Snow load on buildings
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PREFACE

In Canada the load of snow represents usually the heaviest load that roofs have to carry. It is therefore obvious that the magnitude of the snow loads used in design has considerable influence on the cost of construction.

The design snow loads specified by the National Building Code of Canada (1953) are based directly on snow depth measurements made on the ground. It is known that in many cases the average depth of the snow on roofs is appreciably less than that on the ground. At the same time certain shapes of roofs tend to accumulate snow, due to drifting under wind action, to a depth which is much greater than the average depth on the ground.

Realizing this situation the Advisory Structural Group of the Associate Committee on the National Building Code asked the Division of Building Research to undertake a country-wide survey of actual snow loads on roofs. The first objective was the determination of the relationship between the snow load on the ground and the actual snow load on various types of roofs.

The second objective was the study of the various factors affecting snow loads on roofs. For example, to what extent do wind, temperature, insolation and heat loss affect snow accumulation on roofs? What is the influence of orientation, shape and size of roofs? With answers to questions like these it is hoped that magnitudes and patterns of snow loads can be established which are more accurate than those used now.

The survey was started during the winter of 1957-58 with observations of depth and density being made at over 60 stations across Canada. These observations have already indicated tentative answers to some of the questions, but before any definite conclusion can be drawn, the results of several winters will be required.

In order to gain further information on snow loads it was thought advisable to review the work of other countries on this subject, especially those countries with winter conditions similar to Canada's. To this end a number of Russian publications dealing with snow loads have been translated and are presented here. The similarity of Russian and Canadian winters makes these translations particularly pertinent.

The translations were made by Mr. D.E. Allen who was a member of the Building Structures Section of the Division until September 1958 but is now a graduate student at the University of British Columbia. The valuable assistance of Mr. G. Belkov of the National Research Council's Translations Section in checking all the translations is gratefully acknowledged.

Ottawa
July, 1959

Robert F. Legget
Director

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SNOW LOADS ON BUILDINGS

by Eng. A. F. Nikolaev (of the Research Institute of Industrial Construction)
Translated from "Stroitel' (The Builder)", 1935, vol. 8, no. 10, pages 18-26

The problem of specified snow loads on buildings, especially on industrial buildings, is extremely important in our country during this extensive growth in construction. However its accurate solution presents great difficulties.

When snow falls without any wind, it must be evenly distributed over the roof surface. But this is only at the beginning.

Because of inadequate roof insulation the building temperature begins to melt the snow unevenly. Where the snow is in contact with heat-conductive materials, e.g. glass (single glazing), the snow will melt more quickly than over wooden spans. This will also occur partly on warm roofs.

During snowfall with wind, snow will accumulate on roofs, but unevenly. Snow accumulates in protected places of low wind speed. However, if at a given wind flow direction and at a given speed snow accumulates in places of calm, at an increase of wind flow speed without a change in direction a place of calm is no longer calm and snow will not fall in this place. In places where snow accumulates at all wind speeds (i.e. in calm places) the snow accumulation will be the greater the higher the wind speeds for a given snow concentration, because the amount of snow passing through a square unit per unit of time will be greater with high wind speed than with low wind speed.

Even if only two factors are taken into account, temperature and wind speed for a given direction, the accumulation of snow is extremely complex. If all factors affecting snow accumulation on roofs are taken into account, i.e. the shape of the roof, the roughness of the roof, the speed and direction of the wind, physical properties of the snowflakes etc., it is not possible to solve this problem in total. It is only possible to take into account a given factor influencing the irregularity of loads if we can study one factor by eliminating all the rest. This condition forces the researcher to make use of models set up under artificial conditions.

Therefore the problem of determining accumulation of snow on roofs is to be solved approximately with sufficient accuracy for practical requirements.

Snow load specifications existing up to July 1933, were much too large, with insufficient basis and not reflecting the real snow loads.

The new specification OST 7626 (with a new edition OST 4535/3 being printed) can be regarded as a first approximation to the truth, although they suffer from a number of shortcomings and require more preparation particularly for complicated roof shapes.

The aim of this article is to explain standard 7626, pointing out this problem of the builder, and its estimation from the point of view of observations and experiments conducted at the Research Institute of Industrial Construction.

1. Basic Calculation Formula

"Unified Standards" determine snow loads from the mean of the maximum snow depths on the ground*.

"1. Snow loads in kg/m^2 of horizontal roof projection are determined from the mean of the yearly maximum observed snow depths on the ground in accordance with Table I.

The ground snow depth h, in centimetres, is taken from the nearest meteorological station as the mean of the maximum observations from the last ten years. Where there are no such records h is taken from the accompanying chart, and for mountain areas - from the accompanying table.

As a basis for snow load calculation the formula $P_s = 1.6h$ expresses that the largest snow load (P_s kg/m^2 horizontal roof projection at a pitch of 20° to 30°) depend largely on the ground snow cover depth (h in cm)."

If h is expressed in cm., then the dimensions of the coefficient 1.6 must be kg/m^2 x cm.

Expressing the length in metres, for a coefficient of 1.5, we obtain

$$\frac{kg}{m^2\ cm} = \frac{kg}{m^2\ m/100} = 100\ \frac{kg}{m^3}$$

Thus the coefficient

$$1.6\ \frac{kg}{m^2\ cm} = 160\ \frac{kg}{m^3}$$

gives the weight of snow per unit volume (1.4 per m^3).

* Table I, page 19, is a quotation from the Standard.

By giving the unit weight of snow a value of 160 kg/m^3 at the end of winter (i.e. in March) and not 240 to 250 kg/m^3, which is the actual unit weight, signifies that only 64-67 per cent of the snow on the ground accumulates on the roof.

The Research Institute of Industrial Construction, engaged in investigations of snow loads on buildings, have carried out measurements of snow accumulation on the roofs of industrial buildings. Such measurements were also carried out on roofs of the second stage of construction of 1 GPZ (Feb. 9, 1933). The building was not maintained and was heated very little during the 1932-33 winter, and therefore the influence of inside temperature on snow melt can be neglected.

Fig. 1 shows a snow load profile on a cross-section of the second stage of the GPZ shop. The horizontal axis shows the horizontal projection of the clerestoreyed roof cross-section and the vertical axis shows the total snow load on all four elements of each clerestorey span (the fourth part being the space between the clerestoreys) expressed in cm^2 of the snow accumulation cross-section.

If the load on all of the building was evenly distributed over its horizontal projection, the depth of snow cover would be 19 cm. If this is compared to the snow depth on the ground which, according to the records of Timiriazev Agricultural Academy was 27.5 cm. on March 9, it appears that snow loads for roofs of trapezoidal clerestoreys of type 1 GPZ in Moscow are 69% of the ground load, which is 2-4% greater than the calculated (the roof and ground snow densities according to our measurements were the same at 0.24 to 0.25).

To get roof and ground loads, we multiply the depth in metres by the unit weight.

$0.275 \times 240 = 66$ kg/m^2 for density of 0.24

or $0.275 \times 250 = 68.75$ kg/m^2 for density of 0.25

on the ground.

On horizontal projection of roof we have

$0.19 \times 240 = 45.6$ kg/m^2

or $0.19 \times 250 = 47.5$ kg/m^2

According to the calculation formula the evenly distributed load on the horizontal projection of the roof is

$$P_s = 160h = 160 \times 0.275 = 44 \text{ kg/m}^2$$

i.e. 1.6 - 3.5 kg/m^2 less than the actual, which is 3.6% for a density of 0.24 and 8% for a density of 0.25. Although the calculation is somewhat underestimated, it meets the actual value close enough.

2. Determination of snow load on a building

"For complicated roof profiles: with trapezoidal or rectangular clerestoreys (lengthwise and transverse), with unequal heights of the different parts, multi-bayed cylindrical roofs etc., the possibility of snow accumulation in lowered roof parts blown away from the higher parts should be taken into account. Therefore snow loads taken from the maxima of Table 1 (corresponding to a pitch of

20-30°) are reduced 50 per cent for higher parts, but are taken not less than 25 kg/m^2. This 50 per cent is transferred as an evenly distributed additional load on one side of the axis of the lower part of the roof.

If the higher roof part has a concave profile, no reduction of load on the higher part is made, but lower parts take an additional load of 50 per cent.

For roofs without attics, which are planned for melting of snow, the load is reduced to conform with the calculated heat conditions, namely:

(a) For roofs which have moderate heat loss (with a thermal resistance from 1.10 to 0.75) at inside temperature of 15°(C) and having 2/3 the roof area over heated air space, snow loads are reduced 50 per cent.

(b) For roofs with great heat loss (with a thermal resistance less than 0.75) and heat flow over 800 cal./hour/m^2 of horizontal roof projection, the snow loads are reduced 75 per cent.

(c) In addition, in the above cases, stresses are to be checked for the full snow load (with no reduction for melting) and the permitted stresses in the roof elements should be increased by 35 per cent."

Consequently, according to "Unified Standards" the loads on the profile GPZ can be calculated as follows:

The ground snow depth is determined from the table and chart* given in the standards. For Moscow this depth is 48 cm. From Table I (in bold print) for h = 60 cm. or less, the greatest load is 100 kg/m^2 (corresponding to a

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* Tables and charts are not given in this paper.

slope of 20-30°).

On Section I (Fig. 2) the load is

$Q_1 = 0.5 P_s L_1 = 0.5 \times 100\ L_1$ kg/lin. m.

$= 50\ L_1$ kg/lin. m., or $Q_1 = 50$ kg/m^2.

On Section II, the load taken is $P_s\ 0.5 L_2$ plus half the load on the higher section, or $0.5\ P_s L_1$, or a load

$$Q_2 = P_s\ 0.5\ L_2 + 0.5\ P_s L_1 = 0.5\ P_s\ (L_1 + L_2)$$

This load must be evenly distributed on length L_2. Therefore, the load per m^2 of projection of Section II is expressed as:

$$Q = \frac{0.5\ P\ (L_1 + L_2)}{0.5\ L_2} = \frac{100 \times 12.20}{8.10} = 152 \text{ kg/m}^2$$

On Section III of Fig. 2 the load is

$Q_3 = 0.5\ P_s L_2$ kg/lin.m. $= 0.5 \times 100\ L_2$

$Q_3 = 100$ kg/m^2

Since the roof of GPZ has moderate heat loss and an inside temperature of + 15°(C) according to "Unified Standards" the snow loads are reduced 50 per cent.

