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SNOW LOADS

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FINAL REPORT

University of Pisa

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1. Executive Summary

The scientific work carried out under EC Contract n^{o} 500269 is aimed at improving the scientific knowledge and models for the determination of snow loads on buildings by producing a sound common scientific basis which can be accepted by all European countries involved in the drafting of Eurocodes.

The research programme is in two consecutive phases. Phase I provides methods and techniques for the determination of ordinary and exceptional snow loads on the ground in order to produce a new European ground snow load map. Phase II will investigate methods and techniques for determination of snow loads on roofs and define appropriate criteria for determining the serviceability loads on such roofs. This contract covers only Phase I.

This report is the deliverable required at the end of the first phase of the research, it follows the interim report and describes the research work carried out and the results obtained.

The work has reviewed current practice in eighteen European countries and in consultation with the appropriate National Meteorological Offices, has identified the statistical techniques and data that were both available and required for determining characteristic snow load values. Similarities and differences between individual national approaches were identified which led to the development of a reference model for statistical analysis of ground snow loads. This model was applied to all European countries in which snow data have been collected, in an homogeneous way, under this research phase.

In some regions isolated very heavy snow falls have resulted in snow loads significantly larger than those that normally occur. Such snowfalls significantly disturb the statistical processing of more regular snowfall data. Additionally statistical techniques appropriate for more continuous and longer lying periods of snow result, may be inappropriate for countries with more intermittent, irregular or short duration snowfalls, such as in the UK and Denmark. Both of these aspects were examined and criteria for identifying and approaches for treating them proposed. These approaches were tested, using relevant data, in order to confirm their provenance.

Geographical Information Systems (stet - have been)used in order to produce the European Ground Snow Load Map. A range of options and computer software for handling, interpreting and visualising the relevant data were explored and appropriate recommendations made. Basic geographical information eg. station co-ordinates and altitudes, and characteristic ground snow load values were supplied by each Partner to allow the map infrastructure to be defined.

During the map elaboration phase criteria were defined for regionalisation of data in order to achieve consistency across Europe in deriving a map not substantially influenced by national boundaries. Different homogeneous climatic regions were identified on the basis of geographic and climatic consideration and their influence on snowfalls. Specific load - altitude correlation functions were used to define zoning procedures to serve as a basis for Eurocode provisions.

In the present research general statistical methods were applied to investigate the distribution of snow with time as well as its geographical distribution. Particular concern was paid to the variation with altitude, even though many other factors affect the snow deposition. Due to the difficulties encountered in collecting data, their availability and in their quality checks, altitude was considered as the main factor influencing the snow load values at each site.

Grouping many European countries together it was possible to recognise certain regularities in the phenomenon of snow deposition. The result of this work is presented in form of a map of Europe, allowing the design ground snow load to be determined at any place, both in digital and numerical formats. The snow load on the ground at each site, is obtainable as a function of the altitude of the site, belonging to a fixed zone, and of the snow load at zero level in the same zone. This approach, widely used in the national prestandards included in the Eurocode 1, Part 2-3 Snow Loads, was employed, for the first time uniformly all across Europe, in order to overcome inconsistencies at national borderlines.

Furthermore for the first time on the European scale exceptional snow load values have been considered. They were defined in a numerical way and places where such exceptional values were encountered were localised in Europe, in order to find out geographical, meteorological and all other possible sources of influence which should have lead to the registered exceptional snowfalls.

Whilst there have been problems in acquiring data from a temporal viewpoint the work has been developed satisfactorily. Results have not indicated any need to alter the objectives of the contract nor to adjust further the contract's timetable. The final deliverables conform to the contract deadlines.

2. Introduction

The scientific work which has been carried out under the present research phase is concerned with the design specifications of civil engineering works and supports the development of the structural Eurocodes. In particular it is aimed at improving the scientific knowledge and models for the determination of snow loads on buildings by producing a sound common scientific basis which can be accepted by all European countries involved in the drafting of Eurocodes. This should eliminate inconsistencies that could prevent Member States from reaching agreement on the relevant European Standards.

The research programme is divided into two consecutive phases. Phase I provides methods and techniques for the determination of ordinary and exceptional snow loads on the ground in order to produce a new European ground snow load map. Phase II will investigate methods and techniques for determination of snow loads on roofs and define appropriate criteria for determining the serviceability loads on such roofs. In general a wide range of roof types common throughout the European countries should be examined. The aim will be to develop a common drift and depletion model to reduce the number of roof types to be investigated. Snow loads on roofs are needed because ground snow loads alone do not take into account roof geometries and their effects on snow eg local drifting.

This contract covers only Phase I. The research has been focused on two tasks:

Task Ia: Characteristic snow load on the ground

Task Ib: Exceptional Snow Loads.

The contract requires an interim report, already submitted according to the timetable of the present research phase defined in the contract (Annexe III to the contract), and the final report at the end of the Phase. The final report describes the work carried out and the results obtained during the reference period.

This final report, in addition to Chapters 1 and 2, i.e the Executive Summary and the Introduction respectively, includes: Chapter 3 which outlines the methodology of approach for the definition of ground snow load, both ordinary and exceptional, all over Europe; Chapter 4 which describes the work carried out and the results obtained in Tasks Ia and Ib, Chapter 5 deals with the European Snow Load Map elaboration phase and the obtained results; Chapter 6 which discusses the effects of the results on the overall work of the contract and on the Eurocodes. Also there are seven Annexes dealing with administrative items related to the contract (Annex 1) and with specific technical items (Annexes 2 to 7).

3. Methodology of approach

The structural design of buildings is based on possible design situations characterised by typical load values. Such characteristic loads have to be fixed at a level to ensure a safe construction whilst recognising that economic pressures will seek to reduce design loads as much as possible in order to avoid over-designed structures. Especially in mountainous regions the snow load often has an important impact on the design and hence the costs of any roof and substructure.

At the beginning of structural analysis of buildings live loads and climatic actions given in standards were simply based on estimates bound to be improved by subsequent experience. Nowadays, thanks to remarkable progress in the field of the theory of safety for buildings the assessment of design loads can be based on comprehensible scientific procedures.

Usually a probabilistic model is applied to represent variable loads. Similar to other actions, e.g. actions due to wind, temperature or earthquake, the snow load on roofs varies not only with time but also in space (topographical position of the site). In the present research these two influences were treated separately. Firstly the variation of snow loads with time (usually a period of many years) was investigated at pre-defined places represented by the stations of observation. By applying extreme value statistics to these observations, a snow load was derived corresponding to a given probability of exceedence. Of course, the resulting snow load is valid only for this place.

To give reliable results, any statistical analysis has to be based on as much measured and thoroughly checked data as possible. Owing to the lack of an internationally agreed procedure for measuring the amount of snow, the data obtained form the 18 CEN member states were quite different. Detailed information on the database used is given in section 4.3.1.

Statistical analysis had to be performed on load values. Only a few countries offered water equivalent values (weight of the melted snow cover) which could be used directly. In other countries only depth measurements were available. They had to be transformed into loads by using appropriate densities (cf. 4.3.2).

The current discussion about global warming due to atmospheric pollution ("greenhouse effect") could raise some doubts if the findings reported in this document could serve as a forecast for the years to come. In the long run, a gradual increase of the average temperature could result in a reduction of the snow load on roofs, but on the other hand, this change of the climate could also provoke more extraordinary weather conditions causing higher snow loads.

Thus for the moment there is no convincing evidence either for a reduction or for an increase of the snow load so that in this research the meteorological causes of snow deposition have been considered to form a "steady state" process, at least during the time that records have been kept (usually between 20 and 40 winters, though at some stations for more than 90 winters). This means that within a series of years of observation every winter has the same weight.

Secondly the geographical distribution of snow was investigated. Among many local conditions influencing the amount of snow observed at a given place generally the altitude above sea level is the predominant one. This holds for most parts of Europe, but in some regions hardly any correlation was found between snow load and altitude. In these regions other effects may have a prevailing influence on the quantity of snow being deposited, e.g. the total amount of precipitation, mean air temperature, radiation or distance to the sea. In the framework of the present research only a simplified model focused on the influence of the altitude could be pursued. Within a distinct climatic region the snow load is considered to be a function of the altitude of the site, but affected by random deviations (including also topographical effects). This allows a mean altitude function to be defined for each climatic region, except for those regions with show a poor correlation with altitude (for these regions cf. section 5.5).

The result is given either by a map of the characteristic ground snow load itself or by a map defining zones which correspond to a certain deviation from the snow load given by the mean altitude function. In both cases a spatial model has to be applied to extend the information valid for the place of observation to a larger area, thus covering the entire surface of the participating countries of Europe. The method of spatial interpolation is described in section 5.1.

Chapters 4 and 5 give detailed background information on the procedure followed.

4. Ground Snow Loads

4.1 Introduction

In order to determine the dimensions of roof structures, the engineer needs the value of the snow load on the roof. Generally, this load is less than the snow load on the surrounding ground. Existing snow load codes (including ISO 4355 [3]) assume that the snow load on the roof - all other conditions kept constant - will be proportional to the snow load on the ground :

$$s_{k,roof} \quad = \quad s_{k,ground} \cdot f\left(C_e, C_t, \mu_i\right)$$

The function f (without dimension) may contain several influences (e.g. exposure (C_e), thermal transmission (C_t) or shape of the roof (μ_i)) and it may vary from one part of the roof to another, whereas, for a particular construction site, the characteristic snow load on the ground $s_{k,ground}$ is a constant value and must be given in the code on snow loads.

Phase I of this research programme is concerned especially with the snow load on the ground which is the most determining influence for the snow load on the roof.

Information on snow loads on the ground can be found in the national codes of European countries. Only a few adaptations have been made when these national regulations were transformed into the Annexes A1 to A18 of ENV 1991-2-3 [2].

This assembly of snow information applicable in different CEN member states encouraged comparative tests which revealed certain discrepancies along national boundaries. This is mainly due to the fact that the national regulations have been elaborated completely independently from one another. Many decisions concerning the procedure of measuring the amount of snow, the way of processing the data, the treatment of exceptional snow falls, the choice of an appropriate type of distribution or the accepted interval of recurrence had an influence on the resulting characteristic snow load on the ground. Since the snow load will not change at national borders, the differences arising from the present regulations indicate existing deficiencies leading to inadvertent discrepancies in the safety level.

By trying to develop a common course of action for assessing the snow load on the ground, the present research will improve the existing basis of design and also create a universally applicable tool for the practising engineer. The result of this work is presented in form of a map of Europe, allowing the design characteristic snow load at any place to be determined.

4.2 Characteristic Ground Snow Load

4.2.1 Definition of the characteristic snow load

A record of daily measurements of the existing snow layer at one particular place usually will show a series of irregular ups and downs during one winter season, reflecting the changing weather conditions. Using the annual maximum values, probabilistic analysis allows load levels (characteristic value of the load) to be defined having a certain probability of being exceeded in any one year which is directly associated to a certain mean recurrence interval (MRI). National codes have been based on different mean recurrence intervals of 5, 20 or 50 years, which affects the comparability of the design characteristic snow loads.

For this investigation the characteristic snow load was defined in accordance with the definition proposed by ENV 1991-1 Basis of Design [1] (c.f. section 4.2 (8)) for variable actions and also by ENV 1991-2-3 Snow Loads [2] (section 6). The characteristic value is the snow load which has a probability of only 0,02 of being exceeded within any one year. This corresponds to a MRI of 50 years.

4.2.2. Statistical Model

A very wide variety of global and local conditions may influence the amount and the weight of snow observed at a given site.

Globally, the snow load may depend on circumstances including

climatic region,
average amount of precipitation,
altitude of the site,
distance from the sea or from large lakes

These global influences will be modified by many actual conditions and processes, e.g.

temperature (of the air and of the ground),
average amount of precipitation,
wind (mean wind speed, site exposed or sheltered),
humidity of the air,
radiation, periods of sunshine
rain falling onto snow

In regions having a temperate climate of maritime character, the highest snow load is usually the result of one single snow event, caused by only one low pressure weather system. After a few days the snow usually has melted completely, so that any following snow event may be considered to be statistically independent from the first one.

In areas with a more continental type of climate and/or in mountainous regions, especially at higher altitude, we usually observe the formation of the snow layer by accumulation. The highest snow load will be registered after a series of snow falls, all of which contribute to the maximum snow load.

At present neither a mathematical model is known that would allow the development of the snow layer with time to be calculated nor are all the possible influences sufficiently documented to start such a calculation.

However, for interpolating daily water equivalents between observations with longer intervals, physical models have been used with success. Finland may be mentioned as an example, where water equivalents are recorded twice each month, and daily values are calculated by using models based on daily precipitation and air temperature data for interpolating [26].

For the present research, the snow load at a particular observation station is considered as a multidimensional stochastic variate and the values measured are realisations of this variate. Generally the analysis is based on daily recorded or derived load values. Only this load counts, irrespective of the fact that this value might be the result of either an accumulation or a single snow event.

Pre-determined by the definition of the characteristic value (cf. section 4.2.1) the analysis must not focus on the probability distribution of the daily values, but on the distribution of the maximum values related to a certain period of time. Unlike other climatic loads (wind or temperature) snow has a very clear seasonal rhythm. Therefore, a reference period of one year is particularly well suited for snow loads. Usually the beginning of this period was shifted from the 1st of October by several months in order to cover a whole winter season and to be sure that statistically independent periods were treated as far as possible.

Finally the analysis was based on annual maxima of the snow load on the ground. This sample containing one value per year of observation may be considered as belonging to an underlying extreme value distribution. The best fitting distribution describes the snow load on the ground at the place of observation and allows its characteristic value to be calculated.

There are other situations which the statistical model needs to take into account In southern and coastal areas the records often contain many years without any snow cover. In these cases a mixed distribution was used taking into account the average percentage of years with snow (cf. section 4.3.4). Also at some places the number of years with snow was too small to give reliable results. If these stations could not be discarded, the statistics were based on single snow events instead of years but applying an appropriate correction (cf. section 4.3.4).

Additionally the ENV Background document [4] identified the possibility that some recorded annual maximum values did not fit well with the remainder of the data set and that such values had an undue influence on the statistical processing. Identification and treatment of these exceptional snow loads are explained in section 4.3.6.

4.2.3 Summary of measurement techniques, source and availability of data and comparison of different methodologies adopted in each country for the determination of the characteristic snow load value

The soundest basis for assessing characteristic snow loads is long-term measurements of snow levels at a large number of stations in each country. Direct measurement of snow loads, or the corresponding water equivalent value of a given snow volume, would allow their characteristic values to be determined. However such measurements are difficult and laborious to obtain so that these values are recorded only in some countries and for selected stations. The total number and geographical spread of stations measuring water equivalent values provide insufficient records for them to be used alone as a statistical basis for determining snow load values throughout the countries of interest.

Thus it is necessary to augment available water equivalent data with snow load data derived from snow depth measurements. In order to introduce these registered snow depths into the records of snow load, they have to be transformed into water equivalents using an appropriate conversion factor. These loads are then be subject to statistical treatment to determine the appropriate characteristic snow load value for use in design.

This section summarises the availability of relevant data and compares the methodologies for the determination of characteristic snow loads in each of the participating countries prior to the start of this research.

Annex A.2 contains a short description of the sources and nature of snow data and their availability with each of the 18 CEN countries. This information is summarised in columns 2 and 3 of Table 4.1.

