Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 12 (1984)

Artikel: Snow and ice effects on structures

Autor: Booth, R.L.

DOI: https://doi.org/10.5169/seals-12095

Seminar VIII

Snow and Ice Effects on Structures

Effets de la neige et de la glace sur les structures

Wirkung von Schnee und Eis auf Tragwerke

R.L. BOOTH
Chairman
Carruthers & Wallace Ltd
Toronto, ON, Canada

Robert Booth received his civil engineering degree from the University of Toronto in 1945. After a brief period with the armed services he joined the predecessor to his present firm. During his career he has been responsible for many of his firm's largest projects and is currently its senior principal.

SUMMARY

This paper outlines the effects of snow and ice conditions on buildings and other structures as experienced by a structural engineer practising in Canada. Both direct and indirect effects are discussed in general and in detailed terms in the light of past and current knowledge and experience. The paper also includes conclusions and recommendations for further research and development to achieve a safer and more cost effective design.

RESUME

Le rapport décrit les effets de la neige et de la glace sur les bâtiments et d'autres structures au Canada. Les effets directs et indirects sont envisagés à la lumière des expériences passées et présentes. L'article présente des conclusions et des recommandations pour des recherches et développements futurs, afin d'obtenir un projet plus sûr et plus économique.

ZUSAMMENFASSUNG

Der Bericht beschreibt die Wirkungen von Schnee und Eis auf Hochbauten und andere Tragwerke, wie sie von einem Bauingenieur in Kanada beobachtet werden. Direkte und indirekte Wirkungen werden aufgrund von Erfahrungen und neueren Erkenntnissen besprochen. Der Bericht enthält Schlussfolgerungen und Empfehlungen für notwendige Schritte in Forschung und Entwicklung, um Sicherheit und Wirtschaftlichkeit des Bauens weiter zu steigern.

1. INTRODUCTION

Buildings located in those intemperate parts of the world, where temperatures can remain at sub freezing levels for lengthy periods, must be designed to withstand the loads and other effects imposed on them by snow and ice. Structural designers who practise their profession in such areas must reach some understanding of the characteristics of these materials and, equally important, the climatological elements which produce them. The term, "some understanding", is appropriate because much remains to be appreciated about snow and ice and their effect on structures exposed to their action.

2. GENERAL DISCUSSION AND REVIEW

2.1 Physical Properties of Snow and Ice

Studies of snow have shown that its physical properties and mode of accumulation are dependent on many variables. Age, moisture content, temperature, exposure to wind, characteristics of the surface on which it falls, are some of the conditions which must be assessed by the designer in choosing the design loadings.

The weight of ice is, of course, known quite accurately. What is not known, is the rate of transformation of snow to ice in a given location on a given surface. Hence difficulty is experienced in determining design snow/ice loads. Past and present experience provides ample evidence that, under certain conditions, the accumulation of snow and ice can cause the failure of structures of all descriptions.

The challenge remains for engineers and designers to increase their knowledge of snow and ice so that the risk of structural failure will be reduced.

Because of their nature, snow and ice loads can be controlled by simply raising their temperature, (or lowering their freezing point), until they melt. Then, with proper drainage, potentially dangerous accumulations simply flow off the structure. Unfortunately, the means used to raise the temperature above the melting point can themselves cause distress to the structure to the point where the effect of eliminating the weight can lead to the very failure which caused concern in the first place.

It is important also, to appreciate the effects of snow and ice on the earth which supports or is retained by a structure. Failure of foundations and walls to maintain the equilibrium of structures as a result of freezing or thawing or repeated cycles of both in the supporting soil, can result in just as significant damage as the failure of spanning members to support gravity loads.

2.2 Influence of Wind on Snow Accumulation

The accumulation of snow is influenced significantly by the wind conditions which are present during its deposition. Indeed it is often the uneven distribution of snow resulting from wind action, which causes the overload conditions so damaging to many structures.

Just as the wind can model and shape sand dunes on beaches and deserts, so can snow surfaces undulate across otherwise flat planes. When roughness is introduced in the form of obstructions to the normal wind flow, the pressure variations affecting the buoyancy of the flow are multiplied in magnitude. Thus the wind can cause snow to be deposited in very large quantities in the lee of obstructions and scour snow from the surfaces exposed to windward. As wind eddies move across roof areas, snow is deposited in low pressure locations thus creating a natural obstruction which creates "lee conditions" over a larger area thus causing the initial drift to grow, so long as the wind bearing the snow continues to blow.

In a similar manner drifting can occur on the lee side of sloping and curved surfaces and wherever higher structures adjoin a lower roof.

Thus, the immediate effect of snow on structures is that of superimposing load on them. The responsibility of the designer is simply to identify the magnitude of the load and its distribution.

2.3 Direct and Indirect Effects of Ice

Like snow, the direct effect of ice accumulations on a structure can be related to the gravity and wind forces resulting from measurable (or forecastable) quantities of ice present. In addition to its greater weight, ice, due to its bonding characteristics can coat exposed structural elements to such a degree that their cross-sections are magnified drastically thus exposing them to much higher wind force as well as weight. Bridges, antenna structures, power lines and similar types of structures must, therefore, be checked for the greater surface areas exposed to wind than that presented by the structural members themselves.

If snow's principle effect is to load structures, the effects of ice are at once, more far reaching and insidious. The principle and most difficult problems with ice are related to its transient, physical qualities. In all but the coldest regions of the world, ice and snow are subjected to recurrent periods of alternating freezing and thawing conditions. During thawing conditions, the melt water is free to infiltrate structures. If, having penetrated the fabric of a structure, conditions change so that ice again forms, the expansive forces thus generated, place the very marrow of the structure at peril. If subjected to sufficient repetitions, the structure's useful function will end. No common structural material - - steel, concrete, or timber, can successfully resist the effect of repeated freezing and thawing of water which has penetrated its surface skin.