Therefore, finally, the load on

Section I, $Q_1 = 25$ kg/m^2

Section II, $Q_2 = 76$ kg/m^2

Section III, $Q_3 = 50$ kg/m^2

Figure 3 shows a comparison of actual snow load in kg/m^2 of horizontal roof projection from observations by the Research Institute with loads according to standard OST 7626. The jagged lines show the real snow loads on Section I, II and III and the horizontal lines show the specified load on the same sections. As seen, the actual snow loads on clerestorey 6 (Fig. 4) are larger only in some cases and then for short periods, not more than three to six days, than the specified. However, in general the actual snow loads are less than the specified.

Such a statement, however, can be made only for the winter of 1934-35 when snowfall was light. According to the weather records, the greatest snow depth in the Moscow river basin in the 1934-35 winter was 39 cm. on the second ten-day period of February. Consequently, for winters with great snowfalls, much greater actual snow loads than those specified and over longer periods of time are to be expected.

For roofs having two sloping surfaces or having a curved shape, "Unified Standards" recommend two calculations of snow load (1) full uniform load over the whole surface and (2) one-sided load on half the span.

Where a roof adjoins a high vertical surface the possible formation of snow accumulation should be considered equal to the wall height, but not greater than four times the ground snow depth (4h).

The unit weight of loose snow is taken as 100 kg/m^3.

Consequently, in this case the load

$Q = 2\ h\ 1\ 100 = 1.25\ P_s 1$ in kg/lin. m. (Fig. 5).

The standard gives no indication as to the length of triangular accumulation. However, from the aerodynamic consideration as given in assistant Prof. E. I. Retter's*

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* "Proekt i Standart" (Project and Standard), no.5, 1934.

article dealing with the influence of heights "New standards for wind loads on buildings", this length can be approximated by 20 h.

The unit weight of loose snow is recommended at 100 kg/m^3 by "Standards". Observations, specially taken by the Research Institute, have shown the unit weight of freshly fallen snow to vary between 85 and 190 kg/m^3.

Table 2 gives some unit weights of freshly fallen snow. From the table it is seen that the unit weight of new snow averages 135 kg/m^3.

3. <u>The Influence of Wind on Snow Load</u>

The influence of wind on snow load is taken into account by the standards as follows:

"For unsheltered localities, subject to strong and frequent winter winds (speeds of 12 m/sec. or more)* which prevents snow accumulation on roofs, the loads given in Section 1 (Table 1) are reduced 50 per cent, but not less than 25 kg/m^2."

Thus "Unified Standards" do not give any indication of the snow distribution according to the roof surface and depending on the wind direction. They take into account only the possible formation of snow accumulation in depressed roof parts calculated from the snow blown away from the higher parts. The direction of the wind, prevailing

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*"The wind speeds are taken as the mean of the maxima (seasonal) from the records of the nearest meteorological stations. A speed of 12 m/sec. corresponds to 7 on the Beaufort scale; a speed which sways tree branches or thin trunks."

during snowfall, are not considered by "Unified Standards" at all.

However, the significance of this factor is enormous.

To look at the influence of wind direction, the Research Institute made field observations on buildings during the spring of 1934 (April 14).

On this day, the snow accompanied with a northwest wind fell on the roof which was previously free of snow. The wind speed determined from a Vil'd weather vane reached 14 m/sec. (plate deflected to the horizontal position). The CAGI anemometer at this time registered a speed of approximately 24 m/sec. The temperature was -0.5° (C).

During this time on the I section of the GPZ roof, snow depths were measured on five of the clerestoreys: 13, 11, 6, 3 and 1 at their mid-section, perpendicular to the axis of the clerestorey (Fig. 4).

The following photographs of snow accumulation were taken at the time of observation.

Figure 6 shows a general view of clerestorey 13 after the April 14 snowfall. The sloped part of the clerestorey with windows is snowless. In the inter-clerestorey space the snow depth is minimum. Crossing to the other clerestoreys the snow depth increases appreciably.

Figure 7 shows the leeward side of clerestorey 3 and the windward side of clerestorey 2. The snow accumulated on the leeward side, whereas the windward side was snowless. Comparing these clerestoreys with the former, it is seen that in crossing the clerestoreys (in the direction of the wind), the amount of precipated snow is increased.

Figure 8 gives the change of snow load, totalled over each clerestorey, according to the wind direction. The abscissa gives the accumulated projection of clerestorey cross-section, and the ordinate gives the amount of snow detained by the separate clerestoreys, expressed in cm^2 of snow accumulation on each cross-section. In this form the curve distinctly shows, according to the ablation of the clerestorey depending on the wind direction, starting from clerestorey 13, the amount of snow precipitated on the clerestorey increases. This increase is observed to clerestorey 2, and then the load begins to decrease. Thus the magnitude of snow load on clerestorey 3 is 7.7 times the load on clerestorey 13.

Figure 9 shows the change of snow load on the Sections I, II, III, IV. From the graph, it is seen that, the snow load on Sections III and IV, lying in the leeward of the clerestoreys, increases to clerestorey 3 and then sharply decreases; the snow load on Sections I and II, lying in the windward of the clerestoreys, increases to clerestorey 6, and then gradually decreases to clerestorey 1.

Thus, if there is snowfall with wind whose direction is perpendicular to the clerestorey axis, the following conclusions can be made of the accumulation of snow on clerestorey surfaces.

1. The greater part of snow accumulates on the leeward part of the clerestorey (Sections III and IV).

2. The amount of snow accumulating on each clerestorey, and on each section of each clerestorey, increases (up to certain limits) in crossing from clerestorey to clerestorey in a direction perpendicular to the clerestorey axis and in the direction of the wind.

In the case of the snowstorm of April 14, the difference in the amount of snow accumulating on two clerestoreys was such that the load on clerestorey 3 was almost eight times (7.7) the load on clerestorey 13, located 120 m. apart. We shall try to explain the cause of uneven snow accumulation according to the roof profile.

If the problem of the motion of a snow particle in air is approached mathematically, it leads to the integration of differential equations of the motion of the particle, which in the end are not always possible to evaluate. Attempts at a mathematical approach to the study of the motion of a snow particle in air, which is tied to the problem of snow accumulation at obstacles, has been made by different authors.*

Among the most interesting is the work of Prof. N. E. Zukovskii.

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*Eng. Dolgov, N. E. Combatting snow on Russian railroads; Prof. Rykin, N. A. The work of the aeromechanical laboratories, publication of the Institute of Communication, Petrograd, 1914, No. II; Prof. Zukovskii, N. E. (1) on snowdrifts and (2) on snowdrifts and silting of rivers, publication of the listed articles of Narkomzem, no. 30 and others.

In his first article N. E. Zukovskii explains the following phenomenon. When a snowstorm carrying snow near the ground meets in its path motionless obstacles, then in front of the obstacle are formed snow hollows, and at some distance from the obstacle are formed snow mounds. Zukovskii simplifies the problem by supposing that the obstacle is a large long round cylinder whose horizontal axis is perpendicular to the wind direction.

By selecting a combination of flow paths whose total resultant flow would pass over the cylinder giving a complete as possible description of snow accumulation actually observed and N. E. Zukovskii gives a mathematical account of this process which is qualitatively well-known from observations in the natural conditions. The basic cause of snow accumulation in specific places remains obscure.

The second article of Prof. N. E. Zukovskii, "On snow drifts and silting of rivers", is devoted to the solution of the problem.

Considering the motion of a snow particle on a vertical plane only, Prof. Zukovskii gives the following equation of motion:

$$m\frac{d^2x}{dt^2} = k\,(U - u)$$

$$m\frac{d^2y}{dt^2} = k\,(V - v) - mg$$

$(U - u)$ and $(V - v)$ are the horizontal and vertical projection of the resistance of the air to the moving particles; U and V - the absolute component wind speeds on the x and y axis, which in general terms are functions of the co-ordinates and of time; U and V - the speed components of the snow particle on the same axes; mg - the weight of the snow particle.

The equations show, that in places of calm, i.e. where U and V are nearly zero, there is always an increased snow accumulation. The action of gravity sets out the primary motion in which snow particles begin to settle on the ground or roof. On the other hand, where the wind speeds U and V are large, we can neglect the weight of the particle in the above equations since its effect is relatively small. In this case the component of the particle speed is equal to the component of the wind speed, and the trajectories of the snow particles coincide with the lines of air flow.

Regarding the full determination of this problem, not considering in detail this very interesting article, it is necessary to determine mathematically the speed in each point of space.

Thus the unevenness of snow accumulation on the profile of one of the clerestoreys can be explained by the uneven distribution of wind stream speed at different points near the clerestorey profile.

An anemometer survey, taken on 1 GPZ, confirms this statement. Fig. 10 gives the speeds, measured in the space between the clerestoreys.

Measurements were taken by two Fuss anemometers. The speed at each point is expressed as a percentage of the wind speed at a height of 2 m. from the clerestorey surface. Measurements were taken at this point in every case and simultaneously with the speed measurements of the other points.

Figure 11 depicts the aerodynamic flow, obtained by photographing black ribbon, hanging in the space between the clerestoreys, spaced 1 m. apart.

Figure 12 shows a sketch of the flow, obtained in a tray in the hydrodynamic laboratory of Prof. N. E. Zukovskii in MGU. The flow was obtained by decomposition of water according to the method of Prof. D. S. Vil'ker. The tests were done by E. I. Retter, B. V. Gladkov and the author.

By comparing the distribution of wind speed in the inter-clerestorey space (Fig. 10) with the snow accumulation on the clerestorey profile (Fig. 6 and 7), it is seen that snow is detained in calm places. The deposition of snow is facilitated by the fact that near point A of Fig. 11 and 12 the wind speed vector forms an obtuse angle with all of the snow particle vectors. At point B this angle is acute.

The unevenness of snow accumulation over all the clerestoreys, taken at one cross-section, can be similarly explained, i.e. the increase of snow accumulating on a clerestorey is explained by the decrease of wind speed at this section. The snow-wind flow stream which has a force T upon contact with clerestorey 13 (Fig. 8 and 4) loses part of its energy. As the flow passes to other clerestoreys the loss of kinetic energy, owing to the retarding of the snow-wind stream becomes even greater. However, the decrease of speed is observed only to clerestorey 3, whereupon the speed again increases.