However in seeking to acquire national snow load data for this research, a number of practical problems needed to be solved, including:

- insufficient and incomplete snow data in some countries (measuring snow does not always belong to the standard data set for meteorological stations and gaps existed in apparently complete data records). Record lengths ranged from periods of 6 years upto 100 years.

- In some countries snow data are not only registered by the National Meteorological Offices but also by other organisations, such as the electrical power industries or airports

- Data had to be checked for gross errors ie transcriptional or incorrect units.

- For some countries the data were only available on paper and had to be transformed into electronic format

- Data from some countries' Meteorological Offices needed to be purchased. It was not possible within this contract to buy all the available snow, and supporting meteorological, data for each country. In these circumstances it was necessary to prioritise the required data to ensure adequate coverage over the country concerned with records of sufficient length and quality.

- Some countries eg Norway had undertaken snow loading investigations only a few years before this project and where those investigations were consistent with the aims and approach of this contract no re-elaboration of the basic data was sought [23].

Most countries measure snow depths at a consistent time of the day by ruler to the nearest centimetre. The registered value is usually the mean of a number of readings taken at the same time. It is possible for snow to fall but if the cover at the observation station is less than 0.5 cm it would be recorded as zero. Countries which experience more continuous and regular snowfall generally take readings separated by a number of days whereas those countries which experience irregular or infrequent snow falls usually take daily readings only when snow occurs. The UK has a particular problem with data sets which span from 1960's to the 1980's caused by a change in measurement from Imperial to Metric units in the 1970's. The discrimination in Imperial units was 0.5 inch which was changed to 0.5 cm on metrication. Thus the discrimination of measurements in a long record changes by a factor of approximately 2 and introduces additional uncertainty into those records. Portugal and the Netherlands do not register precise measurements but classify the observed depths by codes which relate to snow depth intervals - these are countries with irregular or infrequent snow falls.

Various models have been applied in the European countries in order to establish a relationship between snow load and snow depth for use in developing their national standards. Within the framework of the present research, the models used in each country have been investigated, compiled and compared. These are summarised in the fourth column of Table 4.1. Four different types of models were found follows:

- *Fixed value for the mean density of snow*. Several countries:- Belgium, Eire, France, Greece, Luxembourg and Netherlands, used a constant value of density for the transformation of observed snow depth into snow loads.

- *Density as a function of snow depth*. The compression of snow depends on the weight of the snow above, thus the mean density may be taken as an increasing function of the total snow depth. Often this relation is not established by using physical principles but by comparing extreme values of the water equivalent to those of the snow depth, measured at the same station and during the same winter. Such an empirical relationship includes statistical elements because the extreme values may not have occurred on the same day. Consequently the term of 'mean density' should be replaced by snow load factor. Snow load factors as a function of the snow depth were used in Iceland and Germany.

- *Density as a function of the place of observation*. In Sweden, Spain and Austria the mean density of snow was correlated to the place of observation. In Sweden constant values were used in different regions of the country and in Spain (where a dependence with time is also considered, see below) and Austria the mean density applied increased with the altitude of the station.

- *Density as a function of time*. In more recent national investigations account has been taken of the fact that where snowfalls result in accumulations of snow on the ground for long periods, eg at higher altitudes, the density of snow tends to increase through the winter period. The transformation of a measured snow depth into a load was made using a higher density if the extreme snow depth value was observed at the end and not at the beginning of a winter. Time dependent densities were used in Italy, Portugal, Spain, Norway and Switzerland.

Table 4.1 : Summary of available snow data and analysis basis of National Standards.

	Available snow data		Method of analysis forming basis of National Standard				
	Snow depth	**Density/Water Equivalent**	**Snow depth to snow load (values are kg/m3)**	**Data analysis**	**MRI**	**Regionalisation**	**Comments**
Switzerland	In 'non-alpine' regions snow depth is measured twice a day	Alpine stations - direct WE	100 - for the new-fallen snow; 200 - for snow after several hours or days since snowfall; 300 - at max snow load; 350 - old snow (after weeks or months since snowfall); 400 - wet snow	Snow depths converted to WE or WE directly; Annual maxima fitted to Gumbel distribution	50	5 zones defined by altitude - each zone has reference altitude for use in ground snow load formula.	Results from previous analyses available
Italy	Daily snow depth data in archive. Summarised data published for every tenth day(up to 1971) and now monthly	Mixture of daily water equivalent of fresh snow and of total snow depth	For low altitude: 250; For high altitude time-dependent relation: 217 - 315 initial density value; 315 mean density value in the constant period of the winter; 315 - 529 increasing density value at the melting period	Snow depths converted to snow loads and annual maxima fitted to a Gumbel distribution. Mixed distribution for zero-values also considered	50	Three national snow load zones each with its own altitude correction.	Daily data required for analysis of stations at low altitude + plus new density function for short period snow accumulation
Spain	Data available for 81 mainland and 3 island stations.	Daily WE data available for 1046 stations when minimum temperature below 0C at thermo-pluviometric stations	326 - 1500 m to 2000 m altitude; 266 - 1000 m to 1500 m altitude; 200 - 800 m to 1000 m altitude; 150 - altitude less than 800 m		50	4 Zones in each of which snow load varies with altitude; Applicable to altitudes less than 2000m	300 WE stations were considered because more significant.
Portugal	Daily observations in 112 mainland stations and 25 island stations	No relevant measurements available	No indication available	No indication available	50	12 Regions specified, only altitude greater than 200m in these regions need to be considered	79 stations were considered because more significant
Greece	Daily **fresh** snow depth with record periods 20+ years	Daily water equivalent of **fresh** snow fall	125	Analysis combined fresh snow depths from consecutive days (maximum of 5 days) and fitted annual maxima to a Gumbel distribution	50	Map in ENV1991-2-3	Data analysed mainly from high altitude stations. Few data at low altitude
Norway	Daily snow depth data from as early as 1895.	Some water equivalent data for the period 1899-1931. Other data	300 - for annual maximum snow.	Annual maximum snow depths fitted to a Gumbel distribution for 551 sites.	5 / 20	Snow loads listed for individual municipalities	Re-analyses use various snow densities depending on month, from 225 to 325kg/m3

		from hydrological studies					[23]
	Available snow data		**Method of analysis forming basis of National Standard**				
	Snow depth	**Density/Water Equivalent**	**Snow depth to snow load (values are kg/m3)**	**Data analysis**	**MRI**	**Regionalisation**	**Comments**
Sweden	Daily snow depth data from as early as 1907.	Some water equivalent data may be available from 1978 + data for the period 1909-25	230 -Norrland to Dalsland region (partly mountainous); 280 - for Götaland's coast, Gotland and Öland (islands); 240 - for remaining parts of Sweden	Annual maximum snow depths multiplied by the appropriate density were fitted to a Gumbel distribution for 40 stations	50	Map of Sweden showing snow load zones	Data re-analysed and map produced 1995 [29], [30].
Finland	Daily snow depth data from 1921	Water equivalent data available from 1951.	Direct measurements of water equivalent, » 250	Annual maximum water equivalents were fitted to a Gumbel distribution for 105 stations	50	Map of Finland showing snow load contours	Data re-analysed and map proposed 1997. Replaces map in annex A of ENV 1991-2-3
Iceland	Snow depths on a routine basis, normally every day.	Measurements to yield density expression?	Not decided	Annual maximum water equivalents fitted to a Gumbel distribution for 121 stations	50	Map in ENV 1991-2-3; 4 zones - 3 with specified loads; 1 with 'special conditions'	Densities 400-500 kg/m3 used by the research group
Denmark	Snow depth data at 7 synoptic stations 1971-79. Earlier data at climate stations 1938	Daily water equivalent data for single station for the period 1971-80	Canadian snow pack model of Leaf/Brink, 200 - for naturally packed snow	Analysis considered single snow pack maxima as well as annual maxima, fitted to Weibull distribution	50	Single snow load value for whole country = 1.0kN/m2	Analysis carried out using data up to 1979/80 data now lost..
Germany	Daily snow depth data for 311 stations in western Germany Periods: 1950-1983) and 23 stations in eastern Germany (Period: 1947 -1993) Some gaps in the records.	WE measurements (3 times per week, not regularly) dating from 1951 are available.	Conversion using average snow density of 215kg/m3 though snow load factor was assumed to vary with snow depth.	Analysis of annual maximum snow depths for 1821 stations with 30+ years of data fitted to Gumbel PDF. Snow density function based on snow depth simplified to single value for code	20	Four national snow load zones each with its own altitude correction	Snow loads in annex A of ENV1991-2-3 have been converted to 50-year snow loads (ie 98% fractile). Data for E. Germany analysed in 1991
Austria	Daily snow depth data with records ranging from 30-50 years on database	Precipitation as snow, but snow water equivalent not measured directly	250-300 altitude less than 1500 m above the sea level; 350 altitude greater than 1500 m above sea level		50	Four national snow load zones, each with its own altitude correction. Additional loads to be considered in areas subject to "orographic" lifting	

	Available snow data		Method of analysis forming basis of National Standard				
	Snow depth	**Density/Water Equivalent**	**Snow depth to snow load (values are kg/m3)**	**Data analysis**	**MRI**	**Regionalisation**	**Comments**
Netherlands	Daily snow data from at least 1961 on database. Snow depth classified according to range of snow depth values with cut points (ie 1,2,5,10cm...)	Not specified	100	Analysis of annual maxima snow depth code to estimate 50-year snow depths	50	Single snow load value for whole country = 0.7kN/m2	
Luxembourg	Daily snow depth data dating from 1949 in manuscript form.	Not specified	150			Single snow load value for whole country = 0.5kN/m2	Snow loads in annex A of ENV1991-2-3 are the same as those for Belgium
France	Daily and 3-hourly snow depth data dating from 1949 on database	Not specified	150	Annual maximum snow depth data re-analysed in 1996 using Gumbel distribution + binomial law for stations with 0-values. Exceptional values removed	50	Four snow load zones specified according to municipal districts and give basic snow load as well as an accidental snow load	Data re-analysed in 1996.
Belgium	Snow depth data dating from 1985 on database. Earlier data (details not specified) analysed in 1967	Not specified	150	Snow depth data analysed in 1967 but no details currently available	50	Single snow load value for whole country = 0.5kN/m2	
UK	Daily snow depth data dating from 1958/59 on database (from 1946/47 in archives)	Daily water equivalent data dating from 1963/64 in archives	150	Crude analysis of annual maxima for very limited number of stations. Regional data fitted to Gumbel distribution	50	Map of UK showing load contours for basic snow load on the ground. Single snow load altitude relationship	
Eire	Daily snow depth data dating from 1940's and 50's on database	No water equivalent data	150	Annual maxima fitted to generalized Pareto distribution	50	Map of Eire showing load contours similar to UK	

As can be seen from Table 4.1 there are differences in both the methods adopted to define mean densities (snow load factors) and the resulting values used in national investigations, ranging from 140 kg/m³ up to 400 kg/m³. Opportunities for harmonisation of these snow load factors were explored and where possible they have been incorporated in the approach discussed in section 4.3.2. However differences are inevitable since they result more from variations in the climatic conditions throughout Europe than from different methods of modelling the snow cover.

Having established a record of ground snow load values at meteorological stations the next step is the determination of the characteristic value of the snow load. However, as seen from the data availability in Table 4.1, the length of observational records is generally insufficient to assess the accuracy of various model probability distributions that might be fitted, and it is necessary to use extreme value statistical theory as explained in section 4.2.2. This leads to extreme value analysis being used in all 18 countries as the basis for deriving the characteristic snow load.

The value of the Mean Recurrence Interval (= 50 years) to be used within this project was given in Section 4.2.1. However as seen from the sixth column of Table 4.1 not all of the countries' National Standards have adopted this value. For example, the German Standard defines an MRI of 20 years, and in Norway a 5 year MRI is generally stipulated though their code does require a MRI of at least 20 years to be used under certain conditions.

As stated in section 4.2.2 the data analysis approach favoured in most of the countries is to adopt extreme value analysis using absolute annual maximum values of the registered snow loads. In so doing it is preferable, if not essential, to utilise only those stations having records covering a minimum total number of winters of the order of 40 to 50. Record lengths of less than 20 years are unlikely to give sufficient confidence if used to estimate 50 year MRI snow loads.

However in some countries, particularly coastal and southern Europe e.g. UK, Denmark, France, Spain, Portugal, Italy, and Greece, snowfalls do not occur every year. Thus the resulting annual snow load records contain both non-zero and zero values and the influence of the zero values, or no snow years, needs to be properly taken into account. In these cases the analysis has assumed the combination of two probabilities - one arising from an extreme value distribution (of the non-zero values), the other a probability of a year without snow. In France, Greece, Italy, Portugal, Spain, and UK, the statistical processing takes account of these zero years (see section 4.3.5) by modifying the probability of exceedence.

In Denmark [24] a different approach was adopted in recognition of the fact that snowfalls usually occur as discrete events with the snow completely melting between such events. There were years with a small number of events or without snowfall. Consequently an approach utilising the maximum snow load in events rather than per year was used. Extreme values were calculated assuming three types of extreme events:

- Accumulated water equivalent for a given snow event exceeded a specified value at some time during the event,
- One snow event in a year produces water equivalent values exceeding a stipulated value at a specified measuring site
- One snow event in a year produces water equivalent values exceeding a stipulated value considering all the measuring sites in the country.

Weibull distributions were used for the extreme value distributions and a Poisson distribution for the number of snow events in a year. However a 50 year MRI was retained.

At the time of this project the UK was in the process of applying a similar event-based methodology to the re-evaluation of its characteristic ground snow loads though using the Gumbel distribution coupled with the average number of events per year (see section 4.3.4).

In some regions of Southern Europe the annual maximum values contain one or two very large values which did not fit the distribution calculated without these values. Consequently in France the characteristic snow loads were determined with these high values excluded and in Greece areas where the observed loads did not fit expected snow load-altitude relationships are designated as 'Special Zones'. In France these excluded high load values were re-introduced into the design process by including accidental load cases derived from them. In Greece the designer was referred to 'specialist advice', for these Special Zones.

Column5 Table 4.1 summarises the analytical methods used in the development of national standards. As stated earlier the majority of national investigations defined the Gumbel (also known as the Fisher-Tippet Type I) extreme value distribution to fit their data best. However a few national investigations used different distributions: Weibull and Log Normal (Denmark, and Germany) and Pareto (Eire).

The national data processing on snow loads is not sufficiently well documented to show clearly the way of determining the parameters of the best fitting distribution. In most cases the best fit was assumed to have been made by the least squares method (LSM) but in some instances other methods such as the method of moments or the method of maximum likelihood may have been used.

To conclude this section the methodology for determining the characteristic snow load generally adopted in the 18 countries can be summarised as follows:

- Record either snow depth measurements and convert into snow loads by multiplication with an appropriate density or snow load factor, or water equivalent values directly.

- Extract Annual or Event maximum values from the snow load data records and rank in increasing magnitude.

- Fit an appropriate statistical extreme value distribution and determine the parameters of this distribution taking account of any exceptional or zero snow years.

- Calculate the probability corresponding to the required Mean Recurrence Interval, as seen earlier usually 50 years, and use this to determine the corresponding characteristic value of snow load from the distribution.

