,}60$$

Combination coefficients

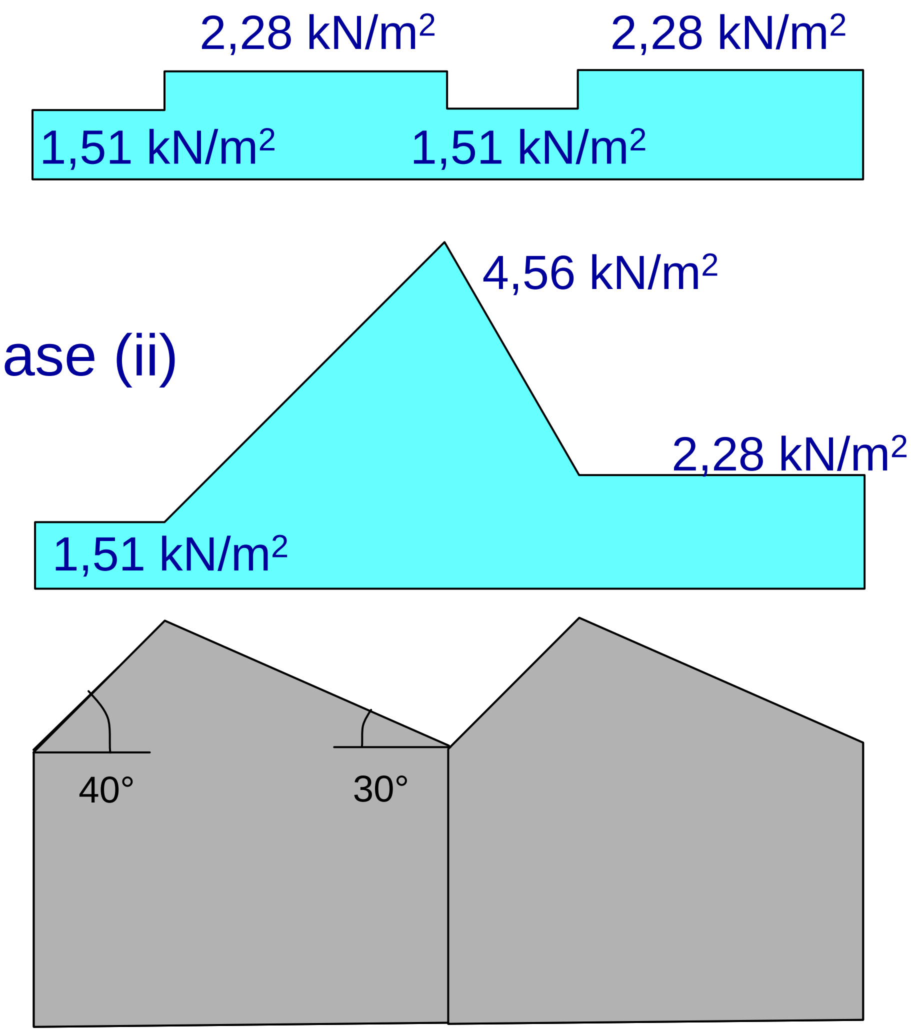
Climatic region: Finland, Iceland, Norway Sweden:

ψ_0 = *0,70*

ψ_1 = *0,50*

ψ_2 = *0,20*

Case (i)



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Section 6 - Local Effects

In addition to snow deposition patterns adopted for the global verification of the building, local verifications have to be performed for specific structural elements of the roof or roof's parts.

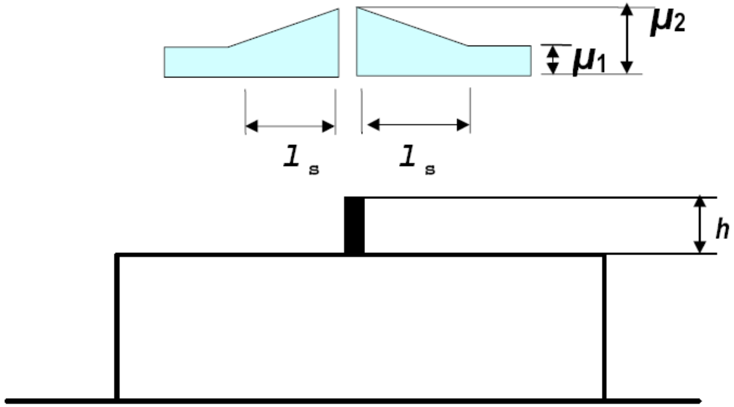
Section 6 of **EN 1991-1-3** gives the forces to be considered for the verification of:

– drifting at projections and obstructions;
– the edge of the roof;
– snow fences.

The **National Annex** may be specify condition of use of this part or different procedures to calculate the forces.

Section 6 - Local Effects

Drifting at projections and obstructions



$\mu_1 = 0,8 \qquad \mu_2 = \gamma\, h/s_k$

where

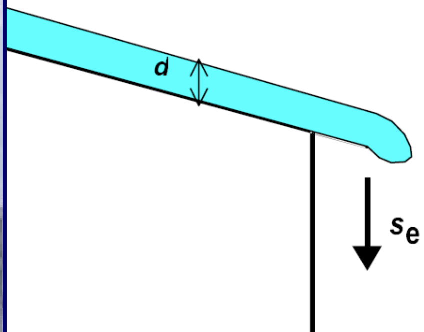
$0,8 \leq \mu_2 \leq 2,0$

γ = 2 kN/m^3 (weight density of snow)

$l_s = 2h \qquad 5 \leq l_s \leq 15$ m

Snow overhanging the edge of a roof

(recommended for sites above 800 m a.s.l.)