Thus the direction and speed of wind during snowfall renders enormous influence on the uneven snow load distribution on building roofs.

Uneven snow distribution is observed:

(1) Between separate parts of any one clerestorey - considering the same cross-section

(2) Between similar parts of different clerestoreys - considering the same cross-section.

(3) At stream flow directions not perpendicular to the clerestorey axis, different loads are observed also on the same part of a clerestorey but at different cross-sections.

TABLE I

(Multiply by 0.2 for p.s.f.)

No. Region	Characteristics of Region	Snow Load $P(kg/m^2)$ on Horizontal Projection of Surface									
		Angle of surface pitch								Curved roofs	
		0^{o}	10^{o}	20^{o}	30^{o}	35^{o}	40^{o}	45^{o}	50^{o}	Rise/span less than 1/6	Rise/span greater than 1/6
1	Without continuous cover	25	25	25	25	25	25	25	0	25	25
	Region with depth										
2	h is less than 30 cm.	40	45	50	50	40	30	25	0	30	25
3	h between 30 and 60 cm.	80	90	100	100	80	60	40	0	60	40
4	h greater than 60 cm.	120	135	150	150	120	90	60	0	90	60

TABLE II

1935 Date	Temperature	Wind Speed (m/sec.)	Snowfall Duration (Hours)	Depth of Fallen Snow (cm)	Unit Weight of Snow (kg/m^2)
5 Feb.	-2.6 -7.7	6.0	9	21	85
7 Feb.	-5	3.5	10	5	110
10 Feb.	-5.3	3.6	3	10	156
10 Feb.	-5.1	5.0	3	13	170
20 Feb.	+1.8	5.0	3	13	190
22 March	-5.3 -5.4	3.0	3	12	100

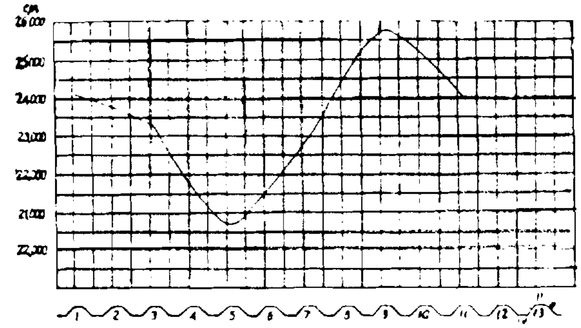

Fig. 1

Change of total clerestorey snow loads in cm^2 of cross-section
(GPZ on March, 1933)

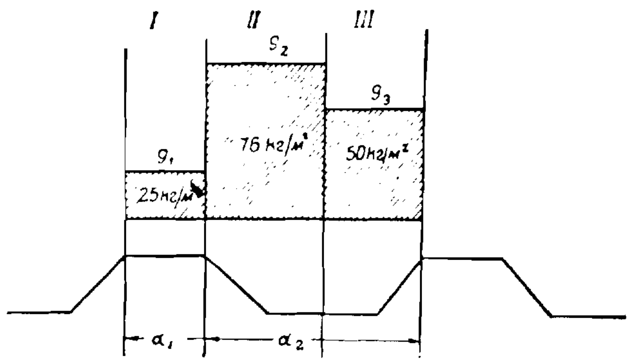

Fig. 2

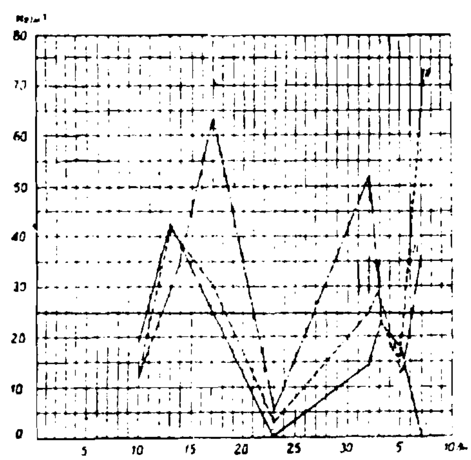

Fig. 3

Comparison of actual and specified snow loads in kg/m^2 horizontal roof projection on clerestorey 6 of GPZ during February and March

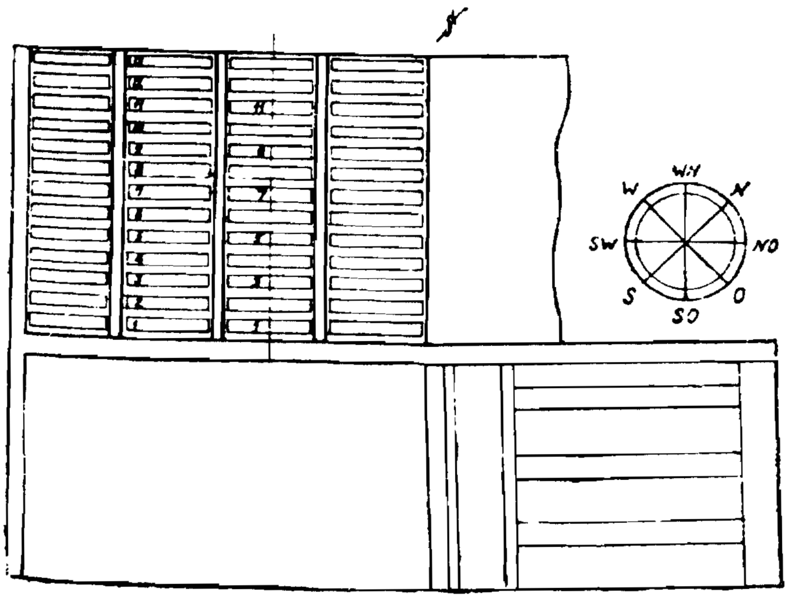

Fig. 4
Plan showing clerestoreys on 1 GPZ of the Kaganovitch works

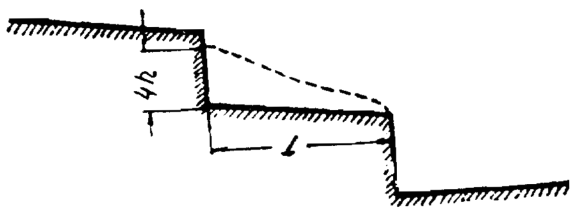

Fig. 5

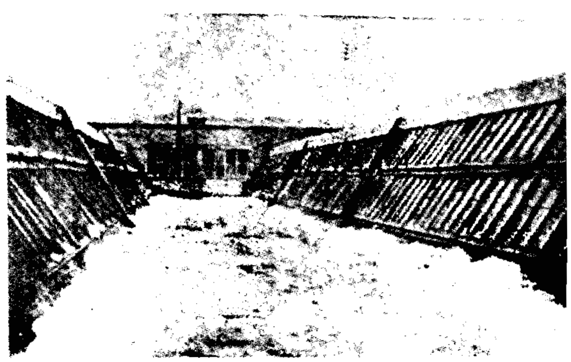

Fig. 6

Fig. 7

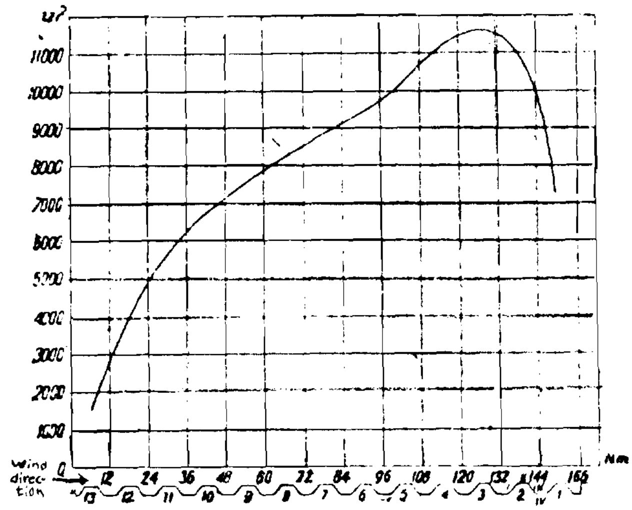

Fig. 8

Change of total clerestorey snow load according to the wind direction on April 14, 1934. 1 GPZ

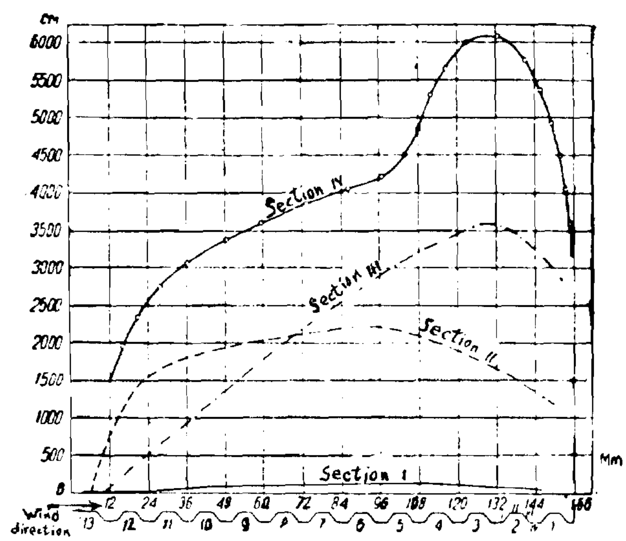

Fig. 9

Change of snow load according to wind direction on 4 sections of the clerestoreys April 14, 1934. 1 GPZ

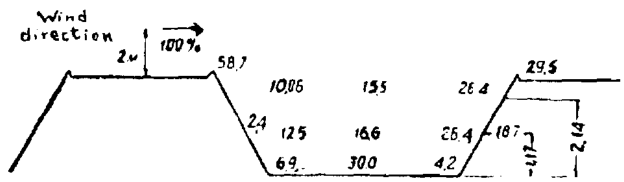

Fig. 10

Distribution of wind speeds in the inter-clerestorey space, 1 GPZ, June 16, 1934

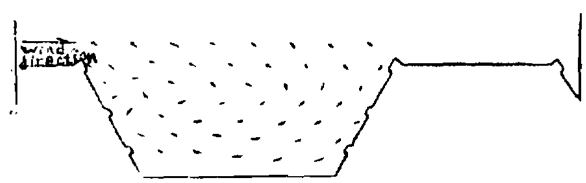

Fig. 11

Aerodynamic flow in the inter-clerestorey space, Jan. 8, 1934. Wind speed 6-7 m/sec

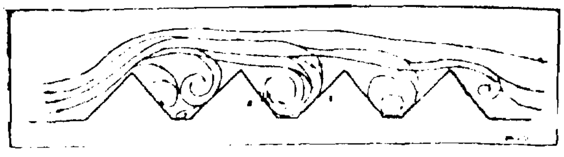

Fig. 12

SNOW LOADS SPECIFIED BY THE RUSSIAN BUILDING CODE

Translated from the Russian "Stroitel'nye Normy i Pravila (Construction Standards and Regulations)" Part II, Section B, Chapter 1, Para. 4, pp. 46-48 (Loads and Load Coefficients for Buildings and Industrial Structures).