4.3 Snow data analysis (calculation)

4.3.1 Database - Available data - Measurements, climatic stations

The following table summarises the data collected by the project partners for treatment using the harmonised statistical method described in the subsequent sections. The table shows the number of stations for which data was obtained in each country (after elimination of data for dubious stations) and the minimum and maximum number of years of data among the stations for each country. Also given in the table is an indicator (D/W) for whether the countries used depth measurements, or water equivalents in deriving snow load values, or both:

Country	No. of stations	Min. no. of yrs data	Max. no. of yrs data	Depth - D Water Eq.-W
Austria	160	28	50	D
Belgium	13	11	31	D
Denmark	-	-	-	-
Eire	14	30	58	D
Finland	172	33	33	D+W
France	127	23	48	D
Germany	331	4	101	D+W
Greece	158	4	36	W
Iceland	121	5	73	D
Italy	99	13	50	D
Luxembourg	1	12	12	D
Netherlands	15	7	36	D
Norway	544	10	50	D
Portugal	104	4	34	D
Spain	300	23	86	W
Sweden	40	52	85	D
Switzerland	168	8	61	W+D
United Kingdom	235	12	47	D

Table 4.2 Summary of contents of the harmonised database for the 18 countries

From the table we see that the number of stations for which useful data was found ranges from 1 in the case of Luxembourg to over 500 in the case of Norway. The total number of stations is 2577. The number of years in the time series ranges from a minimum of 4 to a maximum of 101 for the station Potsdam (OBS) in Germany. The majority of countries used snow depth measurements (or estimates) while four countries used both snow depth and water equivalents.

4.3.2 Model for density of the snow

As already stated the majority of meteorological stations in the CEN member countries measure the depth of snow cover. Only in some countries (Germany, Finland, Switzerland, partially UK) the water equivalent is measured directly. Therefore the participants of the research group had to define what models for conversion of snow depth data into snow load (i.e. models of snow density) should be used.

The exact mathematical description of snow density is very complicated because it depends on many factors and varies among different climatic zones and geographical regions. Each CEN member used for their structural code their own traditional simplified model. Some of these are constant values and some are a function of snow depth or time. The whole list of these models can be seen in section 4.2.3 and in Annex A2. For some countries these historical models were also used in the current work but for some countries new models were elaborated and applied for the conversion of snow depth data.

For example in Norway the snow density depends on time. The values vary from 225 kg/m^3 (December) to 325 kg/m^3 (May) [23]. Therefore the annual maximum of snow depth is multiplied by the corresponding value of density taking into account the time when this maximum snow depth occurred.

For Iceland the research group has converted snow depths into snow loads on the basis of a relation between snow depths and densities varying between 400 and 500 kg/m^3 indicated in a report from Icelandic Meteorological Institute [25].

For Spain and Portugal the research group used the values of snow density recently established by Spanish National Meteorological Office. This approach is similar to that used in Norway:

- for altitude $H < 1500$m the values vary from 100 kg/m^3 (October) to 500 kg/m^3 (April)
- for altitude $1000\text{m} \leq H \leq 1500$m the values vary from 100 kg/m^3 to 270 kg/m^3 for a duration of between 1 and 20 days
- for altitude $H < 1000$m the values vary from 100 kg/m^3 to 200 kg/m^3 for a duration of between 1 and 20 days.

Table 4.3 Models for snow density in different CEN countries used in the present research

No.	CEN member	Density (kg/m^3)
1	Austria	250-300 altitude less than 1500 m above the sea level 350 altitude greater than 1500 m above sea level
2	Belgium	150
3	Denmark	Canadian snow pack model of Leaf/Brink, 200 - for naturally packed snow
4	Finland	Direct measurements of water equivalent, ≈ 250
5	France	150
6	Germany	Snow load factor of German Meteorological Office (DWD) $D = 159.81 + 129.82\, h - 81.09\, h^2 + 59.907\, h^3 - 20.652\, h^4$ for $h < 1.53$ m $D = 270$ for $h \geq 1.53$ m
7	Greece	125
8	Ireland	156.82
9	Iceland	The research group has converted depths to snow loads on the basis of a relation between snow depths and densities varying between 400 and 500 kg/m^3 indicated in a report from the Icelandic Meteorological Institute.
10	Italy	For low altitude: 250 For high altitude time-dependent model is used: 215 - 315 initial density value 315 mean density value in the constant period of the winter 315 - 515 increasing density value at the melting period
11	Luxembourg	150
12	Netherlands	100
13	Norway	225 - 325 for maximum depth occurring in December to May
14	Portugal	no data Spanish data assumed
15	Spain	During the period of maximum snow load: 100 ÷ 500 - for altitude from 1500 to 2000 m 100 ÷ 270 - for altitude from 1000 m to 1500 m 100 ÷ 200 - for altitude from 800 m to 1000 m
16	Sweden	Different values for different parts of country: 230 - for Norrland to Dalsland (Internal, partly mountainous) 280 - for Götaland's coast, Gotland and Öland (islands) 240 - for remaining parts of Sweden
17	Switzerland	100 - for the new-fallen snow 200 - for snow after several hours or days since snowfall 300 - average value at maximum snow load 350 - old snow (after weeks or months since snowfall) 400 - wet snow
18	UK	156.82

4.3.3 Type of probability distribution functions

The process of accumulation and depletion of snow on the ground is complex and depends on many factors (temperature, prevailing wind, humidity, exposure to the sun, geographical surrounding etc). According to the climatic conditions the processes of snow accumulation and depletion can be divided into two basic groups. In a continental (and/or mountainous) climate (above 1000 to 1500 m a.s.l.) the snow accumulates steadily until late winter or early spring and then melts in a relatively short period. The maximum snow load normally occurs in the late winter. In other climates the snow cover is intermittent during the winter. Thus the winter snow load maximum can be achieved through a single snow fall. In some winters there may be no snow at all. In temperate climates the process of snow accumulation and depletion is a combination of these two types.

The occurrence of snowfalls, the duration and intensity of snow loads have a random nature. Therefore investigations of snow should be undertaken on a stochastic basis. To describe the problem exactly, time-dependent processes are needed (see for example [5]). But according to the design philosophy of Eurocodes (for the Ultimate Limit State) the European Snow Map represents only extreme values of snow load, namely values with return period of 50 years. Because the annual maxima of snow load can be considered as stochastically independent variables, the value of return period automatically sets the probability of not being exceeded during one year. Then the characteristic value is defined as the fractile of this probability.

The result of this approach (i.e. characteristic value of snow load) is very sensitive to the choice of the probability distribution function (PDF) used for fitting the statistical data (annual maxima of snow load). Which PDF fits the data best depends primarily on the climatic and geographical conditions at the meteorological station. But the statistical parameters (e.g. size of the random sample) can also play a role.

Different proposals can be found in the research literature. A US investigation [6] shows that the log-normal distribution fits the observed values of the annual maximum snow load better than any other extreme value distribution for most of their weather stations. In [6] it is pointed out, however, that the type of PDF is geographically and climatically dependent. Use of the log-normal distribution is also recommended in [7]. In [8] the snow depth and snow density were considered as mutually independent, random events. Then the 50 year Mean Recurrence Interval (MRI) value of snow load was calculated by means of the Pearson distribution. It was noted that the log-normal distribution also fits the data well but gives a larger characteristic value of snow load.

German snow depth measurements were considered in the research report [9]. The results of this work are summarised as follows: for 60% of all stations the gamma distribution is the best fitting PDF, in second place - the log-normal distribution; only small number of climatic stations have Gumbel or normal distributions as the best fitting PDF. The recommendation to use the gamma distribution for snow loads was later incorporated in the documents [5] and [10]. It seems reasonable to make some comments about the results in [9]:

- The choice of PDF was based only on the Likelihood Probability criterion. The PDF which gives the maximum Likelihood Probability for a given sample is declared as the best fitting one.
- The choice of PDF is sensitive to method of determination of parameters of the PDF. [9] does not state what method was used for the determination of the parameters of the PDF. One can only suppose that it was the Maximum-Likelihood criterion.
- Only snow depth was considered in [9], but the gamma distribution is recommended for the definition of snow load [5, 10], although the conversion of snow depth into snow loads is very complex and depends on some parameters. For Germany, snow density is not a constant (see section 4.3.2) and therefore the best fitting PDF for the depth is not necessarily the best fitting one for the load.
- The results in [9] are based only on West German data, but the recommendation for using the gamma distribution [5, 10] was made for the whole world.

The main disadvantage of using the gamma distribution is that it does not have a theoretical PDF. The calculation of probability and fractiles (and also the probability plot) is possible only by means of numerical integration. Prof. Rackwitz points this out in his recent work [11] and proposes the use of the Gumbel distribution instead of the gamma distribution for rough calculations because Gumbel is the asymptotic extreme value distribution for the gamma distribution.

The latest investigation in Russia uses only the extreme value distribution type I (Gumbel) [12], but it is necessary to note that in Russia a very continental climate dominates. In [13] the Japanese snow data were considered; the extreme value distribution Type I, Type III and log-normal were found to be the most applicable PDFs in Japan.

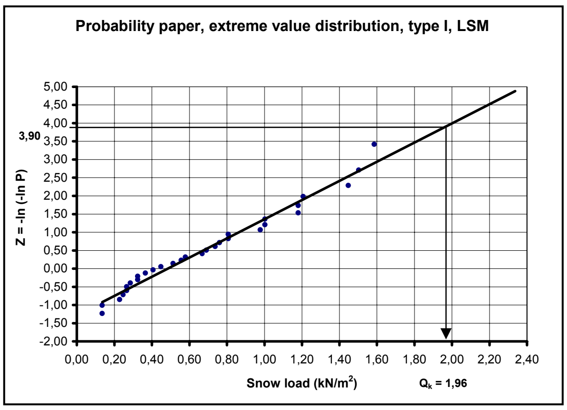
In the current work the detailed statistical investigation of the meteorological station Adelmannsfelden (Germany) was undertaken as a first step. This was done before the water equivalent data were acquired from the German Meteorological Office (DWD). Thus the snow depth measurements were used. Data were converted into snow load according to the load factor of the DWD. The period of measurements was from 1935 to 1968 (a total of 30 winters). The station is located in Baden-Würtemberg at an altitude of 470 m.

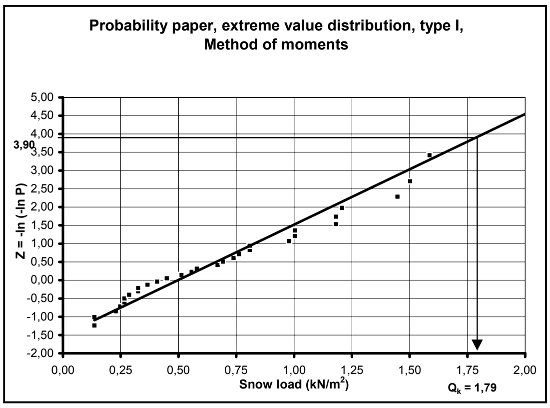
Five different PDFs were considered as candidates for the best fitting distribution:

- Extreme value distribution Type I for maximum (Gumbel)
- Extreme value distribution Type II for maximum
- Weibull (extreme value distribution Type III for minima)
- Log-normal distribution
- Normal distribution

The Maximum-Likelihood criterion for the determination of the distribution's parameters was not applied in this work because for most types of PDF, excluding the Normal one, the use of this criterion leads to the necessity of solving a system of two non-linear equations for each climatic station. This was not reasonable for many hundreds of stations across Europe. Application of the Least Squares Method (LSM) or moment's method makes the calculations both easier and quicker.
One can see for example from the probability plot for the Type I distribution that the line with the parameters of the PDF defined by LSM fits the data better than the line with the parameters of the PDF defined by the moment's method. Moreover, the second line gives the smaller 50 year MRI value i.e. gives a smaller estimate of the characteristic value of snow load (see Fig. 4.1).

Fig. 4.1: Probability plots for extreme value distribution Type I





Therefore, it was decided to use for further investigation only the LSM to obtain the uniform results across the Europe. The results for all five PDFs can be seen in the Table 4.4.

Table 4.4: Comparison of different distribution

N	Type of distribution	Value of snow load with return period (kN/m^2)				Coefficient of Correlation	Likelihood Probability Parameters based on LSM
		50 years		100 years			
		Least Squares Method	Method of Moments	Least Squares Method	Method of Moments		
1	Extreme value distribution, Type I, for maximum	1.96	1.79	2.23	2.02	0.9885	$3.4 \cdot 10^{-7}$
2	Log-normal distribution	2.72	1.88	3.36	2.19	0.9856	$7.3 \cdot 10^{-7}$
3	Weibull distribution	1.83	1.75	2.03	1.92	0.9862	$16.1 \cdot 10^{-7}$
4	Extreme value distribution, Type II, for maximum	5.00	1.79	7.88	2.23	0.9468	$0.5 \cdot 10^{-7}$
5	Normal distribution	1.67	1.56	1.79	1.68	0.9723	$0.5 \cdot 10^{-7}$

Two criteria for the choice of PDF are used in this table:

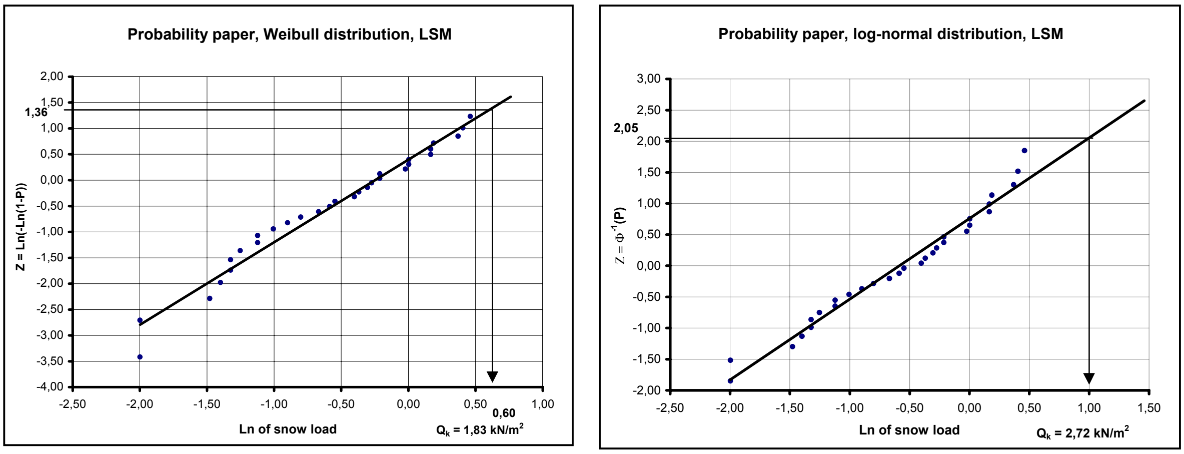
- Coefficient of correlation between reduced variable (according to probability paper) and the original values of snow load sample (or logarithm of snow load). The larger this coefficient (in the ideal case it would be equal to 1) the better the PDF fits the data.
- Likelihood probability. The larger the likelihood probability the better the PDF fits the original data (n.b. this criterion is used very seldom but we follow the work [9]).