$s_e = k\, s^2 / \gamma$

where

γ = 3 kN/m^3

$\gamma k = 3/d < d\,\gamma$ (National Annex)

d is in meters

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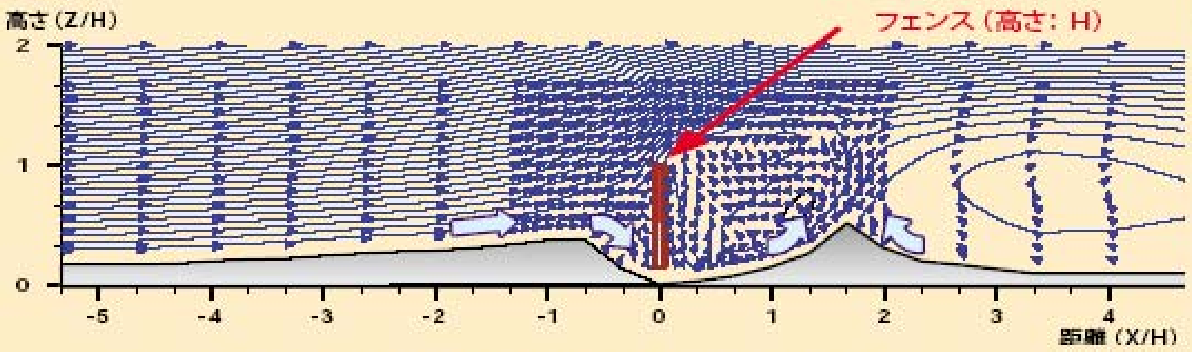
Drifting at projections and obstructions

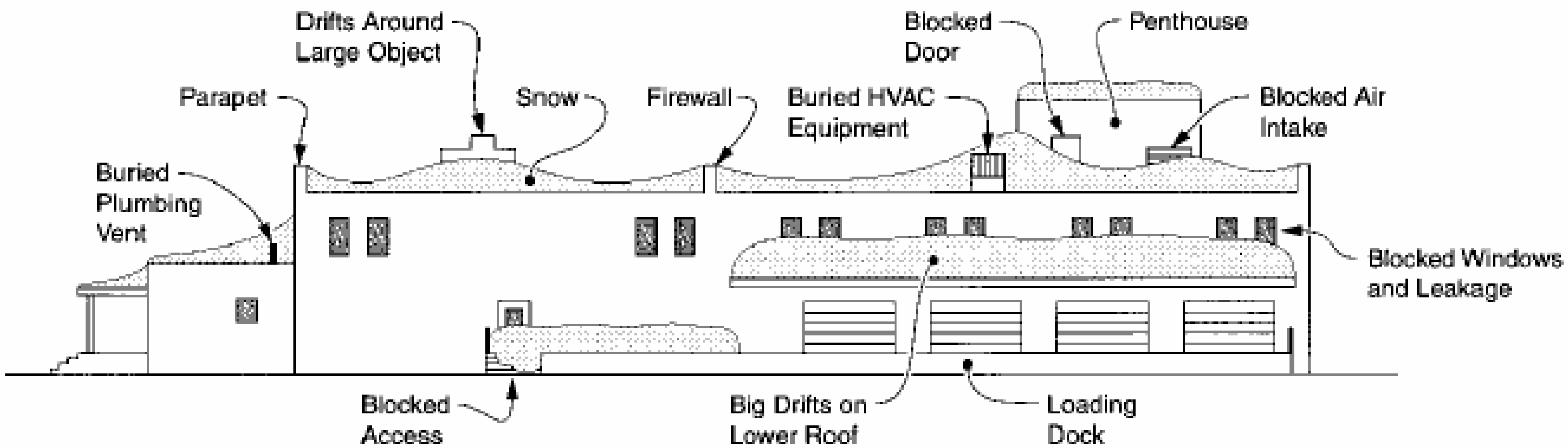


フェンス周りの風の性状と雪の吹きだまり形成の様子

Snow Accumulation and Wind Flow around a Fence

フェンスの屋外試験体

Field Test Fence Model



Snow overhanging the edge of a roof

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Normative Annexes

Annex A – Design situations and load arrangements to be used for different locations

Annex B – Snow load shape coefficients for exceptional snow drifts

Informative Annexes

Annex C – European Ground snow load map

Majority produced during European Research project

Annex D – Adjustment of ground snow load for return period

Expression for data which follow a Gumbel probability distribution

Annex E – Densities of snow

Indicative density values for snow on the ground

Research needs for further developments

1. Compare National Annex maps with the maps of Annex C of EN 1991-1-3 as a first step to obtain a harmonised snow map of Europe by ensuring consistency at borders;
2. Enlargement of the European ground snow load map to cover all the 29 Member States of the EU and EFTA;
3. Influence of roof dimensions on roof shape coefficients;
4. Snow loading on glass structures;
5. Freezing/melting effects.


Thank you for your attention