Snow Loads

The snow load per square meter area of horizontal projection of roof is determined according to the formula

$$P_c = pc \qquad (1.4)$$

where p = weight of snow cover in kg/m^2 depending on the region of the USSR according to Table 4

c = coefficient depending on the profile of the roof according to Table 5.

The load factor "n" for snow load shall be taken equal to 1.4.

The Weight of Snow Cover P

Table 4

No.	Region of USSR (See Fig. 2)	Weight of Snow Cover in kg/m^2 (psf.)
1	I	50 (10)
2	II	70 (14)
3	III	100 (20)
4	IV	150 (31)
5	V	200 (41)

Note: In mountain districts, as well as in the regions of extreme north and far east the weight of snow cover p in kg/m^2 shall be taken numerically equal to 2h, where h = depth of snow cover in cm. taken from meteorological observations as the mean of the maximum yearly depth at a sheltered location for the past 10 years. In the mountain districts the weight of snow cover shall be taken not less than 60 kg/m^2 (12 p.s.f.)."

Value of Coefficient c

Table 5

No.	Shape of roof	c	Note
1	Simple roof, Pentroof and Gable roof slope $\alpha \leqslant 25^\circ$ $\alpha \geqslant 60^\circ$	1.0 0.0	At intermediate angles of roof pitch the coefficient c is found by interpolation
2	Simple arched roof	ℓ/10f	where ℓ = span of arch f = rise of arch The coefficient c shall not be greater than 1.0 nor less than 0.3
3	Complex roof with transversal or longitudinal clerestoreys, with unequal heights of separate parts, etc.	In accord with Fig. 3	The difference in height H is given in metres

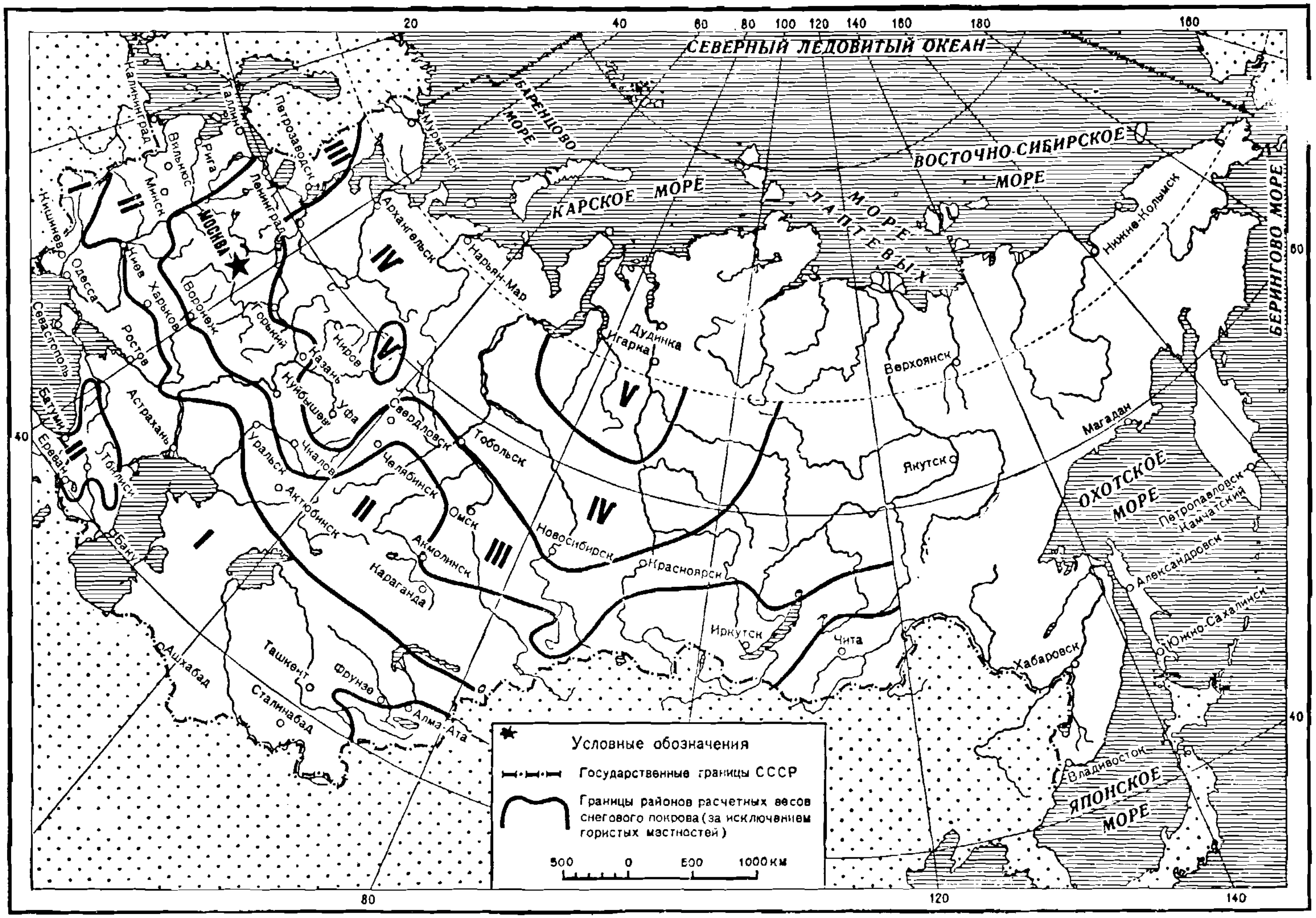

Fig. 2

[Map of U.S.S.R. for calculation of weight of snow cover according to Table 4]

* Notations: State boundaries of the U.S.S.R.

Boundaries of snow load values used for calculation (excluding mountainous regions)

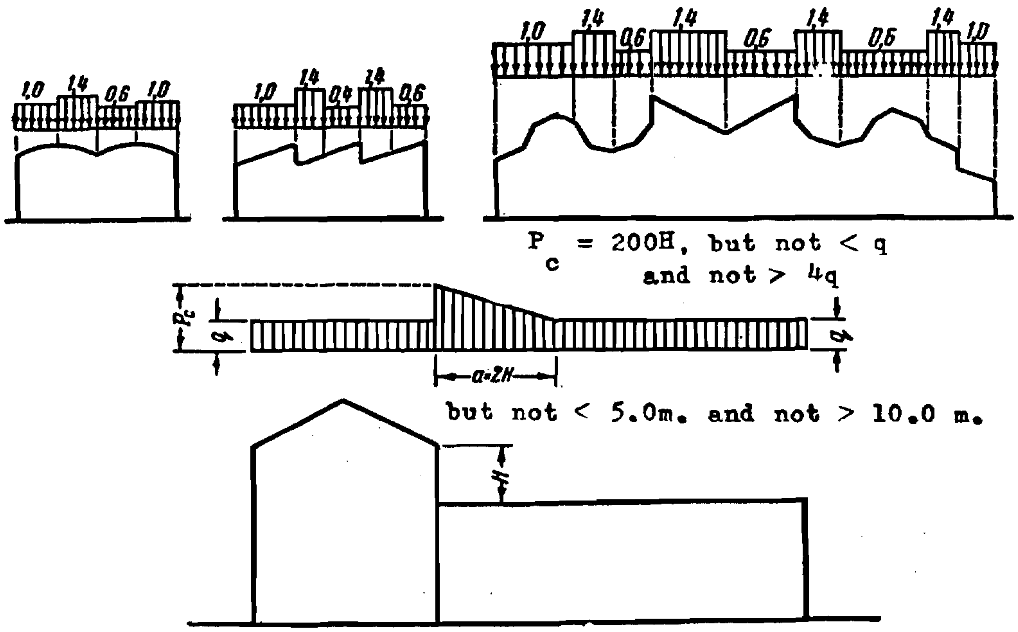

Fig. 3

Values of the coefficient C for different roof shapes

UNSOLVED PROBLEMS IN REGIONS OF INTENSE SNOWFALL

by V. P. Abovskii, A. M. Veksman, V. M. Volkov, G. V. Matysek (Engineers)
Translated from the Russian "Stroitel'naia Promyshlennost' (Construction Industry)", 1954, no. 11, pp. 30-31

Observations during more than 20 years of maintaining roofs of industrial buildings in Siberia show that those responsible for design of projects do not, to a considerable extent, take account of factual meteorological features which determine the mechanism and magnitude of snow cover on roofs.

For many parts of Siberia, wind records show that most strong winds during snowstorms come from the southwest.

This is confirmed from the basic meteorological observations during 1931-1952 given in Table I.

The coincidence of maximum meteorological factors given in Table I creates stable conditions for snow deposition behind obstacles.

Of significance is snow accumulation when there is no snowfall, i.e. wind-drifting of small snow grains from the ground or roof brings about a rapid shift of snow and vortical accumulation with compression behind obstacles.

This results, for those cases where the roof configuration does not allow a free sweep-past of snow, in intensive accumulation of snow drifts at the rate of 1 metre in 24 hours.

The unit weight of snow, from field measurements during January-February, is 300-350 kg/m^3 and in March increases to 450 kg/m^3.

Figures 1, 2 and 3 show instances of intensive snow accumulation.

The direct consequences of the described phenomena were in a number of cases, the quick development of structural deformation of load bearing structural elements of the roof which led to the failure of purlins and trusses.

Snow loads are especially significant for roofs with large areas, 4-8 hectares, which are now being encountered more often, especially because a satisfactory mechanized method of snow removal on roofs has not yet been devised. Of interest is the construction of an industrial building in Siberia, whose roof is shown in Fig. 1.