According to both criteria only three PDFs can be considered possible for fitting to the snow load data:

- Extreme value distribution Type I for maximum (Gumbel)
- Log-normal distribution
- Weibull (extreme value distribution Type III for minima)

If Likelihood Probability is applied then Weibull is in first place. If Coefficient of Correlation is used then Gumbel is in first place, Weibull - second and Log-normal third. But the difference in the coefficient of correlation between all three PDF's is very small. It is confirmed by consideration of the probability plots (see Fig. 4.1 and 4.2). Therefore, it was decided to use for calculations only the first criterion, coefficient of correlation, because this is more objective.

Fig 4.2: Probability plots for Weibull and log-normal distributions



If we consider the Structural Design Codes of 18 CEN countries,(cf section 4.2.3) we find that almost all of the CEN members use the Gumbel PDF (extreme value distribution Type I for maximum), excluding Denmark where the Weibull PDF is applied. To define which PDF's fit better the climatic data in different European regions, is one of the purposes of the current research. It is found from investigations in some countries (for example Italy) that Gumbel is really the best fitting PDF and it was agreed that this distribution would be used for the calculation of the characteristic values of snow loads in whole Europe to obtain the homogenous European Snow Map. However it was also established that in some geographical regions (or countries) the best-fitting PDF can deviate from Gumbel. Germany and Switzerland can be considered as examples of this effect.

4.3.4 Individual event and mixed distribution approaches for irregular snowfalls

As noted in section 4.2.3 some countries: UK, Denmark, Spain, Portugal, France, Italy and Greece experience intermittent, irregular or short duration snowfalls, in contrast to continental and alpine Europe, where more continuous and longer lying periods of snow result. These intermittent or irregular snowfalls are typified generally by the snow melting completely between successive snowfalls so that no residual accumulation of snow results on the ground.

Snow depth records may contain significant gaps at some stations for complete winter seasons because either there was no snowfall at all, or where snow had occurred but was not registered because its depth was less than a measurement threshold. Thus there will be ‘snowless winters’ or ‘zero-snow years’. This generally results in shorter and less populated data sets on which to carry out statistical processing. Thus statistical techniques for determining characteristic snow load values for regions with long-duration snow cover are not appropriate for regions with irregular snowfalls.

This leads to a working definition of irregular snowloads, viz:

> Infrequent and usually short duration snow falls resulting in loads which may have long periods, sometimes years, between their occurrence.

Two principal options are available for the analysis of data sets which exhibit a significant number of ‘zero-snow’ years or where there are short data records. These approaches:- a mixed distribution approach and an event-based maxima approach, are outlined in the following.

Mixed Distribution approach.

Irregular snowloads have been treated, eg. in France, using mixed distributions combining the probability of occurrence of snow within a winter (P_{snow}) with the probability of not exceeding a given value of snow load, s_k ,when there is snow on the ground during a snow-winter. For the latter annual snow maxima are used.

The probability for the snow load not to exceed a given value, s_k , is given by:

$$F\ (X<s_k) = P_{snow} * F_{snow}(X<s_k) + (1 - P_{snow})$$

If the total number of years of observations is N and the total number of years with recorded snow load is n, then the probability of a year having snow $P_{snow} = n/N$.

To estimate the extreme value distribution function F_{snow}, a Gumbel (ie Type I) distribution is fitted to the cumulative distribution of non-zero maximum snow load s_k.

Thus the probability that the load will exceed s_k (ie $F(X>s_k)) = 1 - F(X<s_k)$. If this is equivalent to a 50 year MRI, ie $P_{snow} = 0.98$, then the snow load having a probability of exceedence in any one year of 0.02 is deduced by the relations:

$$F_{snow}\ (X<s_k) = \{0.98 - (1 - P_{snow})\}/\ P_{snow}\ \text{, and}$$

$$s_k = \{-\ln(-\ln(1 - 0.02/P_{snow}))/\ c\} + u$$

where c and u are the parameters characterising the Gumbel distribution.

This approach is similar to that proposed by Thom [14] but fitting the non-zero snow depth values to a Gumbel distribution instead of a Log-normal distribution. The approach is summarised in the following:

A) Extract annual maximum snow load values, including zero, values. Rank non-zero values in order and note the number of 'zero- snow' years.

B) Determine the plotting position for non-zero annual maxima based only on the total number of non-zero years. Plot the ranked non-zero values.

C) Fit a Gumbel distribution to the 'non-zero' values and determine c and u.

D) Determine the 50 year MRI value by taking account of the probabilities of a year with and without snow. Using Gumbel this is expressed as:

$Z = -ln(-ln((0.98-q)/p))$ Where q= no snow probability ie 1 - n/N
and p= snow probability = n/N
N= Record Length
n= total number of non-zero snow years
Z= Reduced Variate

Event-based maxima approach.

The basis for the method outlined here is the analysis of extreme wind speed data by Mayne and Cook [15] in which data sets are augmented by using maximum wind speeds from individual storms instead of annual maxima. In maritime regions snow falls are separated by periods during which snow melts and disappears completely and therefore extreme loads are generated from single snow events. Thus the analogy with wind storm events.

The use of independent event maxima makes most efficient use of the data since it does not automatically discard values which are less than the maxima within any particular year. The method does not specifically identify annual maxima nor 'zero-snow' years. However for design it is necessary to express the characteristic value obtained as the probability of excedence in any one year to ensure consistency with annual maxima approach. This is done by defining the average number of snow events per year which implicitly takes into account the occurrence of years with no snow. It therefore offers an attractive alternative method of analysing short non-zero annual maxima record lengths providing that the event data are available.

Since events rather than annual maxima are being considered it is necessary to reflect this in the statistical processing of independent extremes. We seek the probability that all of the observations of a given variate in a given period are less than a specified value. If there are m such observations then the probability that all such observations are less than x is $P^m(x)$. This is the same as the probability that the largest among m independent observations is less than x. Thus the cumulative distribution function of the extreme value distribution is the cumulative distribution of the parent distribution raised to the power of the sample size. A fuller explanation of this is given in Cook [22]. The sample size in our case is the average number of events in the year and the reduced variate in the Gumbel distribution needs to be raised to this power (see step B later on).

In the application of this method it is important to ensure that the events are inspected for statistical independence. For multiple events occurring very close together in time it may be necessary to treat them as a single event and retain only the largest value of the aggregated events.

The procedure is broadly similar to that using annual maxima and is summarised as follows:

A) Extract and rank in order independent snow event maxima above a selected measurement threshold (eg. 0.5 cm depth or corresponding load equivalent).

B) Determine the plotting position for these events based on the total number of snow events (n) and the total length of record (N):

$$Z = -ln(-ln\ ((m/n+1)^{\ n/N}))$$

C) Fit Gumbel to the tail of the distribution ie to the right of the mode.

D) Determine the 50 year MRI from $Z = -ln(-ln(0.98))$

n.b. For steps B) and D) an alternative procedure can be used:

B) Determine the plotting position for these events:

$$Z = -ln(-ln\ (m/n+1))$$

D) Determine the 50 year MRI from $Z = -ln(-ln(\ P\ ))$, where

$$P = 1 - N / (50 \cdot n)$$

4.3.5 Exceptional ground snow loads - definition, identification

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. This leads to the the definition of exceptional snowloads used in this research, viz:

> Isolated and very infrequent snowfalls where the resulting snow load is significantly greater than the loads in the general body of snow load data and its inclusion in that data set distorts the statistical analysis.

A prime example of exceptional snowfall is Perpignan, France, where a snow depth of 85cm was recorded in 1954 compared with the next largest snow depth value of 46cm. The effects of including this high value in the distribution and on subsequent analysis are discussed in the New European Code for Snow Loads background document [4].

Figure 4.3 illustrates a typical extreme value plot in which a high value appears. It is important that the authenticity of that value is established by screening the raw data for gross errors, seeking comparison with data values recorded at neighbouring stations or taking meteorological advice from the competent meteorological authority. Some such values found during elaboration of UK snow load data were shown to be gross errors by this process.

Assuming that the authenticity of the high value is confirmed, is the value part of the same population as the main body of snow data for that station or is it from a different population?

Evidence for being part of a different population would need to be sought from meteorological considerations. The fact that it is a higher value than the remainder of the observed values is insufficient to make that decision. The value could be part of the same population and simply be the early occurrence of a snowfall with a very long MRI ie. a large valued member of the population that has occurred in the early part of the data record. It should be remembered that a 100 year MRI value does not mean that 100 years will elapse before it occurs or that it will occur regularly at approximately 100 years. Given a very long data record it will occurr on average once every 100 years, but only when data has been collected for thousands of years will this be evident!

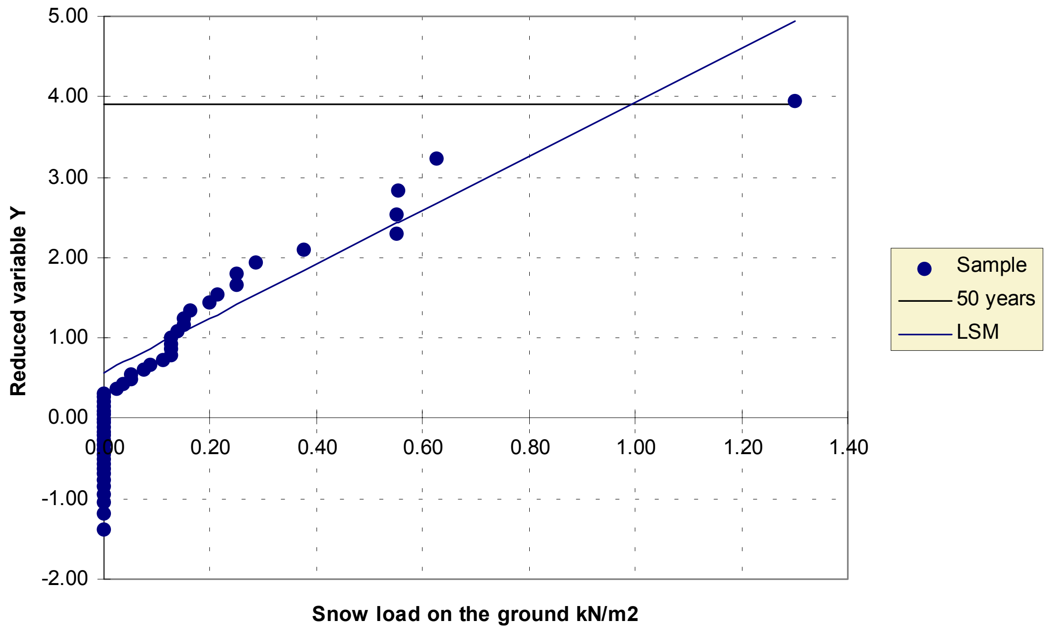


Figure 4.3 Extreme value plot in which a high value appears (Pistoia, 58 m a.s.l. - Italy)

If the value is a member of the population then if data collection, and evaluation, continues well into the future, and the process is stationary, values would appear between the largest and next largest values in the above plot and within the main body of data. Of course the plotting position, and hence the determination of the parameters of the extreme value distribution, will change with the increase in data points but the largest value will tend to move further away from the origin along the reduced variate axis, ie. closer to the best fit line and its influence on the corresponding parameters will diminish. Eventually this largest value may be moved sufficiently that it no longer would be regarded as exceptional and therefore no longer excluded from the statistical analysis. At that time its effect on the determination of the distribution parameters would be insignificant and indeed little different from continuing to neglect it. Mayne and Cook [15] illustrate this by showing what happens to a single high value as the sample size is increased progressively by factors of two, three and four.

In the absence of this 'future' data and recognising the length of records that would be required what do we do now? If high values cannot be excluded from the populations through physical or meteorological reasoning then we must conclude that they should remain. However the argument in the previous paragraph supports the approach to exclude the point and determine the distribution parameters from the main body of extreme value data.

The next section considers the criteria for identifying exceptional ground snow loads and how they are accounted for in the analysis.

4.3.6 Treatment of exceptional ground snow loads

The definition of exceptional snow loads in the previous section was descriptive, it does not provide the quantitative information necessary to classify types of snow loads prior to undertaking an analysis of snow data. Moreover as seen from Fig 4.3 values that might be regarded as exceptional can only be identified by examination of the annual or event maxima plots for each station according to the methods outlined earlier in section 4.

What is needed is an objective criteria against which specific values can be compared to determine whether they should be included or excluded from the characteristic snow load calculation procedure. The 1996 revision of the French Code of Practice N84 took into account exceptional snow loads according to the following criteria derived from snow depths:

$$(H_{50X} - H_{50})/ H_{50X} > 0.5 \quad \text{and} \quad H_{max} > 1.50H_{50}$$

H_{50X} is the 50yr MRI value with the maximum value of snow depth **included**,
H_{50} is the 50yr MRI value with the maximum value of snow depth **excluded,**
H_{max} is the maximum value of snow depth, and
1.50 is a factor deduced from the safety factors in the French structural design codes.

None of the codes of practice of the other 17 countries include such a criterion.

The criteria above suggested that a generalised criterion might take the form

$$s_m = k \cdot s_k \tag{1}$$

where: s_m is the largest snow load registered,
s_k is the characteristic value determined by excluding the largest value, and
k is a constant coefficient

Initially a ‘working’ value of k =1.5 was chosen based on the French approach reinforced by Partners’ judgement. However it was necessary to provide a stronger and more rigourous justification for the value of k. To achieve this two approaches are presented: one from a statistical point of view, and the second from consideration of the action and resistance equations in the ENV Basis of Design 1991-1 and ENV 1992 "Design of Concrete Structures", Part 1-1 "General Rules and Rules for Buildings" [17].

If the Gumbel (Type I) extreme value distribution is used in processing the data then the P-fractile of distribution is calculated as:

$$x_p = u - ln(-ln\, P) / c \tag{2}$$

The parameters u and c can be determined using the method of moments viz:

$$u = m - 0.57722 / c \qquad c = 1.2825 / s$$

where: m - mean value of the sample
s - standard deviation of the sample
V - coefficient of variation of the sample ($V = s / m$)

Following substitution (2) can be written as:

$$x_p = m \{1 - 0.78\, V\, [\, 0.577 + ln\, (-ln\, P)\,]\, \} \tag{3}$$

The Eurocodes do not define directly a return period to be associated with accidental actions. However both the German Reactor Safety Rules for Nuclear Stations and the UK Design Standard for Nuclear Structures set the same value of 10000 years for natural events. This corresponds to the fractile value with the probability of not being exceeded during one year of 0.9999. The Characteristic Value for variable actions is defined as a value with a return period of 50 years (ie. $P = 0.98$). From this approach k can be defined as the ratio of these two values viz:

$$k = x_{0.9999} / x_{0.98} \ .$$

From Eq. (3):

$$x_{0.98} = m \{ 1 - 0.78 V \ [0.577 + ln (-ln0.98)] \} = m (1 + 2.59 V) \qquad (4)$$

$$x_{0.9999} = m \{ 1 - 0.78 V \ [0.577 + ln (-ln0.9999)] \} = m (1 + 6.73 V) \qquad (5)$$

Thus $k = (1 + 6.73 V) / (1 + 2.59 V)$ (6)

k depends on V, the coefficient of variation of the data set. Obviously this value will be different for different data sets and not a single universal value for all registered data. Figure 4.4 shows for example the coefficient of variation for the German data.