Sudden overloads of snow on a roof under construction brought about deformation failure of the trussed beam supporting the roof. In one case, one formation of purlins had a sag of 17 to 24 cm. which is 3 - 4 times larger than the allowable; in other cases the failure of supporting slant members of metal trusses brought about sagging in the chords on the average of about 60 cm. (Fig. 4).

However, there was no failure of the roof supporting beams or the roofing slabs. This is explained by the continuous wire ties between concrete roofing slabs and the bond of the cement joint-filler, resulting in a roof that is to some extent monolythic and thus able to carry a load independently over a considerable span without collapse.

In the above case of purlin deformation, after removal of the snow load, the slab base shifted because of the residual deformation of the purlin and assumed a mean location between the designed and maximum sag in places of overload.

To sum up, it is necessary:

(1) to quickly bring into reality the decision of the Technical Office of the Ministry of Construction dealing with the problem mentioned here. The decision noted "that the Research Institute (TsNIPS) and Hyprotis up to now have not been giving proper attention to the highly serious problem of finding a specification for snow deposition on roofs of industrial buildings and that a method of protection against snow loads on industrial buildings must be an indispensable part of the project".

(2) to refrain from a formal attitude toward the design of roofs of industrial buildings in Siberia and the Far East but to take into account the influence of local meteorological conditions.

(3) to design roofs of a shape which provide for a maximum sweep away of snow; in particular it is desirable to arrange roofs without vertical projections in the direction of the prevailing wind, with clerestoreys arranged parallel to wind direction with a streamline shape of the clerestorey ends; in cases where it is possible, to substitute for roofs with clerestoreys ones without clerestoreys.

(4) For roofs of large size, having more than two slopes, the possibility of mechanized snow clearing should not be over-rated especially since during a snowstorm, clearing is not possible.

On the basis of the foregoing, one can conclude that in those cases where on a roof part there is observed intensive snow accumulation, the structural calculation of roof trusses for this part must be based on actual accumulation, i.e. structures must take the snow load even if a minimum coefficient of research is used.

The scientific investigation and planning organizations must soon generalize available methods of roof maintenance in Siberia, the Far East and other regions of the Union. Along with this the problem should be thoroughly studied in laboratory conditions, since the data used at present, those on which the standards are based, and those used in technical literature have become obsolete.

Table I

Wind Direction	N	NE	E	ES	S	SW	W	NW
Wind Frequency %	4	6	7	13	25	32	10	3
Mean Wind Speed m/sec.	2.6	3.0	2.6	3.6	5.4	6.2	4.8	2.8
Snow Storm Wind Frequency %	0.1	0.1	0.5	3.0	29.0	56.0	11.0	0.4

Fig. 1

Snow on a roof between the south ends of the clerestoreys and the wall protruding above the roof. The snow depth is 2.3 m

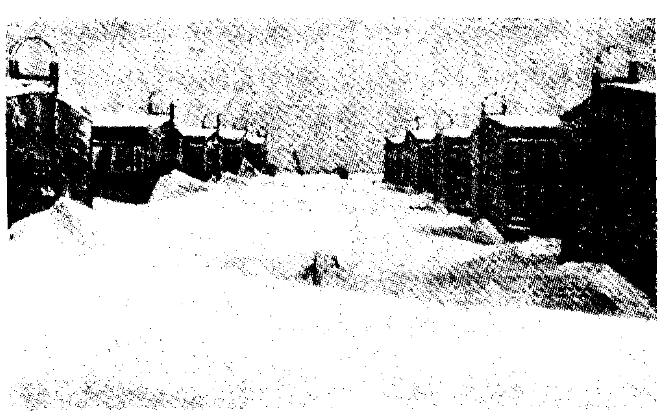

Fig. 2

Snow drifts between the ends of the clerestoreys.
Maximum snow depth is 1.9 m

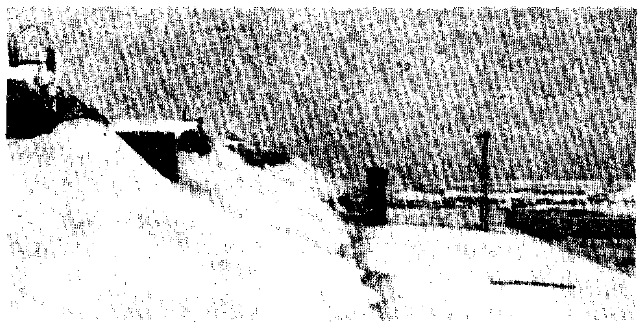

Fig. 3

Snow drifts on a roof along the north ends of the clerestoreys

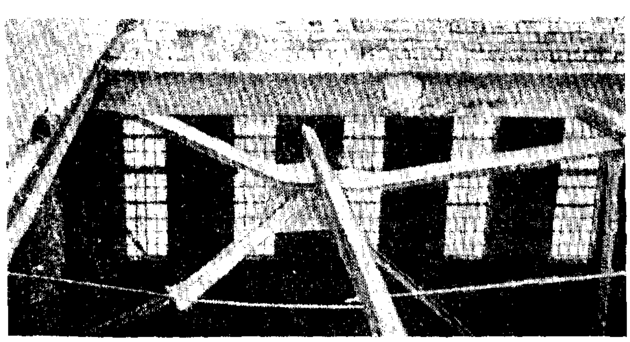

Fig. 4

Metal roof structure after removal of roof slabs (view of the deformed upper chord and strut support failure)

THE PROBLEM OF SNOW LOAD SPECIFICATION

by E. D. Kan-Khut

Translation from the Russian "Stroitel'naia Promyshlennost
Construction Industry" 1954, No. 12, pp. 22-23

In the regions of the USSR where there are frequent and strong winds (for example, in most of Kazakstan) snow never accumulates on flat roofs but does accumulate as great drifts behind roof projections.

Up to now, standards on snow loads (OST 90/058-40) and building standards and regulations do not take into account these local features of climate in sufficient measure.

In Fig. 1 is an illustrated contradiction between the specified standard and the actual load (taken in Karaganda Province).

(a) For flat roofs with slight slope, the established standard load is 70 kg/m^2 (14 p.s.f.)

Snow on flat roofs as the above is not retained. Even in the case of snowfall without wind, which is extremely uncommon in Karaganda, the load on flat roofs never comes near to the standard specified. Only once in 8 years (1933-1940) was the monthly snowfall more than 10 cm. (4 in.) which is, with a density of 200 kg/m^3 of loose snow (not packed by the wind), a load of no more than 20 kg/m^2 (4 p.s.f.). It should be taken into account that there are no long periods in Karaganda without strong winds, which sweep all the snow from flat roofs. Therefore for flat roofs with small slope (up to 10°) a maximum load of 20 kg/m^2 (4 p.s.f.) can be used.

The thickness of ice deposit on roofs is usually small and ice formation is located for the most part near cornices. Because of this, one can assume that ice does not affect the design load for roofs very much.

(b) For a roof near the walls of a roof projecting higher the OST 90/058-40 standard specifies a load of 93 kg/m^2 (19 p.s.f.), and the building standards and regulations a snow load of 112 kg/m^2 (23 p.s.f.).

If the coefficient of overload of 1.4 is taken into account, the standard load becomes 112 kg/m^2 x 1.4 = 157 kg/m^2 (32 p.s.f.).

The actual snow load depends first of all on the height of the projection H. Up to a certain value of H (which will differ for different localities), a maximum height of snow drift of 0.9H, and an average of 0.7H can be assumed (Fig. 1).

From measurements on building constructions in the Karaganda it was determined that the density of snow drifted behind a projection reaches 350 kg/m^3.

For example, taking a height of projection H = 2.0 m. which is not very large, we obtain a load which in this case is the actual load

$p = 0.7H \quad = 0.7 \times 2.0 \times 350 = 490$ kg/m^2 (98 p.s.f.),

or approximately three times the standard specified.

Periodic snow removal from roofs does not prevent large snow accumulations behind projections, since snow removal from behind projections is out of the question during snowstorms with wind speeds from 15 to 40 metres per second.

(c) For inclined roofs the specified snow load decreases from 70 kg/m^2 (15 p.s.f.) to 0 kg/m^2 with the following increase in slopes: according to OST 90/058-40 from 25° to 50°, according to the building standards and regulations from 25° to 60°.

Actually on the leeward side of roofs with a slope of 35° - 45° snow accumulations up to 1.0 metre high have been observed (Fig. 2), that is a load reaching 350 kg/m^2 (70 p.s.f.).

The reason for the contradiction between specified and actual snow loads in places where there are high and frequent winds, is that in deriving the data only the amount of snowfall was considered, whereas distribution of snow is also a function of the wind speeds. Both OST 90/058-40 and the structural standards give the same snow loads for Minsk and Karaganda, whereas snow is distributed on roofs differently in Kazakstan where there are higher winds than in Byelorussia.

The incorrect consideration of snow loads leads to the following errors:

(1) All roofs with a slope less than 10° and without projections have specified loads which are too large and are never encountered in practice.

A decrease of the specified load (from 70 to 20 kg/m^2 in Karaganda) provides a saving of about 8 rubles/sq. m. The introduction of a supplement to the existing standard snow loads for some regions of the USSR would provide an economy of many millions of rubles every year.

(2) All roofs having steep slopes or projections have specified snow loads which are much less than the actual loads. Because of this in one of the regions deformations and even collapses occur often.

In connection with the use of light constructions, the ratio of snow load to total load becomes more important; therefore the problem of correct estimation of snow load acquires special importance.

In our opinion, it is absolutely necessary that the Central Committee (Ts.N.I.P.S.) as soon as possible organize field observations and work out specification proposals for snow loads which take into account the actual accumulations of snow in relation to the velocity of the wind.