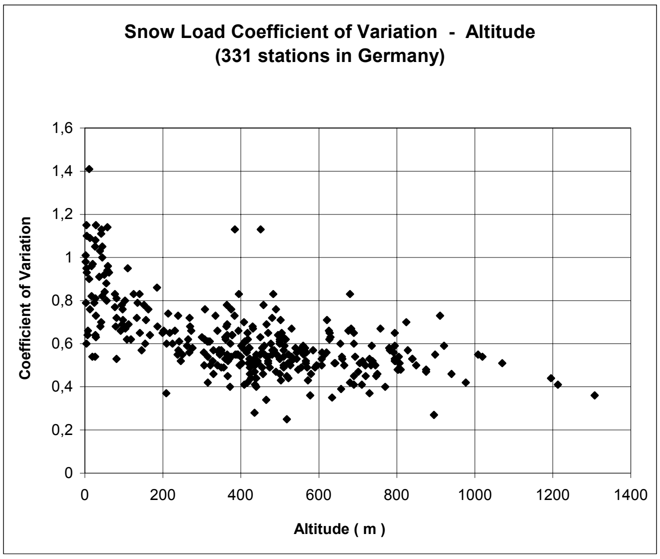


Figure 4.4: Coefficient of variation of snow loads for climatic stations in Germany

Though there is a wide deviation the value of 0.6 is calculated as the average from all the data. Additionally Annex C in ENV 1991-2-3 EC1 Part 2.3 Actions on structures - Snow Loads [2] advises that in calculations to determine return periods for ground snow loads different to that of the characteristic, a value of 0.5 may be assumed for the coefficient of variation.

Substituting V=0.6 in (6) results in $k = 1.98 \approx 2.0$; {For V=0.5, $k = 1.90$}

For a return period of 1000 years the fractile value is 0.999 and retaining V=0.6, results in $k = 1.55 \approx 1.6$. {For V=0.5, $k = 1.51 \approx 1.5$}

Thus the foregoing suggests that loads which satisfy $k \geq 2$ can be considered to have a MRI of the order of 10,000 years and that loads which satisfy $k \geq 1.5$ have a MRI of the order of 1,000 years.

We now seek corroborative evidence from the Eurocodes. ENV 1991 - 1 "Basis of Design" [1] defines in Section 4 "Actions and environmental influences" § 4.1 "Principal classifications" (2) snow loads as variable actions. This generally relates to snow loads determined by the methods of sections 4.3.4 and 4.3.5.

But allowance is made in Clause (4): "Some actions, for example seismic actions and snow loads, can be considered as either accidental and/or variable actions, depending on the site location (see other Parts of ENV 1991 [1])". This permits exceptional snow loads to be treated as accidental loads.

Therefore, if the snow event is identified as exceptional, ie. related to the characteristic load by equation (1), then in design the snow loads should be treated as two cases: persistent/transient (P/T) situations and accidental (A) situations.

The coefficient k needs to be determined by taking into account not only consideration of the actions, but also the influence of the resistance.

Following ENV 1991 - 1 "Basis of Design" [1], Section 9 it shall be verified that:

$$E_d \leq R_d \tag{7}$$

where: E_d is the design value of the effect of action
R_d is the corresponding design value of resistance

For simplification consider the case when snow load is the only variable action and there is only one permanent action (e.g. self-weight). Then according to Clause 9.4.2 "Combinations of actions" of ENV 1991-1 [1] there are two cases to consider:

a) persistent and transient design situations for ultimate limit states verification other than those relating to fatigue

$$E_d = \gamma_G \cdot G_k + \gamma_Q \cdot Q_k \tag{8}$$

b) accidental design situations

$$E_d = \gamma_{GA} \cdot G_k + A_d \tag{9}$$

where:

$\gamma_G = 1.35$	the partial safety factor for permanent action
G_k	the characteristic value of permanent action
$\gamma_Q = 1.5$	the partial safety factor for variable action (snow load)
Q_k	the characteristic value of variable action (snow load)
$\gamma_{GA} = 1.0$	the partial safety factor for permanent action for accidental design situation
A_d	the design value of accidental action
$A_d = \gamma_A \cdot A_k$	
$\gamma_A = 1.0$	the partial safety factor for accidental action(snow load)
A_k	the characteristic value of accidental action (snow load)

According to ENV 1992 "Design of Concrete Structures", Part 1-1 "General Rules and Rules for Buildings" [17]:

P/T:	$R_d = R_{k,c} / \gamma_C$	for concrete	(10)
	$R_d = R_{k,s} / \gamma_S$	for steel reinforcement or prestressing tendons	
A:	$R_d = R_k / \gamma_{CA}$	for concrete	(11)
	$R_d = R_k / \gamma_{SA}$	for steel reinforcement or prestressing tendons	

where:	$\gamma_C = 1.5$	the partial safety factor for concrete (P/T situations)
	$R_{k,c}$	the characteristic value of concrete
	$\gamma_S = 1.15$	the partial safety factor for steel reinforcement (P/T situations)
	$R_{k,s}$	the characteristic value of steel reinforcement
	$\gamma_{CA} = 1.3$	the partial safety factor for concrete (Accidental situations)
	$\gamma_{SA} = 1.0$	the partial safety factor for steel reinforcement (Accidental situations)

Using Eq. (7), (8) and (10) it is possible to write for P/T situations for concrete:

$$1.35 \cdot G_k + 1.5 \cdot Q_k \leq R_{k,c} / 1.5$$

Considering as an unfavourable case $G_k = 0.5 \cdot Q_k$ and noting that $Q_k = s_k$ then:

$$3.26 \cdot s_k \leq R_{k,c} \tag{13}$$

Similarly for Accidental situations Eq. (7), (9) and (11) and $A_K = s_m = k \cdot s_k$ from Eq. (1) give:

$$1.0 \cdot G_k + k \cdot s_k \leq R_{k,c} / 1.3$$

Taking again as an unfavourable case $G_k = 0.5 \cdot Q_k$ then:

$$(0.65 + 1.3 \cdot k) \cdot s_k \leq R_{k,c} \tag{14}$$

Because the right hand sides in Eq. (13) and (14) are the same (ie the characteristic value of concrete strength), the left hand sides (the design value of the action effect) shall also be the same, independent of the design situation. Then k can be calculated as:

$$k = (3.26 - 0.65) / 1.3 = 2.0 \tag{15}$$

Thus in this illustration, for $k \geq 2.0$ the governing design load case will be the Accidental situation

Other ratios of G_k / Q_k can also be considered. Assuming $G_k = Q_k$, results in $k = 2.28$, and for $G_k = 1.5 \cdot Q_k$, $k = 2.56$

Considering the case $G_k = 0.5 \cdot Q_k$ as unfavourable, isolated snow events with $k \geq 2.0$ should be fixed as accidental ones. From a pragmatic point of view events with $1.5 \leq k < 2.0$ may be also considered as accidental with $k = 2.0$ for subsequent calculations.

If we look again at Eq. (8), (9) with, for example, $k = 2.0$ then we would have

P/T: $E_d = 1.35 \cdot G_k + 1.5 \cdot s_k$ (16)

A: $E_d = G_k + 2.0 \cdot s_k$ (17)

The more unfavourable of these two situations (and therefore the decisive one) depends on the ratio of the characteristic value of permanent action to the characteristic value of the snow load. Manipulating the above indicates that if this ratio is greater than 1.42 then P/T is the decisive situation.

If the snow load is not the only variable action, the characteristic values of the other variable actions multiplied by appropriate partial safety factors and combination coefficients should be added in the equations (8) and (9) as stated in ENV 1991-1 [1] Chapter 9. In these cases the snow load is considered to be the dominant action and both design situations will need to be verified.

The foregoing discussion on the Eurocodes confirms the view that snow loads that are more than twice the characteristic value, calculated by excluding the largest value from the statistical processing, should be regarded as exceptional and considered in design as accidental actions. It is less supportive for load values of 1.5 times the characteristic value and this needs to be evaluated further in specific design situations. However the statistical consideration indicates that removing such values from the statistical processing is valid if the interpretation ascribed to those values is that they have MRI values in excess of approximately 1,000 years.

Thus the criterion for identifying 'exceptional load' values in the observations is expressed as:

> *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 load value shall be treated as an exceptional value.*

The following represents the methodology for identifying and handling exceptional snow loads and is applicable to either annual maxima or event maxima approaches. It assumes that the extreme values of the parent population fit a Fisher-Tippett Type I extreme value distribution and that the parameters of this distribution are determined by application of the method of Gumbel. However in general other extreme value distribution could be used, e.g. Log-normal or Weibull.

A) For the annual (or event) maxima data set rank the maxima in ascending magnitude excluding the largest value. The reduced variate Z is determined from:

$Z = -ln\,(-ln\,(m/(N))$ where N is the number of maxima, and m is the rank

B) Best Fit straight line using appropriate technique - eg. LSM

C) Evaluate parameters of best fit line and determine the 50 yr MRI value excluding the largest value using the following

$$Z = -ln\,(-ln\,(0.98))$$

D) Determine the value of k = largest value/ 50 yr MRI from C. If $k < 1.5$ then repeat steps A) to C) with the inclusion of the largest value in the statistical processing.

E) Record the 50 year MRI value and the largest value if it has been classified as an exceptional value.

5. European Snow Loads Map

5.1 Methodology of map development - methods and tools for spatial interpolation techniques

This research on European Snow Loads Mapping required bringing together information from the 18 different countries involved, improving the degree of harmonisation with respect to previous work and presenting a final result in the form of a map or series of maps. The main item of information concerned is the estimated 50 years MRI value for the ground snow load at a particular station.

The engineer needs a presentation of the snow load offering a clear and easy way to read the characteristic value at any site situated within a certain region. At first sight, the simplest solution would be to set up a map giving directly the characteristic snow load at any place. However, in all mountainous areas of Europe such a map would have to be extremely detailed and would largely follow the topographic relief. The national annexes A in ENV 1991-2-3 [2] show that in most parts of Europe the best way to present the snow loads in a map for the use by engineers is to define areas in which a given altitude function can be applied. These altitude functions can be given by mathematical formulae or by numeric tables.

In some European regions, in particular Norway and Iceland, the correlation between snow load and altitude is very low or even insignificant and it is difficult to find an appropriate altitude function. In these areas other methods of presentation are used.

The characteristic snow load may be considered as a multidimensional stochastic variate. The fact that usually the correlation between the snow load and the altitude of the place of measurements is very strong permits the use of a simplified model. In this model the characteristic snow load is assumed to depend only on the altitude (altitude function) but the values calculated at the meteorological stations are affected by random deviations (due to statistical uncertainties in the calculated value and also due to neglected influences, e.g. exposure of the station, radiation, local effects etc.).

Experience has shown that the form of the altitude relationship can vary from region to region across Europe. It is therefore necessary to identify and define major **climatic regions** in which a particular form of height relationship (i.e. a particular formula) holds, and then within these regions to identify **zones** where particular values for parameters of the formula apply. By ensuring that the parameter of the height relationship which varies from zone to zone, called the **zoning number**, varies through a small range of integers the map of zoning numbers becomes a map of **snow load zones** which is useful for engineers.

The practical steps involved in the mapping process for the major part of Europe using height relationships can be summarised as follows:

1 - identification/choice of major **climatic regions**

2 - for each region:

2.1 - find the best fitting altitude functions for the region using all data points in the region

2.2 - reduce the characteristic snow load at the individual stations to a zoning number by inverting the altitude function

2.3 - develop a surface of interpolation to extend the zone numbers from the individual stations to the whole region.

Both the regionalization and the zoning were to some extent iterative processes requiring trials and adjustments in order to identify the best representative regions and altitude functions.

Several different methods and computer programmes for performing the interpolation were evaluated, and these are reviewed in Annex 5.

The mapping process was carried out using the standard projection of the European Commission (Lambert - Azimuth, Central Meridian = 9.00, Reference Latitude = 48.00), while the cell size used was10 Km.

5.2 Climatic regions

The 18 CEN member states considered in this research extend from 35° latitude in Crete up to more than 70° latitude at North Cape. Instead of treating each country separately, as in the past, this work took account of climatological differences largely ignoring the political boundaries.

Europe was divided into ten different climatic regions. These were chosen for a combination of reasons and factors, taking into account physical boundaries (seas, mountains) where possible, known boundaries in precipitation patterns, and in some regions choices based on the observed spatial behaviour of the 50 year MRI values.

Below are listed the regions which are also illustrated in Figure 5.1.

Iceland
Norway
Finland, Sweden,
UK and Eire,
Central East (main part of Germany, Denmark)
Central West (main part of France, Benelux)
Alps (Switzerland; Austria and parts of Germany, of France and of Italy),
Iberian Peninsula (Spain and Portugal),
Mediterranean Region (main part of Italy; south part of France),
Greece

It was assumed that the snow loads observed within the same climatic region would result from more or less common meteorological conditions. During the work with the data and the resulting snow load map, the delimitation of these climatic regions was modified and optimised in order to obtain a more uniform result.

Initially the UK and Eire were treated as one region, separated from continental Europe by the sea. The same for Iceland. Major distinctions were then drawn between the Scandinavian countries, remaining Central Europe, the Alps and the Mediterranean countries.
Within Central Europe the analysis of the scatterplot revealed two different populations, this area was therefore split into two, a western part more similar to the UK and Eire, and an eastern part more similar to the alpine region but with lower snow loads.
Within the Mediterranean countries Greece was observed to have a noticeably different scattergram of MRI/Altitude and was therefore separated out. The Iberian peninsula was also treated as a separate region.
The Alps region was initially defined using the 500m height contour, but examination of the data behaviour showed that the rest of Austria could usefully be merged with this. Also, for similar reasons the Mediterranean region was extended to include the French Provence. Here again the 500m height contour was used as it is known to be in good agreement with the precipitation pattern. While in the case of the French Provence the information on the boundaries has been supplied as a map, in the Alps the boundary has been determined using a digital elevation model and contouring the 500 m height values. These contour lines do not include all the points above or below 500 m. This is due to the fact that contouring is based on grid data, therefore the cell size of the height data and the cell size chosen for interpolation determine the resolution of the final region obtained. In this case the height data had a 1 minute resolution (GISCO - Eurostat), while the contouring was done on a 20 Km cell size. This choice reflects the general approach of using projected data (Lambert - Azimuth, Central Meridian = 9.00, Reference Latitude = 48.00) rather than geographical co-ordinates, while the choice of the cell size reflects the detail used in defining the climatic regions.

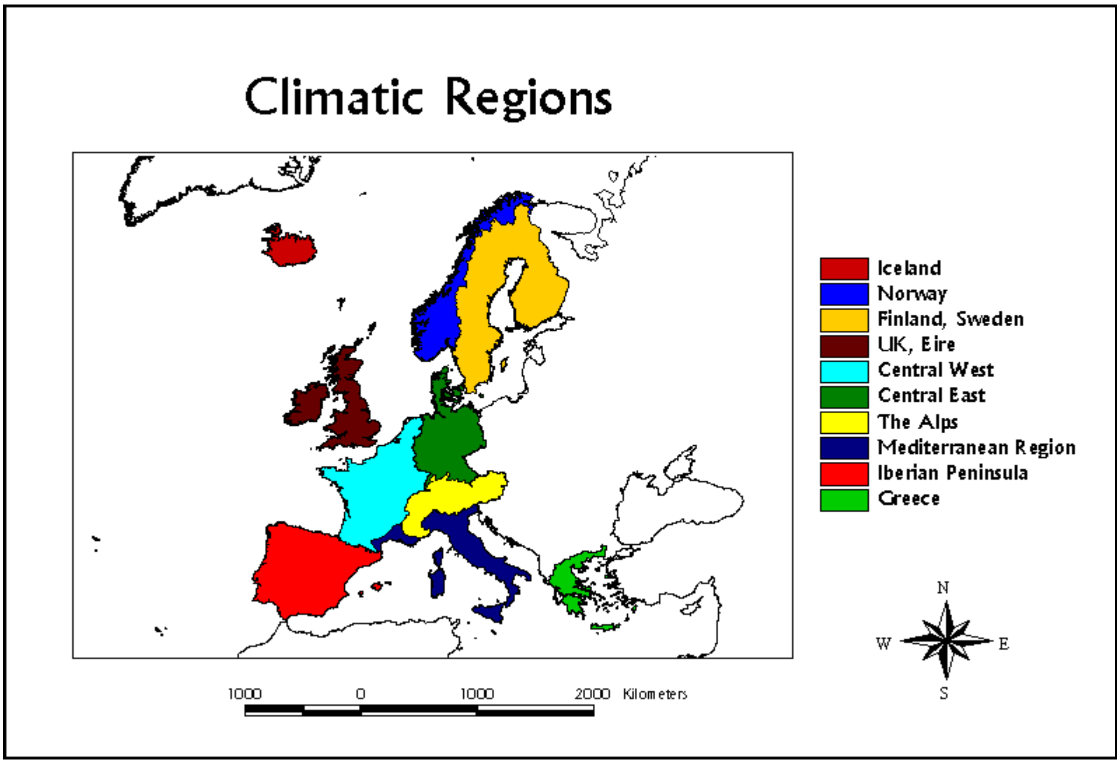


Figure 5.1 European Climatic Regions

5.3 Altitude functions

The climatic regions were tailored in order to group areas in which a common relation between the characteristic snow load and the altitude may be expected. Obviously in some regions the altitude is not the main influence and sometimes there is even no correlation at all with the geographical altitude. In these cases other global or local conditions may have a strong influence the snow load.

Fortunately, in most of the climatic regions the characteristic snow load at the stations plotted against the altitude show a clear correlation. Instead of presenting the snow load itself with all its variation with altitude, it is preferable in these regions to define it by zones in which the same altitude function is to be applied. Presenting the characteristic snow load by zones and functions allows much easier reading, especially for mountainous regions.

Firstly the general tendency of the increase with altitude was derived from the scatterplot containing all stations within one region. As an example Fig. 5.2 shows this graph for the Alpine Region. While at sea level the points usually are very close together, they show a large scatter in high mountains. Obviously, the snow loads measured near mountain tops are influenced very much by strong winds which tend to reduce the snow at exposed spots while increasing it at protected places at the same altitude. This effect is tried to be considered selecting the measuring site.

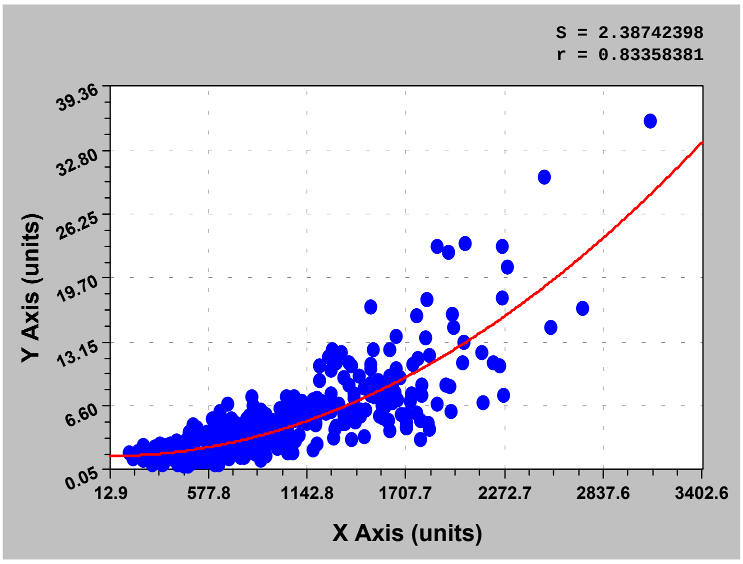


Fig. 5.2 Example for a best fitting altitude function (Climatic region: Alpine Region; a = 1.46 kN/m² ; b = 0.83 m)

In order to find a best fitting curve, different types of function were compared by looking to the coefficient of correlation. Often these coefficients were very similar, so that final preference was given to the most simple of these functions.

Two types of functions were retained, one parabolic, the other linear. The best fitting function reflects the average increase of the characteristic snow load with altitude. As a special case the linear function comprises also a horizontal line, which means no variation of the snow load with altitude. This is used in regions showing poor correlation with altitude and it means that the map shows the snow load directly without an altitude dependency.

The southern countries (Iberian Peninsula, Mediterranean Region, Greece), the Alps and northern Germany & Denmark are best represented by a quadratic function of the type:

a) Parabolic type of altitude function

$$s_k \quad = \quad a\left[1+\left(\frac{A}{b}\right)^2\right]$$

Sweden & Finland, the UK & Eire, northern France & Benelux are best represented by a linear function of the type:

b) Linear type of altitude function

$$s \quad = \quad a+\frac{A}{b}$$

s_k characteristic snow load (kN/m²)

A altitude above sea level (m)
a parameter (kN/m²)
b parameter (m)
($b \rightarrow \infty$ gives $s_k = a$ independent of the altitude)

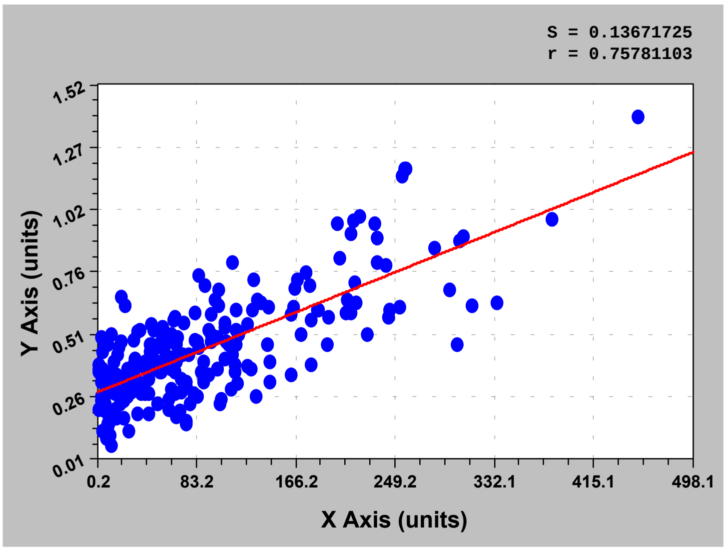


Fig. 5.3 Example for an altitude function (Climatic region: UK, Eire; a = 0.278, b = 142 m, r = 0.76)

As can be noted easily the parameter “a” reflects the snow load at sea level.

Iceland and Norway do not show a clear altitude-snow load relationship (see Fig. 5.4.) in fact the correlation coefficient is very low (r = 0.21). In this case the information evaluated is the snow load directly.

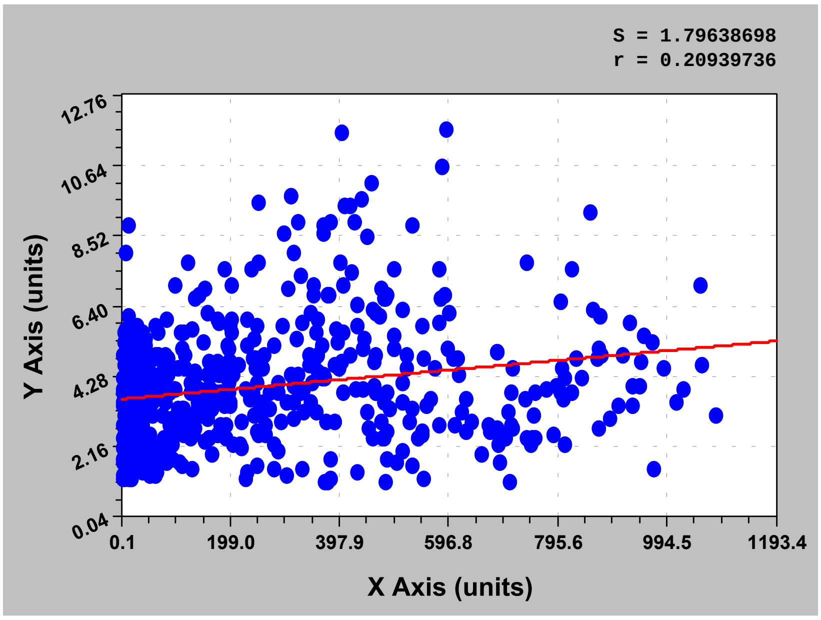


Fig. 5.4 Example for the absence of a clear altitude-snow load relationship (Climatic region: Norway; a = 3.60, b = 2456 m, r = 0.21)

5.4 Zoning

The altitude function represents the average increase of the snow load with altitude. As can be seen on the plot Fig. 5.2, some stations will belong to snowy areas with a snow load higher than the value given by the general "law", others will stay below the average. This means that the best fitting function has to be replaced by several curves allowing different zones to be distinguished in relation to the average altitude function. By varying the first parameter a, the average function can be widened into a fan of similar altitude functions covering all existing deviations from the average.

Every single station lies between two of these curves and may easily be classified into the corresponding zone. Within each of the zones one altitude function indicates the snow load depending only on the altitude of the site.

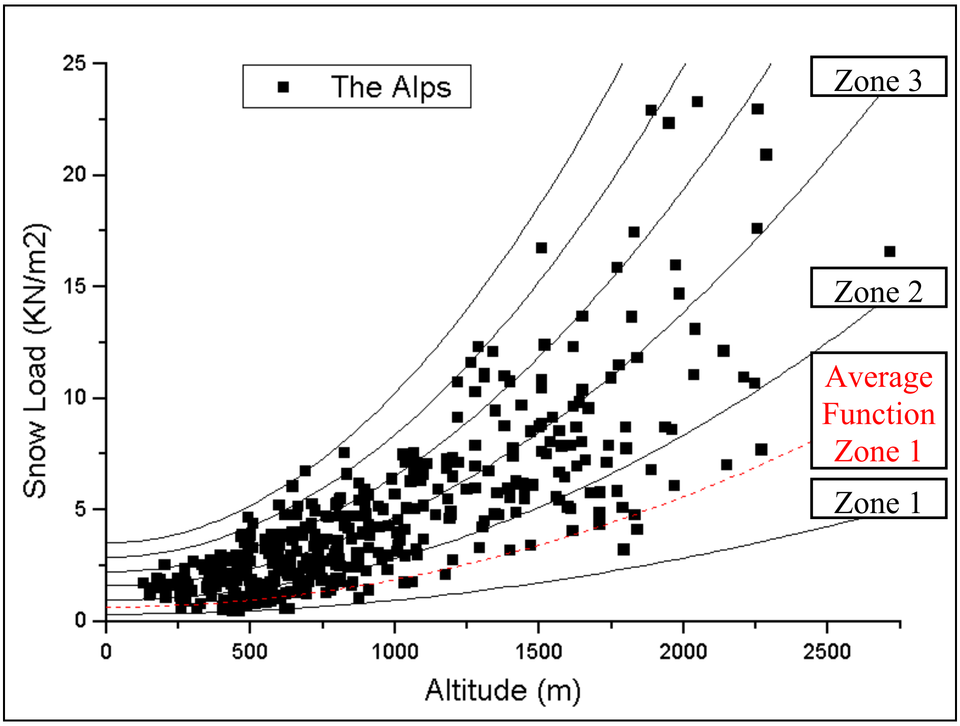


Fig. 5.5 Example for Zoning - Alpine Region.

But which of the altitude functions, the upper limit or a curve representing the average, shall be maintained for practical use? The safest way would be to use the upper limit, covering all stations within the zone. However, though this proposal would correspond to the general thinking of design engineers to keep always "on the safe side", it would also introduce an additional margin of safety, at least for the majority of the stations, having an impact on the safety coefficients. This would also be true if the upper limit was replaced by an intermediate function near to the upper limit covering for example 90 % of the stations.

Therefore it was decided to propose the <u>average function of the zone.</u> This means that approximately half of the stations will have a characteristic snow load smaller than that given by the function, whereas for the other half the real value is greater. The difference can be as much as half the width of the zone. In this case the safety coefficient is not altered systematically but subject to random variations. They are considered to be covered by the modelling uncertainties which were taken into account in the safety coefficients (cf. ENV 1991-1 [1]).

Nevertheless these deviations should be reduced as much as possible. They depend on the chosen number of zones. Choosing many zones allows a very precise presentation of the snow load but the corresponding maps will be difficult to use. Here again a compromise had to be found. Generally the subdivision of one climatic region into four or five zones seemed to be acceptable. Sometimes more zones were used temporarily to be able to classify isolated high values, but for practical use these zones have been grouped to one single zone.

If the best fitting average "altitude function" is a horizontal straight line, the fan of curves will become a series of equidistant horizontal lines. The zones are the grouping of all stations with approximately the same snow load, irrespective of the altitude.

Each set of zones is valid only for one climatic region. At both sides of regional borderlines the zone may be different but applying the corresponding altitude functions the resulting snow load will be quite similar because the procedure of analysing the data was uniform.

Presenting spatially continuous varying data by means of zoning and contour lines usually gives a result easy to handle in practice. But inevitably one has to accept certain inaccuracies due to the steps from one zone to the next one.

5.5 Regions showing insufficient correlation: snow load - altitude

The scatterplots showing the snow load of the stations in the regions of Norway and Iceland do not indicate any relation between the characteristic snow load and the altitude of the stations. Therefore the snow load can only be presented in form of isopleths. Within the present research it was not possible to check if other conditions e.g. the distance to the sea may have a distinct influence on the characteristic snow load. This question must be left for further research work.

5.6 Exceptional snow loads representation

The application of the methodology outlined in section 4.3.6 resulted in exceptional loads being identified at stations in: Austria, Belgium, Eire, France, Germany, Greece, Italy, Portugal, Spain and UK. A total of 159 stations were identified, 47 of which are in Spain and 44 in the UK. The individual stations and corresponding summary data is listed in Annex A4 and the locations of which are displayed in Fig 5.5 and on the relevant maps in Annex A6. It should be noted that for the UK stations listed in Annex A4 the 'No of snow winters' is the number of actual snow events that have occurred during the recording periods. The event method of analysis (see section 4.3.4) does not specifically identify snowless winters. However to allow comparison with stations in the table which use annual maxima values an estimate of the number of snow winters can be obtained from the average number of events per year. This is outlined at the foot of Table A4.2 in Annex A4.

The date of occurrence of the largest load is given. This should help National Meteorological Offices to identify weather systems causing such events. It is understood that Meteo France have published meteorological explanations for the exceptional snowfalls that occurred at Perpignan in 1954, Corsica in 1985, and Grenoble in 1990. It is observed that the exceptional loads at the stations in northern Germany listed, all resulted from a single weather system in 1979 that persisted in that area for about two weeks.