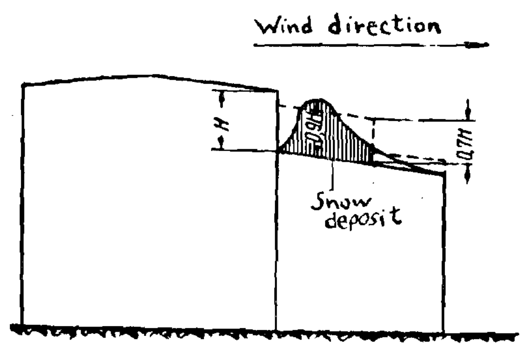

Fig. 1

Shape of snow-drift on a roof ledge

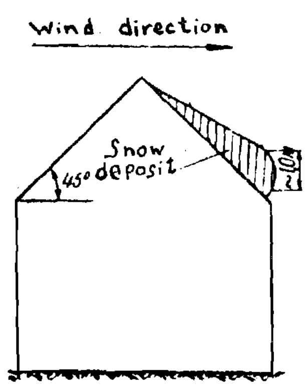

Fig. 2

Snow-drift on a steeply pitched roof

SNOW LOADS ACCORDING TO STRUCTURAL STANDARDS AND REGULATIONS

by I. I. Golden'blat, B. G. Korenev and A. M. Sizov (of the Central Research Institute of Industrial Construction - TsNIPS)
Translation from the Russian "Stroitel'naia Promyshlennost' (Construction Industry)", 1956, no. 6, pp. 25-27.

In connection with the preparation of "Construction Standards and Regulations" and observed large permanent deformation of load carrying members of some industrial roof structures(1) the Research Institute of Industrial Construction carried out an examination of snow loads. The distribution and magnitude of snow loads were examined in all parts of the USSR. Also investigated were the influences of snow loads in causing excessive building deflections and roof failures which were reported after heavy snowfalls.

The magnitude of the design snow load on a building roof depends on: the quantity of snow precipitating on the ground in the area, i.e. meteorological data, the roof shape and building dimensions, regularity of roof maintenance.

Besides these principal factors determining roof snow loads, there are others which must be accounted or corrected for; i.e. wind speed and direction, the ability of snow to be drifted, and also the presence on roofs of ventilation ducts, pipes, parapets, etc.

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(1) See from V. N. Abovskii, A. M. Vekman, V. M. Volkov, G. V. Matysek "Unsettled problems in the planning of industrial buildings in regions of intense snowfall" to "Building Industry" No. 11, 1954

Taking into account factors is extraordinarily difficult and undoubtedly leads to complex functional relationships.

Such a problem is usually approached in engineering practice at the start by picking out the principal causes of such phenomena, investigating them, and then drawing conclusions which are verified in practice. Meteorological data, the roof shape and building size, most obviously influence the calculated snow load. We shall consider the influence of roof maintenance conditions on the snow load.

The problem is purely an economic one and there are two possible points of view at its solution.

The defenders of the first point of view, who aim mainly at reducing maintenance cost, maintain that snow loads should be stated without regard to possible snow removal from the roofs because of the difficulty of snow removal from large roofs and the necessity of having special staff for carrying out the work, etc.

The defenders of the second point of view, who aim at reducing building costs, maintain that calculated snow loads should be given for standard roof designs taking snow removal into consideration.

In the "Structural Standards" snow loads are adopted taking into account proper maintenance and snow removal from the roofs. The setting of roof snow loads from meteorological data only leads to excessive cost which is highly undesirable, especially in view of the extensive construction and the need for great economy in materials.

The distribution and magnitude of snow loads for different geographic regions were analysed from meteorological records taking into account peculiarity of the region.

Standard snow loads are determined as the mean of maximum yearly snow cover from 10 years of observations at a protected location, using a unit weight of 200 kg/m^3 for snow.

It is necessary to point out that the snow load adopted by the Standards Committee for buildings takes into account experience in construction and maintenance of buildings using the earlier snow load standards.

The general analysis of snow loads made it possible to derive a more precise value for the snow load and to increase it for regions with large snow cover.

For example, for regions adjoining Novosibirsk, Kemenof and Tobolsk, the snow loads of "Structural Standards" were raised to 150 kg/m^2 (30 p.s.f.) from 100 kg/m^2 (20 p.s.f.) from the earlier standard OST-90058-40.

To assess the effect of snow load on roof structures where excessive deformation or collapse occurred after heavy snowfalls, comparisons of stresses were made between the condition of actual snow loads and the condition of snow loads from OST-90058-40.

As an example, Fig. 1 shows part of a cross-section of an industrial building measuring 189 x 114 metres

(620 x 375 ft.) with a roof supported by steel trusses. This figure also shows a snow accumulation of triangular shape behind the clerestorey of the truss in bay 11-12. The roof collapsed at this span due to this condition.

A comparison of the stresses in the truss members from the dead load plus snow load according to OST-90058-40 and from the dead load plus actual snow load of triangular shape, is shown in Fig. 2.

From this it is seen that actual snow loads greatly exceed the design stress in most of the truss members. The greatest increases occur in the members having small stresses and in the members directly loaded (e.g. in bar V_5 where the increase of stress is most significant; i.e. from 688 to 1822 kg/cm^2 (9.8 to 25.9 ksi.) or 165%).

The analysed stresses of a number of buildings located in different geographic regions revealed the influence of actual snow loads in the permanent structural deformations of a number of roofs.

These analysed stress conditions of structures established the following:

(1) Roof constructions having large permanent deflections after heavy snowfalls were found to have defects. Snow loads were the decisive factor in causing large permanent deflections and collapse in some cases.

(2) The density of the snow measured after causing large deflections exceeds the average density of newly fallen snow, which testifies to the fact that snow was not cleared off the roof and as a result it became compressed.

(3) These permanent deflections after strong snowfalls were observed in diverse geographic regions.

(4) Snow on roofs is distributed irregularly and accumulates in lower roof sections.

To get actual records of snow distribution on roofs, field observations of accumulations on a number of industrial buildings were taken in the 1954-55 winter near Moscow. Figure 3 shows a plan of an industrial building roof measuring 125 x 60 m. (410 x 197 ft.) with a two-storey lean-to, where accumulation observations were conducted. On this plan, the plotted isolines of snow load show how irregularly the snow is distributed accumulating at the walls of projecting roofs near to the shape of a triangle as seen by the distribution. The height of the snow load triangle reaches 350 - 400 kg/m^2 (70 - 80 p.s.f.), which exceeds the standard snow load for the Moscow area by 3.5 to 4 times. On the other hand, the results of the observations show that for the whole roof the total snow loads do not exceed the standard.

These investigations of irregular snow load distribution on roofs suggest refinements for standard roof designs as an addition to "Structural Standards and

Regulations" in which, for roofs which are properly maintained, snow removal should be taken into account.

As a supplement to the redistribution of snow load on complex roofs analogous to the redistribution used in the previous standard OST-90058-40, an additional rule was introduced to take into account snow accumulation on roofs at the walls of storey projections.(2) This rule can be formulated in the following way.

On lower roof at walls or projected storeys snow accumulations of triangular shape are possible.

The magnitude of the standard snow load on the lower roof at roof projections is taken as Pc = 200H, not more than 4P and not less than P (Fig. 4), where H = height of projection in metres; P is the standard weight of snow according to the Research Institute (TsNIP) in kg/m^2.

The length of triangular snow a is taken as a = 2H, not more than 10 not less than 5 metres.

It is our opinion that this rule for taking triangular snow accumulation into account does not apply to differences in roof levels formed by light or ventilation clerestoreys, since on window surfaces systematic snow removal is necessary. On these sections the snow load should be calculated with a snow drift coefficient of 1.4.

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(2) Similar recommendation in a somewhat different form was provided in the standards on snow loads OST/BK7626b (1 June 1933) and replaced by OST-90058-40 (1 August 1940).

Where window openings occur in a wall of a higher building standing adjacent to a lower building the difference in height is taken from the bottom of the window opening to the surface of the lower roof.

Combinations of the principal loads with triangular snow load can be treated as a supplementary factor, and in the calculation of the columns and stanchions supporting the roof, one can neglect triangular snow loads.

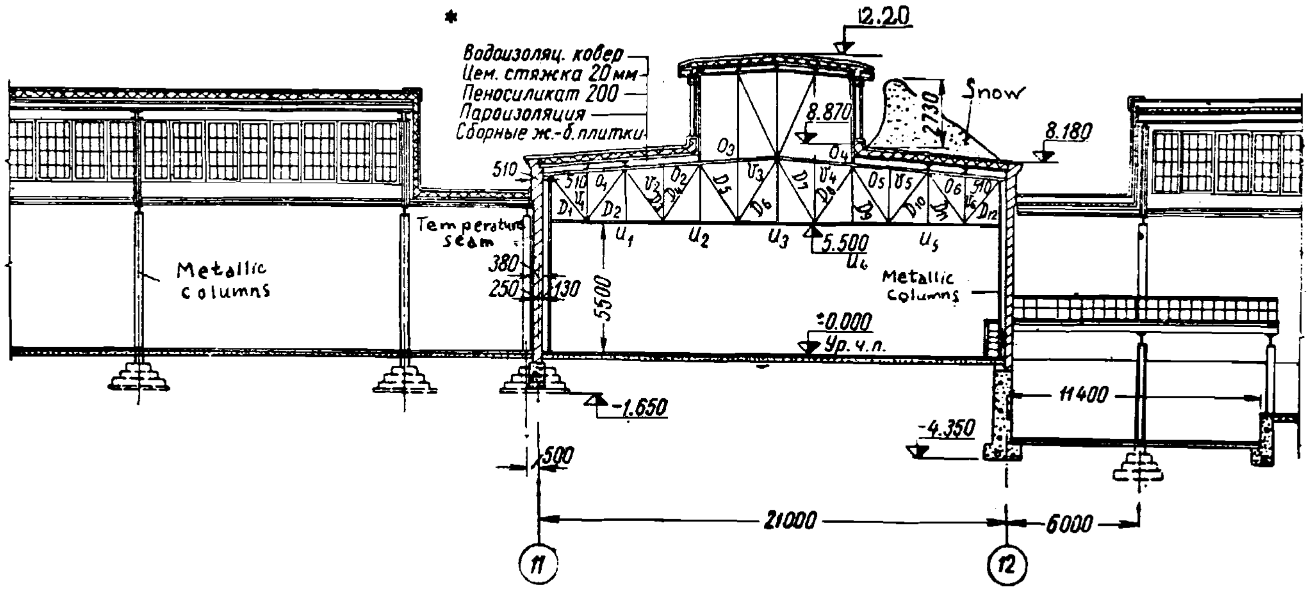


Fig. 1

Cross-section of a shop and snow accumulation in bay 11-12

* Waterproof layer
Cement parging 20 mm
Foam silicate 200 mm
Vapour barrier
Concrete slabs

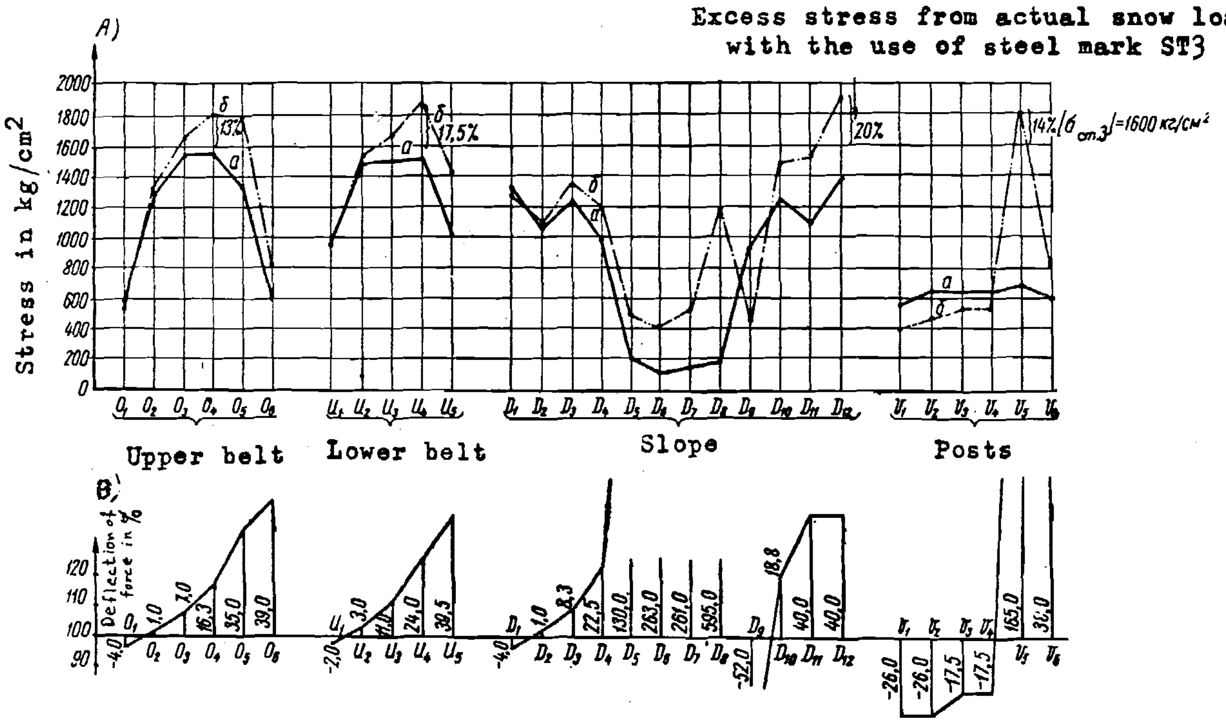
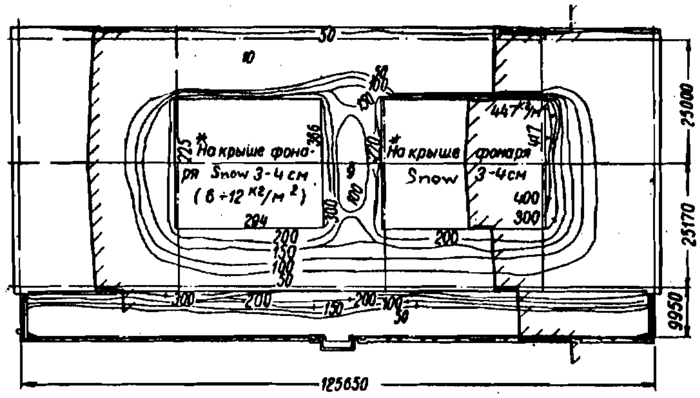


Fig. 2

The influence of overload of snow on ceiling truss

A. Stresses in the legs of the truss for different types of loading: (a) from the permanent load according to the design and snow loads according to OST-90058-40; (b) from the permanent load according to the design and actual loads of snow

B. The deviation of forces in the elements of the truss with snow from standard taken at 100%



* on the roof of clerestorey

Fig. 3

Plan of roof of building with curves of equal snow loads

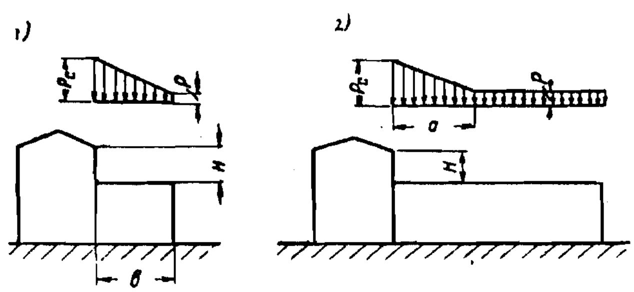


Fig. 4

Snow loads in places adjoining buildings of different heights
1 - when b < a; 2 - when b > a; (1 - length of triangular snow accumulation; 2 - length of adjoining lowered building)

SNOW LOADS

by E. D. Kan-Khut
Translation from the Russian "Stroitel'naia Promyshlennost (Construction Industry)" 1957, no. 1, p. 50

In recent issues of the "Construction Industry" the problem of determining a snow load standard for industrial buildings is examined repeatedly.[1,2,3,4]

In our opinion, the authors' (Golden'blat, Korenev and Sizov) latest recommendation is too simplified an approach towards a specification of snow loads for design. They consider that the quantity of snow load in different regions of the Soviet Union can be represented only by the thickness of snow cover, thereby presuming that for all of the Union snow can be regularly cleared from the roof and in such a way avoid possible overload of roofing construction. Such an assumption appears to be erroneous.

In connection with this, since the main capital investments of the sixth Five-Year Plan occur in the eastern part of the Soviet Union including Zapolyari, Kazakstan and different regions of Siberia, it is most important that there be a correct method of establishing snow loads. These regions frequently experience violent snowstorms with wind speeds from 15 to 40 m/sec. (34 to 90 mph). The most powerful blizzard usually occurs in the spring, is usually accompanied by snowfalls, and lasts 2 to 7 days and sometimes more. With such powerful winds it is not possible to clear off the roof. During blizzards, the snow is drifted from high places until the drifted snow almost reaches the height of projections and there are no measures for snow removal that can reduce the maximum load of drifts. Further, it must be considered that during snowstorms the snow is almost always wet and is packed by the wind to a unit weight usually more than 200 kg/m^3 (which is the density assumed for the same conditions by the standard loads).

The authors of the above-mentioned article consider that snow load among clerestoreys can be figured from a coefficient of snow drifting of 1.4. However this coefficient is small for many eastern regions of the Soviet Union having powerful winds and for the standard snow load, the formula given by the Regulations (Ts.N.I.P.) for adjoining buildings of different heights should be used (i.e. $P_c = 200\ H \quad 4P$ where H = projection height in meters and P is the standard snow load in kg/m^2).

The example of the steel truss cited by the above authors (Figs. 1 and 2 of their article) is not very convincing. The indication that even on uncleared roofing actual snow load creates stresses only 20% above the allowable refers only to the example given which represents buildings with obsolete roof construction. If the authors considered prefabricated reinforced concrete roofing panels 6 to 12 metres long, then the increase of stress at the same snow load would be considerably greater. Generally, it should be considered that in the transition towards lighter roofing construction, the relative significance of snow loads increases and it is therefore especially important to have a correct snow load standard.

Conclusions

1. To avoid possible structural damage because of incorrect design snow loads in the extensive eastern regions of the country, there should quickly be worked out and published additional instructions in the Regulations (Ts.N.I.P.) which define the snow load boundaries. The snow load between clerestoreys of industrial buildings should be calculated from the formula $P_c = 200\ H$ 4P of the Regulations (Ts.N.I.P.) as for the case of adjoining buildings of different heights. For combinations of other loads with snow load, only loads which often repeat themselves should be considered.
2. It is necessary to review the standard weights of snow cover for each region, because multiplying the depth of snow cover by a unit weight of 200 kg/m^3 gives snow load values that are evidently too low.
3. Mechanical, pneumatic, chemical or other methods should be considered in the near future for easy removal of snow from the roof. This is especially important because in many industrial buildings erected in standard sections, snow can be removed from the roof only over the ends of the building which is difficult to do.

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LESSONS FROM TWO ROOF COLLAPSES

by A. M. Korablinov, L. S. Krauze (Engineers)
Translation from the Russian "Stroitel'naia Promyshlennost (Construction Industry)", 1957, no. 7, pp. 18-21

At the end of December 1956 in the Urals with the temperature at -13°C, failure occurred in the three-hinged arches and supported structures in the middle parts of a storehouse of raw mineral materials built and put to use in 1951.

The storehouse, 234 metres long, was divided by temperature joints into three sections - north, middle and south. A plan of the storehouse is given in Fig. 1.

Its construction consisted of metallic three-hinged arches of trapezoidal shape with a span of 30 metres and spacing of 6 metres. Located at mid-span 14 metres above grade was a longitudinal conveyor tunnel. The storehouse roofing consisted of corrugated asbestos-veneer over the purlins. Along the store was a luminous clerestorey with vertical windows (Fig. 2).

In the south roof of the middle section the arch roofs of spans 29, 30 and 31 were reinforced because of the location there of loading equipment.

According to the evidence of eye-witnesses collapse began with span 28 and spread to the north; the west side collapsed first followed closely by an eastward spread. Falling first, the west half of arch 28 received the greatest deformations being bent 180° from the flat position (Fig. 3).

The reinforced arches, located in spans 29, 30 and 31 withstood collapse although individual members (purlins, trusses, etc.) received considerable damage.

From the meteorological observations the general precipitation of snow in this region is given by the following records (in mm.).

1951-52	74.4
1952-53	129.5
1953-54	102.1
1954-55	134.8
1955-56	85.9
1956 to Dec. 26	147

After the collapse the snow layer on the roof remained on part of the store, from which the actual snow load was determined. The snow depth consisted of:

(a) on the roof of the conveyor gallery 150-200 mm.

(b) above the luminous clerestorey - 500 - 750 mm. reaching 1100 mm. on the western side and 900 mm. on the eastern side

(c) on the inclined part of the arches (constant slope) 570 mm.

Mixed with the snow was a great quantity of dust and ashes, the mixture having a unit weight of 235 kg/m^3. Thus the actual snow load on the inclined arches was 134 kg/m^2.

The snow cover on the arches is shown in Figs. 4 and 5.