Of these 159 stations, 75 have k values greater than 2.0 (k as defined by equation 1, section 4.3.6). Whilst the majority of values lie in the range $2.0 < k < 3.0$, there are a few with $k > 4.0$. It is worth noting that many of these stations have small characteristic values and relatively small maximum values, eg. for Morecambe (UK), the maximum registered load value is 0.30 kN/m^2 , the calculated characteristic value is 0.12 kN/m^2 and the value of k is 2.47.

The map representation currently is to indicate the location of these stations differentiated between those which have values $k > 2.0$ and those having $1.5 < k < 2.0$. Three pieces of supporting information are needed for each station - the characteristic load, the maximum registered load and the corresponding k value. In some countries eg Portugal and Spain, it is possible to identify broad

regions in which there are numbers of stations considered to have exceptional loads and indicate these as regions where snow loads need to be treated, in part at least, as accidental loads as suggested in section 4.3.6.
However it should be remembered that whilst ENV 1991-1 [1] allows the possibility of exceptional snow loads being treated as accidental loads, only one country: France, follows a similar route in its National Standard. Thus this concept is not well established in the remaining 17 CEN countries involved in this research and gaining acceptance of this philosophy may not be easy.
Thus no firm decisions have been taken yet on how these stations should be integrated with the main body of data. . In fact, for the time being, it is probably better to retain the exceptional stations in a separate map in order to facilitate consideration of this work by the Project Team charged with conversion ENV 1991-2-3 [2] into full EN status.
However such consideration is likely to examine the characteristic values of neighbouring stations and the design envelope produced from the regionalisation and zoning since this may automatically account for some, if not all, exceptional values within that region. Some exceptional loads in light snowfall regions may be disregarded because they may be the result, more from the measurement discrimination (cf section 4.2.3) and our identification/selection criteria, than from actual meteorological conditions.
Furthermore small exceptional ground snow loads assume less significance since most loading codes stipulate minimum imposed roof loads to cover maintenance access, etc.. This may be sufficient to account for these snow loads. However this argument weakens when there are potential load combinations, a topic being addressed in phase II of this research activity.

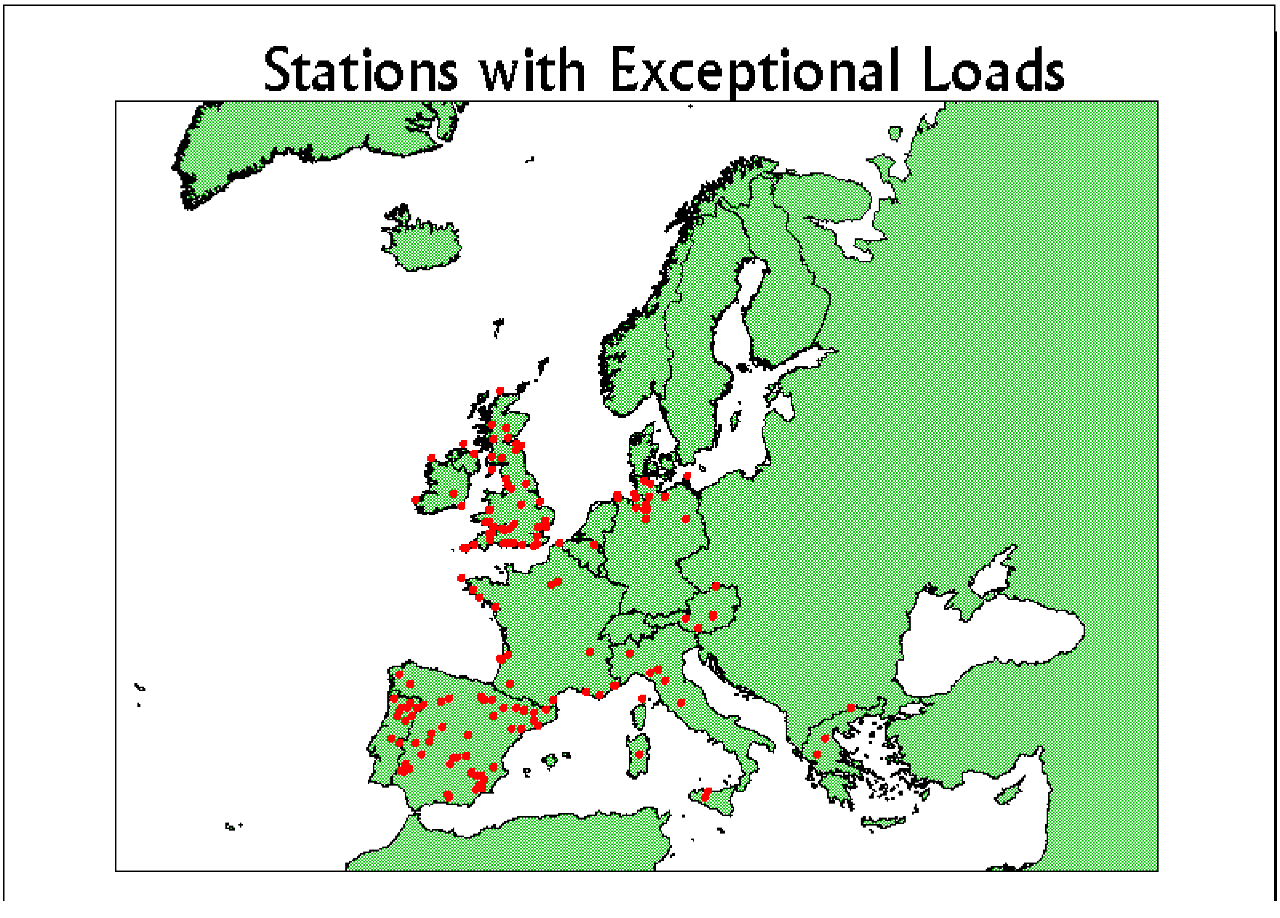


Figure 5.5 Location of station where exceptional snow loads have been encountered.

5.7 Final ground snow load map presentation

The final analysis was made on the reduced data set, ie without exceptional snow load values. For every climatic region the best fitting curve (horizontal, linear or quadratic) was chosen.
Iceland and Norway do not show a significant altitude - snow load relationship, the function used is therefore the horizontal one, this means that the snow load is independent of altitude. In this case the value mapped is the snow load directly.
For the three regions Sweden & Finland, United Kingdom & Eire, Central West the best fitting curve is the linear one:

$$s = a + \frac{A}{b}$$

s = Snow Load (KN/m^2)
A = Altitude above Sea Level (m).

The best fitting curve allows the parameter b to be determine; this information in turn allows the value of parameter a for every data point to be determined and therefore the range of parameter a (ie. snow load at sea level)
This is the information needed to produce the fan of curves that determine the zoning:

$$s = (a_{\min} + Z * \left[a_{\max} - a_{\min}\right] / NZ) + \frac{A}{b}$$

while the representative altitude - snow load relationship for a specific zone (the middle value) is given by:

$$s = (a_{\min} + [Z - 0.5] * \left[a_{\max} - a_{\min}\right] / NZ) + \frac{A}{b}$$

s = Snow Load (KN/m^2)
A = Altitude above Sea Level (m)
NZ = number of equidistant zones.
Z = integer zone number (varying between 1 and NZ)

The remaining climatic regions (Central East, Alpine Region, Mediterranean Region, Iberian Peninsula, Greece) all show a quadratic relationship between altitude and snow load:

$$s = a\left[1 + \left(\frac{A}{b}\right)^2\right]$$

s = Snow Load (KN/m^2)
A = Altitude above Sea Level (m).

Again the best fitting curve allows the parameter b to be determined, then the value of parameter a (ie. snow load at sea level) can be calculated for every data point and the fan of curves produced:

$$s = (a_{\min} + Z * \left[a_{\max} - a_{\min}\right] / NZ)\left[1 + \left(\frac{A}{b}\right)^2\right]$$

while the representative altitude - snow load relationship for a specific zone (the middle value) is given by:

$$s = (a_{\min} + [Z - 0.5] * \left[a_{\max} - a_{\min}\right] / NZ)\left[1 + \left(\frac{A}{b}\right)^2\right]$$

s = Snow Load (KN/m^2)

A = Altitude above Sea Level (m)
NZ = number of equidistant zones.
Z = integer zone number (varying between 1 and NZ)

The spatial interpolation of the a values to a regular grid and the contouring of this grid of values using a specific range of parameter a ($(a_{max} - a_{min})/NZ$)) allows the zoning maps to be obtained. For this research inverse distance weighting with a radius of 100 Km (except Norway: rad = 50 Km) and an exponent = 2 was used for the interpolation of parameter a. While the radius is rather big an exponent equal to 2 assures that the data points closest to the centre of the new cell get the highest weights, while the points further away receive only very little weight (see Annex 5 for further details).

A mean filter was then applied to the resulting maps to reduce the effects of single data points, as single data values are subject to errors and/or might represent local phenomena. The effect of this filter is to smooth the interpolated surface over a certain distance. In the present work the neighbourhood chosen was a rectangle of 30 Km height and width (= 3 cells), this is rather small compared to the radius used in inverse distance weighting (50 - 100 Km) and assures that no major changes are introduced with this smoothing procedure (see Annex 5 for further details).

Detailed information on the values of parameters a and b, the function used and the resulting maps can be found in Annex 6 for every climatic region.
Before presenting every single climatic region, some general observations can be made. A basic aspect in spatial analysis is related to the sampling density and data point coverage of an area. In the present analysis data points were included for meteorological stations having a sufficient number of years of measurement to assure statistical significance. The sampling density varied from country to country and might therefore be different in different parts of a single climatic region and even insufficient, leading to "No Data" zones on the final map (for example in Sweden). The data point coverage might not be homogeneous even on a country level. It is important to note that the absence of data points in areas with special micro climatic conditions make it impossible to represent this phenomenon on the final map, for example the absence of stations at sea level (mild climate) in Greece might produce an overestimation of snow load values in these areas.

A feature of some of the final maps is the presence of some remaining isolated small areas. These might represent a special micro climatic phenomenon important for the area concerned or, alternatively, could be related to the particular position of a single meteorological station and are therefore not important for the zoning procedure. These small isolated areas should be reviewed on a case by case basis.

CLIMATIC REGION: ALPINE REGION

The alpine region is best represented by a quadratic altitude - snow load relationship. After fixing parameter b and the extent of parameter a, the values were divided into 5 zones using equal ranges of a (the snow load value at sea level). The correlation coefficient for the 5 zones ranges between 0.998 and 0.965. The radius adopted in inverse distance weighting is of 100 Km and was determined by the low density of data points in France and Italy.

CLIMATIC REGION: CENTRAL EAST

This climatic region actually consists only of northern Germany as it was not possible to get detailed data on snow loads from Denmark. It is best represented by a quadratic altitude - snow load relationship. After fixing parameter b and the extent of parameter a, the values were divided into 5 zones using equal ranges of a (the snow load value at sea level). The two highest zones were then merged as both contain only a small number of data points. The correlation coefficient of these 4 zones ranges between 0.965 and 0.994. The radius adopted in inverse distance weighting is of 100 Km and allows a good coverage of the area.

CLIMATIC REGION: CENTRAL WEST

This part of continental Europe shows climatic conditions very similar to the UK and Eire and is best represented by linear altitude - snow load relationship. After fixing parameter b and the extent of parameter a, the values were divided into 5 zones using equal ranges of a (the snow load value at sea level). The two highest zones were then merged as both contain only a small number of data points. The correlation coefficient of these 4 zones ranges between 0.896 and 0.964. The radius adopted in inverse distance weighting is of 100 Km as the sampling density is rather low.

CLIMATIC REGION: GREECE

This climatic region is best represented by a quadratic altitude - snow load relationship. The extremely reduced scatter of data points and the low number of points in zones 3, 4 and 5 suggested that these three zones could be merged together even if the resulting correlation (0.57) is rather low. Furthermore this approach is on the safe side, as most of the values are lower than the representing function. The correlation coefficient in the other two zones ranges between 0.850 and 0.901.
The zoning number assigned to every zone is not an integer number, instead the number assigned to a specific zone is the one required in the above specified formula.
The choice of a radius of 100 Km allows a good coverage of this climatic region, but it omits all the islands in the south - east.
As mentioned above the irregular coverage with data points might cause some distortion especially along the coast. In fact there are no data points to represent the milder climatic conditions in this area.

CLIMATIC REGION: IBERIAN PENINSULA

This climatic region is best represented by a quadratic altitude - snow load relationship. The extremely reduced scatter of data points and the low number of points in zones 3, 4 and 5 suggested that these three zones could be merged together even if the resulting correlation coefficient (0.74) is lower then in the other two zones (0.856 - 0.960).
The zoning number assigned to every zone is not an integer number, instead the number assigned to a specific zone is the one required in the above specified formula.
Special mention should be made of the Azores islands, which are not included in the map. These islands have never had any snow, as shown also by the values of the stations there,. Therefore no specific map has been elaborated for themand the snow load value in this area is strictly equal to zero kN/m^2.

CLIMATIC REGION : ICELAND

The final map of Iceland is a map of snow loads, as there is no altitude - snow load relationship. The zoning chosen can be seen in the scatter plot in annex 6, the characteristic value for every zone is the middle value of the range covered.
The range of snow load values is rather high (1 KN/m^2 - 16 KN/m^2) and this produces some snow load zones covering a very wide range of values with limited spatial extension.
The absence of data points in the central part means that we cannot represent any special meteorological phenomena present in this area, but there is no population there.
The reduced density of points required the use of a radius of 100 Km for interpolation but inverse distance weighting assigns low priority to points further away.

CLIMATIC REGION: MEDITERRANEAN REGION

The Mediterranean region is best represented by a quadratic altitude - snow load relationship. After fixing parameter b and the extent of parameter a, the values were divided into 5 zones using equal ranges of a (the snow load value at sea level). The two highest zones were then merged as both contain only a small number of data points.
The zoning number assigned to every zone is not an integer number, instead the number assigned to a specific zone is the one required in the above specified formula.
The correlation coefficient for the 4 remaining zones ranges between 0.989 and 0.911. The radius adopted in inverse distance weighting is equal to 100 Km and assures the coverage of most of the region. Only a very small “No Data” area appears in the south of Sardinia.

CLIMATIC REGION: NORWAY

The final map of Norway is a map of snow loads, as there is no altitude - snow load relationship. The zoning chosen can be seen in the scatter plot in Annex 6, the characteristic value for every zone is the middle value of the range covered.
The scatter of the data is rather high, though less important than in Iceland, values ranging between 1 KN/m^2 and 11.5 KN/m^2. Again the spatial extent of the highest zone, covering a wide range of values, is extremely reduced.
The good coverage with data points allowed the adoption of a smaller radius (50 Km) for inverse distance weighting (exponent = 2), this is important for a climatic region such as Norway, which is known to have micro climatic variations, especially along the coast.

CLIMATIC REGION: SWEDEN, FINLAND

This climatic region is best represented by a linear altitude - snow load relationship. After fixing of the value of parameter b and the extent of parameter a, the data were divided into 5 zones using equidistant linear functions. As in other cases, examining the scatterplot revealed a low number of points in the two highest zones. It was therefore decided to put these two zones together. The resulting subdivision of the data points in the scatterplot into zones is shown in Annex 6. For every zone the middle function represents the altitude - snow load relationship for that zone. The zoning number assigned to every zone is not an integer number, instead the number assigned to a specific zone is the one required in the above specified formula.
The resulting correlation coefficients for every zone, ranging between 0.847 and 0.959, reveal good agreement between data points and their representation.