The design of the storehouse was based on the conditions of the standard OST-90058-40 which for the inclined roof gives a snow load of 60 kg/m^2. Thus the actual load was more than twice the design load.

In checking the arch members for actual snow load it was found that the stress in them reached the limit of instability, which resulted in the buckling of arch 28, this being the fundamental cause of the failure.

Somewhat later in about the same locality a failure of two metal trusses in another shop roof occurred. The shop consisted of two spans with a middle clerestorey. The roof section is shown in Fig. 6.

The shop roof was covered with corrugated asbestos veneer, two layers of mineral wool, total thickness 90 mm., cement filler 35 - 40 mm. thick and an impermeable cover.

In the south (leeward) bay, the slanting member in two of the trusses (from the left support) buckled. This resulted in a sagging of 600 mm. in the lower truss assembly. The truss construction of the clerestorey averted collapse.

Snow on the roof had a considerable admixture of industrial dust. The unit weight of snow cover was 220 to 390 kg/m^3. The actual snow load, according to the measured depths on different places reached 500 kg/m^2.

Thus the maximum snow loads on one sq. m. of roof exceed the design by nearly five times. This led to the first assumption, i.e. that excessive loading was the only reason for collapse. However, subsequent specification reflected that snow cover on a roof has a shape approximating a triangle and therefore the general snow load only exceeded the design load slightly.

The dead loads were somewhat greater than the design loads because the thickness of the concrete slab was nearly twice as large as the stipulated design. The total load on the truss (dead and snow) was 51.73 T against 36.6 T according to the design or 141%. In the damaged slanting member 8 (see Table) with the calculated loading the force was 11 T and the stress was 1390 kg/cm^2. Even accounting for the increase in actual loads, the stress in the slanting member should not have reached the limit threatening damage.

The trusses of the adjacent bays, designed as simply supported members were actually made continuous. A check was made of the design and actual loads for this building. The results of this check calculation are given in the table in the form of values of the forces in the truss members and for comparison, the forces calculated for a simple truss are given.

The following table clearly presents the redistribution of force in the truss members as a result of the change of statical arrangement and a change to continuous structure. Assuming continuity, the stress at the cross-section that failed is 2170 kg/m^2 at the design load and 3100 kg/m^2 at the actual load.

Member		Calculated Truss Force in Tons		
Type	Designation from left side of truss	Simply Supported at the design load	Continuous at the design load	Continuous at the actual load
Upper Chord	1	0	0	0
	2, 3	-37	-21.4	-22.9
	4, 5	-52	-24.6	-29.6
	6, 7	-52	-15.4	-20.4
	8, 9	-41.5	+ 2.1	+ 2.7
	10	0	+19.8	+26
Lower Chord	1	+21.5	+12.8	+13.9
	2	+46.5	+24.6	+27.9
	3	+53.5	+21.4	+27.1
	4	+47.7	+ 7.3	+11
	5	+18.8	-12	-15.8
Slanting members	1	-30	-18.2	-19.3
	2	+21	+10.8	+11.9
	3	-14.2	- 4.8	- 7.7
	4	+ 7.7	- 0.6	+ 1.9
	5	- 2.5	+ 5.3	+ 3.9
	6	- 2.4	- 9.5	-10.2
	7	+ 7	+13.9	+16.9
(Failure)	8	-11	-17.2	-24.6
	9	+29.5	+13.1	-17
	10	-24.5	-10.7	-13.6
Vertical Members	1	- 3.8	- 3.8	- 3.1
	2	- 3.8	- 3.8	- 4.5
	3	- 3.8	- 3.8	- 5.3
	4	-10	+ 5.6	+ 9.5

This shows that by adding more members to strengthen the structure such as ties or other members without strictly observing the conditions of statics, can lead directly to the opposite results.

No matter how different were the structures that failed, and how different the circumstances leading to failure, there are several general conclusions which may be offered.

(1) In both cases snow had considerable admixture of industrial dust and ashes, which increased the unit weight of snow cover, and in the case of the storage barn created a higher frictional coefficient between the snow cover and the roof. This explains the formation of 570 mm. of snow on so steep an inclination.

In our opinion the same approach to the calculation of roof snow cover cannot be made for conditions of probable snow pollution by industrial waste.

The scientific research institute must study the influence on snow load calculation for conditions of industrial waste admixture.

(2) Since the snow loads from the earlier standards for the Urals are much below the actual for this last winter, the loads must be revised in this region. First of all those structures which are light and for which snow loads are predominantly significant, must be checked.

(3) It is necesary to increase the design accuracy and responsibility for the quality of building construction. It should be noted that in the raw material warehouses the arch rise is very small at 1/67 of the span and the design must therefore be carried out especially thoroughly.

Damage of the metal structure of the shop roof is an instructive example of the danger of arbitrarily changing the structural design of a building.

(4) Maintenance of the roofs of many buildings is not carried out satisfactorily. It may be that for multi-bayed buildings of very large size snow removal from roofs sometimes becomes a complicated problem. However in the two cases examined here snow removal would not have presented any difficulties.

The formation of snow drifts 1.6 m. high (almost the height of a man) on shop roofs of metal construction could not have gone unnoticed and should have caused uneasiness about the condition of the roof; nevertheless no measures were taken to clear the roof of snow.

Designers must undertake the development of mechanisms which quickly clear the snow from roofs which are difficult to clear with the usual methods.

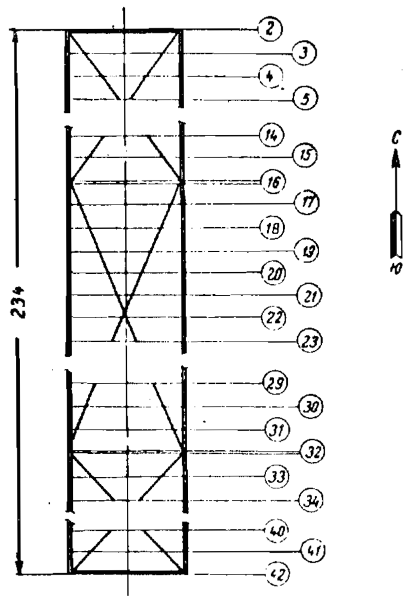

Fig. 1

Plan of the storehouse

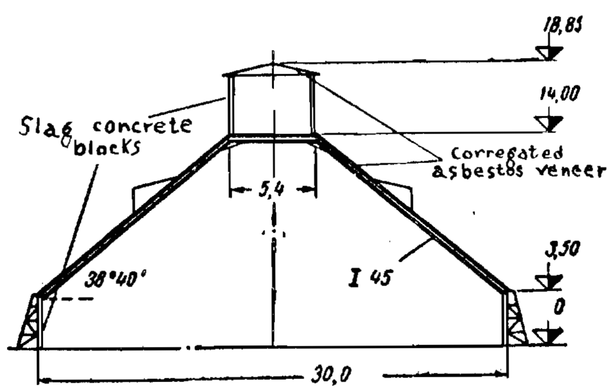

Fig. 2

Luminated clerestorey with vertical windows

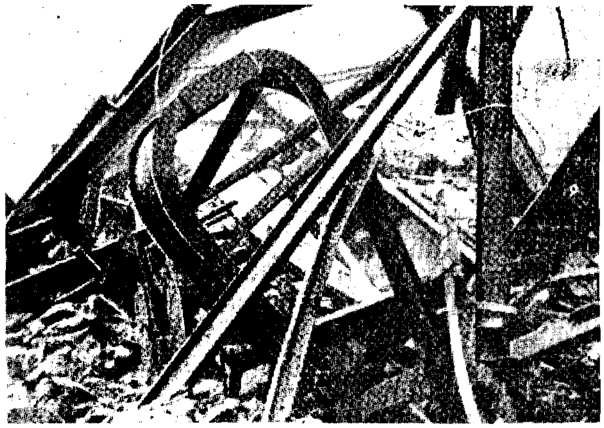

Fig. 3

Deformations causing the collapse of the west half of the arch

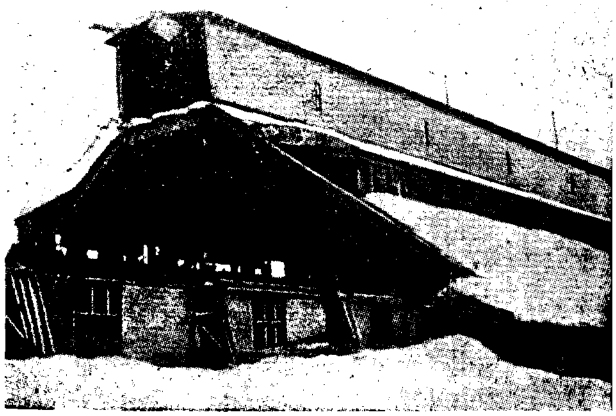

Fig. 4

Snow cover

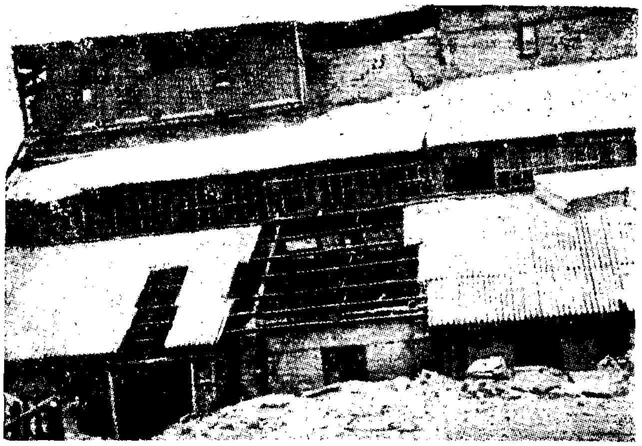

Fig. 5

Snow cover

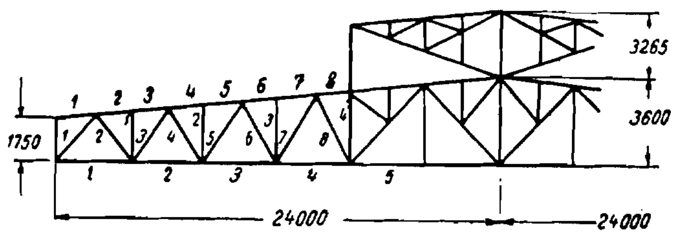

Fig. 6

Roof section