The sampling density, being very different in Sweden and Finland, required a compromise in the choice of the radius (100 Km) for inverse distance weighting. Even so the low coverage of data points in the central part of Sweden produces a “No Data” area. The adoption of a bigger radius would allow this area to be covered also, but finer detail would be lost in the remaining areas of the climatic region.

CLIMATIC REGION: UNITED KINGDOM, EIRE

This climatic region is best represented by a linear altitude - snow load relationship. After fixing of parameter b and the extent of parameter a, the data was divided into 5 zones using equidistant linear functions. The correlation coefficients for the single zones, ranging between 0.959 and 0.979, reveal good agreement between data values and representing function.
The low number of points in Eire forces the adoption of a radius = 100 Km for inverse distance weighting.

5.8 Regional boundary consistency

The European snow load map, developed by processing the available data with uniform methods and procedures, no longer presents discontinuities at the borders between States or local administrations. This was one of the major criticisms of the Eurocode 1, because such discrepancies coming from the individual national codes do not have any physical reason. The only exception is that part which covers the Norwegian territory, where the snow falls are strongly affected by local effects and the zoning results are too complicated for practical use.
The map, as already shown, presents ten climatic regions, further subdivided into zones with different load levels. At the boundaries of such regions and zones differences of load values for neighbouring sites take place, due to the particular climatic conditions of each region and to the scatter of the data.
An example of the results is given in table 5.1.

Table 5.1 : Characteristic snow load at different places

Climatic Region	Zone	Place	Altitude (m)	Longitude (DD)	Latitude (DD)	Calculated (kN/m^2)	Measured
Mediterranean	**2**	Torino (I)	237	7.65	45.08	0.86	-
Mediterranean	**4.5**	Milano (I)	107	9.17	45.47	1.70	-
Mediterranean	**1**	Nice (F)	10	7.20	43.65	0.23	0.15
Alps	**1**	Grenoble (F)	386	5.33	45.37	0.83	0.66
Alps	**1**	Geneve (CH)	430	6.13	46.25	0.88	0.50
Alps	**1**	Zurich (CH)	556	8.53	47.33	1.03	0.87
Alps	**2**	Innsbruck (A)	577	11.35	47.27	2.11	2.58
Central East	**2**	Frankfurt/Main (D) (Stadt)	125	8.68	50.15	0.65	0.65
Central East	**4.5**	Berlin (D) Zehlendorf	45	13.30	52.47	1.22	1.34
Central East	**3**	Hamburg (D)	13	10.00	53.63	0.79	0.71
Central West	**2**	Amsterdam (N) Schipol	-4	4.77	52.30	0.23	0.30
Central West	**3**	Bruxelles (B)	68	4.33	50.83	0.47	-
Central West	**2**	Paris (F)	77	2.33	48.82	0.32	0.29
Central West	**1**	Toulouse (F) Francazal	166	1.37	43.63	0.24	0.26
Iberian Peninsula	**1**	Barcelona (E) Fabra	420	2.12	41.42	0.16	0.06
Iberian Peninsula	**1**	Sevilla (E)	8	-5.98	37.42	0.09	-
Iberian Peninsula	**1**	Porto (P)	93	-8.60	41.13	0.10	0.00
UK - Eire	**3**	London (UK) Heathrow	25	-0.45	51.48	0.33	0.35
UK - Eire	**2**	Dublin (IRL)	71	-6.25	53.43	0.27	0.33
Sweden, Finland	**2**	Stockholm (S)	44	18.07	59.35	1.96	1.80
Sweden, Finland	**3**	Helsinki (FIN)	22	24.99	60.21	2.52	-
Greece	**1**	Athens (G)	53	23.73	38.00	0.39	-
Norway	**3.25**	Oslo (N)	66	10.73	59.95	3.25	-
Iceland	**2**	Reykjavik (IS)	52	-21.90	64.13	2.00	2.04

6. Conclusions

The DGIII's scope that directed this research work was to establish a sound basis for the improvement of the ENV 1991 2-3 and to improve the lack of scientific basis that clearly emerged during the extension of the first ENV 1991 2-3, with an homogeneous approach to the definition of ground and roof snow loads all over Europe.
The first phase of the research dealt with the definition of the new European Ground Snow Loads Map (phase Ia) and with the definition and treatment of the exceptional snow load values encountered in some European regions (phase Ib).

One of the main problems encountered in the development of the study carried out under phase Ia was the basic snow data collection from each National Meteorological Office. Snow data, in fact (see Section 4.3.1 and Annexe A2), were not homogeneous both for the geographical distribution of meteorological stations, for the length of the recording period and for the nature of data themselves. These differences made it quite difficult to set up a procedure for data quality checks, in order to achieve a common quality standard. The collection of data and the assessment of their quality took more time than planned. For these reasons the investigations were limited to the available historical snow data sets, and they were particularly addressed to the study of the possible relationship of snow load with altitude, although several other influences should also have been considered important.
The data were then analysed using an homogeneous technique, which was discussed in order to achieve a common approach to the calculation of characteristic values, and to overcome conceptual differences in the values obtained in different countries, reducing to the minimum the possible sources of discrepancies in the map elaboration.
The ground snow load maps were elaborated with advanced computer techniques, which allowed all the data coming from homogeneous climatic regions to be utilised and to obtain maps discarding local effects, and, for the first time on European scale, largely uninfluenced by national boundaries.

This project has produced the first snow load map for Europe with a firm scientific basis and it is commended to the CEN Project Team on Snow Loads. This map is suitable for development for engineering application and can easily be tailored to the specific requirements of that Team (once known) to form the European Snow Load Map for the Eurocode on Actions. Such development work is likely to include subjective smoothing of the zones to take more account of physical geography in regions with few recording stations and some simplification of the map to acknowledge the influence of minimum imposed roof loads in the design procedure.

The development of studies in phase Ib dealing with exceptional snow loads represents the first effort made on European scale for the definition of such values and for their treatment. Before the present research work only French researchers had treated exceptional snow loads.
The result of the study on exceptional snow load values lead to the geographical identification of European areas where the phenomenon occurs. In the Annex 6 is presented a map of Europe with the climatic stations where exceptional values were found according to the definition given in the present research work (see Section 4.3.5). The map can be used as a basis for future research activities aimed at improving knowledge about these events, a better understanding of climatic and meteorological reasons for such important snowfalls and to an improvement of their statistical treatment.

The present research work gives first indications on how the exceptional values might be treated in the code, i.e. on how to take account of them without altering significantly the map of ordinary snow loads dealing with them separately.

During the whole research phase co-operation links have been established and maintained with: National Meteorological Offices for the collection of data, with National Technical Contacts, who contributed to the study of ENV 1991 2-3, and who were invited to co-operate with the research group. We have also received particular contributions from the following National Technical Contacts:

Prof. Apeland NTC for Norway;
Mr Akerlund for Sweden
Mrs. Currie (on behalf of Mr J Mills NTC for Great Britain);
Mr. Del Corso NTC for Italy;
Mr. Gabl NTC for Austria;
Mr. Hansen for Denmark
Mrs. Nylund for Finland
Mr Pálsson for Iceland
Mr. Stiefel NTC for Switzerland;
Prof. Trezos NTC for Greece.

The development of the present research activity has been, in many fields, the first homogeneous European scientific effort to overcome the lack of knowledge and to achieve a common basis for the definition of snow loads.
The Scientific result seems to be fully positive and provides a good basis for the future definition of European snow maps and future research activities aimed at a better understanding of the snow loading, started by DGIII when the present research group was commissioned to carry out this study.

Pisa, March 16th 1998.

For the research group

(Prof. Luca SANPAOLESI)

7. List of References

7.1 References cited in the text

[1] CEN ENV 1991-1 : 1994 Basis of Design. CEN Central Secretariat, Brussels

[2] CEN ENV 1991-2-3 : 1995 Snow Loads. CEN Central Secretariat, Brussels

[3] Revised ISO 4355 Basis for design of structures - Determination of snow loads (approved in 1993)

[4] Del Corso R. Gränzer M. Gulvanessian H., Raoul J., Sandvik R. Sanpaolesi L., Stiefel U. "New European Code for Snow Loads", Background Document, University of Pisa, Report No. 264, 1995

[5] CIB "Action on structures. Snow loads", Report by CIB Commission W81, First edition, August 1991

[6] Ellingwood B., Redfield R., "Ground Snow Loads for Structural Design", Journal of Structural Engineering, ASCE, Vol. 109, No. 4, 1983, pp. 950-964

[7] ANSI A58.1, "Minimum Design Loads for Buildings and Other Structures", American National Standards Institute, Inc., New York, 1982.

[8] Akerlund S., "Snow depth and Snow Loads in Umea", First International Conference on Snow Engineering, Santa Barbara, California, July 1988, US Army Corps of Engineers, Special Reports 89-6, pp. 3-7

[9] Luy H., Rackwitz R., "Darstellung und Auswertung von Schneehöhenmessungen in der Bundesrepublik Deutschland", Berichte zur Zuverlässigkeitstheorie der Bauwerke, Heft 31, München, 1978

[10] JCSS Probabilistic Model Code, Part 2: "Actions on structures", 2.12 "Snow Load", Draft September 1996

[11] Bachmann H., Rackwitz R., Schueller G., "Tragwerkszuverlässigkeit, Einwirkungen", in "Der Ingenierbau", Vol. 8, Ernst & Sohn, 1997

[12] Otstavnov V. "Elaboration of Draft Map for Snow Loads in Russia", Research Report 16-13-135/96, CNIISK, Moscow, December 1996 (in Russian)

[13] Izumi M., Mihashi H., Takahashi T."Statistical Properties of the Annual maximum Series and a New Approach to Estimate the Extreme Values for Long Return Periods", First International Conference on Snow Engineering, Santa Barbara, California, July 1988, US Army Corps of Engineers, Special Reports 89-6, pp. 25-34

[14] Thom H. C. S. "Distribution of Maximum Annual Water Equivalent of Snow on the Ground" Monthly weather review, April 1966, Vol. 94, No 4 (265-271)

[15] Mayne J. R. and Cook N. J. "Extreme wind analysis" CIRIA Conference "Wind Engineering in the Eighties", London 12-13 November 1980.

[16] JCSS, Background Documentation Eurocode 1 (ENV 1991) Part 1: Basis of Design. First Edition March 1996 n° 94

[17] ENV 1992 "Design of Concrete Structures" Part 1-1 General Rules and Rules for Buildings

[18] ESRI ArcView and ArcView - Spatial Analyst: Commercial Software from Environmental Systems Research Institute, Inc. (USA), Version 3.0.

[19] Golden Software Inc: Surfer: Commercial Software,. (USA), Version 6.01.

[20] Y. Pannatier: Variowin: Commercial Software, University of Lausanne (Switzerland), Version 2.1.

[21] Geoeas: Freeware, EPA. (USA) - Reference : ENGLUND, E. & SPARKS, A. (1991), Version 1.2.1.

[22] N J Cook, The designer's Guide to Wind Loading of Building Structures - Part 1: Background, damage survey, wind data and structural classification, Butterworths, London, 1985

[23] Sandvik, R.: Snow loads for Oslo, Asker and Bærum (In Norwegian) NBR 1989.

[24] Allerup, P. et al: Snow Pack Maximum Water Equivalent in Denmark. Danish Meteorological Institute Climatological Papers No. 14, Copenhagen 1985.

[25] Jonasson, K., Jónsson, T.: Fifty years snow depth in Iceland (in Icelandic). Icelandic Meteorological Office, Reykjavík, September 1997.

[26] Vehiläinen, B.: Snow cover models in operational watershed forecasting. Publications of Water and Environmental Research Institute. Report no 11, Helsinki 1992.

[27] Leaf, F. and Brink, G.: Computer simulation of snow melt within a Colorado subalpine watershed. Fort Collins 1973.

[28] Sandvik, R.: Snow Load Variation with Altitude in Norway. Second International Conference on Snow Engineering. Santa Barbara, California, June 1992.

[29] Åkerlund, S.: Snow and wind loads (In Swedish) Boverket 1994.

[30] Eriksson, E. M., Taesler, R.: Analysis and mapping of the basic values of snow loads on ground (In Swedish) Boverket 1995.

7.2 References in international literature

[31] Geographical Information Systems, D.J. Maguire, M.F. Goodchild and D.W. Rhind (editors), Longman Scientific and Technical, 1991, ISBN 0-582-05661-6

[32] Fundamentals of Spatial Information Systems, R.Laurini and D. Thompson,Academic Press, 1992, ISBN 0-12-438380-7

[33] Handling Geographical Information, I. Masser and M. Blakemore (editors), Longman Scientific and Technical, 1991, ISBN 0-582-06730-8

[35] Proceedings of the 2nd EC-GIS Workshop, Genova, June 26-28, 1996. Peckham R.J. (editor) EUR report no. 16441 EN.

[36] Proceedings of the 3rd EC-GIS Workshop, Leuven, June 25-27, 1997. Peckham R.J. (editor) EUR report no. 17715 EN.

[37] Sanpaolesi, L. et al.: The Eurocode on Actions: Snow Loads, Atti XIII Congresso CTA, Abano Terme, 1991.

[38] Sanpaolesi, L. et al.: Italian and European Standards - Eurocodes, Rivista Costruzioni Metalliche, 1992.

[39] Sanpaolesi, L. et al.: EC1: Snow Loads, IABSE Symposium, Davos, 1992.

[40] Sanpaolesi, L., Del Corso, R.: The evolution of standards on Snow Loads - European and Italian Standards"”Rivista Costruzioni Metalliche, 1994.

[41] Del Corso, R. : Statistics of Snow Loads in Turin: the effect of exceptional values, ICASP 7 Paris, France 1995 p. 645-649.

[42] Del Corso, R., Mercalli, L.: Analysis of snowfall series observed during long periods at four meteorological stations in the Italian territory. 3rd International Conference on Snow Engineering, Sendai, Japan 1996, 257-264.

[43] Sanpaolesi, L., Del Corso, R., Ligarò, S.: Analisi statistica dei vaolri del carico di riferimento al suolo in Italia. Giornale del Genio Civile, Anno 121, 3 265-278.

[44] Martinec, J.: Expected Snow Loads on structures from incomplete meteorological data. Journal of Glaciology, Vol. 19, No. 81, 1977.

[45] Gruner Ltd.: Probabilistic Analysis of ground snow data for Swiss meteorological actions, 1998

ANNEXES

ANNEX A1 ADMINISTRATIVE MATTERS RELATED TO THE RESEARCH

ANNEX A2 SNOW LOADS / HEIGHTS DATA BASE / DENSITY MODELS

ANNEX A3 PROBABILISTIC ANALYSIS OF GROUND SNOW DATA: EXAMPLES

ANNEX A4 EUROPEAN SNOW LOAD DATA SET

ANNEX A5 GIS TOOLS IN DATA HANDLING /MAPPING

ANNEX A6 EUROPEAN GROUND SNOW LOAD MAPS

ANNEX A7 COLLECTION OF MAPS FOR EACH CLIMATIC REGION