2.4 General Summary

Thus, in general terms, the effect of snow and ice on structures can be related to:

2.4.1
The gravity forces imposed by their weight and the weight of equipment used to remove them,

2.4.2
Wind forces acting on the structure as a result of enlarged areas due to the build up of ice,

2.4.3
Internal disintegrating forces caused by water which has penetrated structural materials changing to ice,

2.4.4
Disintegrating forces caused by corrosive salts in solution with such penetrant solutions causing the oxidation of structural materials;

2.4.5
Heaving/settling movements of foundations due to freeze/thaw of supporting soil.

3. DETAILED DISCUSSION

3.1 Gravity Effects

The phenomenon of snow drifting in the lee of obstructions is generally recognized. Building authorities throughout the colder regions of the world require provisions to be made for the phenomenon in the form of higher loads on structural areas adjacent to such obstructions. The undulating surface of snow is also recognized by such authorites by requiring structural members supporting such areas to be designed to resist both uniform and non-uniform distributions of snow loading. Drift effects are also recognized on the lee side of pitched roofs and again both uniform and non-uniform distributions of snow are required for the design of such roofs.

The current (1980) issue of the National Building Code to Canada outlines in considerable detail the provisions which must be made for uniform and non-uniform snow loading on buildings. These requirements are supplemented by considerable discussion on snow loads in a commentary contained in a supplement issued with the actual Code itself.

The simple identification of locations where snow drifting is likely to occur and the likely drift depth can, at best, provide only qualitative information for snow accumulation. The climatological history at the site of a given structure must be considered before quantitative values for the accumulation of snow over the winter season can be considered.

The quantitative values for snow loading provided by codes like the National Building Code of Canada are based on observations and measurements which have been made for many years. Most other Codes for areas subject to significant snow accumulations, also base their requirements on field observations in appropriate locations. Countries such as Canada which are large and which have extremely varied climatology, can, at best, establish design snow loads based on the results of observations at relatively few locations, to represent quite large areas. A balance must be struck between dangerous underestimation of likely snow and ice accumulations and the economic losses resulting from overly conservative estimates. Designers of buildings and other structures exposed to snow loadings must, in every way possible, encourage those engaged in snow research, in their attempts to quantify more accurately, the design loads which should be used. The frequent news of structural failure resulting from excessive snow loading bears witness to the need for such continuing research.

The density of snow increases with its age to values approaching that of ice. This factor must be recognized by the designer when dealing with structures located in areas unlikely to experience thawing conditions over long periods of time. Also, roof structures with varying insulating characteristics, can experience critical accumulations of ice loading caused by melt water from snow lying on poorly insulated roof areas suffering high heat loss from within, draining and refreezing on unheated eaves or other areas where little or no heat is present.

Often the designer must look beyond the simple identification of the design snow load which can accumulate. In many cases, the weight of equipment used to dispose of or otherwise remove the snow, can be a critical force on the structure itself. On bridges, snow plows can literally pile the snow into drifts at the sides of the road bed itself. Plazas over underground parking garages, often must be recognized as being exposed to the weight of heavy snow removal equipment which can gain access to the plaza area from adjacent roadways. Owners of open air parking garages often may create signicant overloading by designating a storage area within the garage itself to pile snow removed from the other garage areas.

3.2 Wind Effects On Ice Coated Structures

While the effect of ice storms does not significantly increase the overall shape of buildings exposed to wind forces, the very opposite can be true of slender structures such as antenna towers and transmission towers. These structures are often designed to employ relatively slender, individual elements of small dimension to make up the skeleton trusswork which forms the tower. It is obvious that a truss component 10 cm in width, when exposed to an ice storm capable of causing a 3 cm build up of ice, will result in a drastically increased obstruction width to wind forces. It is important to remember also, that the weight of such coatings can result in significant additional P-delta forces as lateral sway due to wind on the increased obstruction area occurs.

3.3 Effects of Internal Forces Caused By Freezing

The expansive forces which result from the freezing of water which has penetrated the structural elements themselves is one of the two most common causes of structural distress.

While rain and melting snow are obvious sources of external water available to penetrate structural elements, condensation of water vapour escaping from the interior of building structures comprises a third major source of "penetrant" water. External water can be prevented from entering structures by designing or otherwise protecting the integrity of their external surfaces against cracks or other flaws allowing the ingress of water. Condensation water on the other hand requires the installation of efficient vapour barriers on the warm inside surfaces to prevent the passage of water vapour into the structural element. Energy conservation measures in the form of increased insulation of structures due to higher energy costs have disclosed the weakness of vapour barrier design previously thought to be adequate. This is particularly true in older structures. In fact, in a few months, structures which had existed happily for 100 years or more prior to the installation of additional insulation materials, have suffered phenomenal deterioration as a consequence of condensation caused by faulty air and vapour barriers.

Water, which has penetrated the actual structural element or material and then freezing, has great potential to cause damage. The expansive forces resulting from the freezing of internal water in concrete and masonry materials cause the matrix of the material to be broken up. Repeated freeze/thaw cycles can lead to the complete disintegration of the material. Similarly, the formation of ice in joints or cracks in a structural element increases their width and, in the case of internal cracks, causes spalling of the surface. The damage resulting from these (crack widening) effects, accelerates because the widening/spalling/disintegrating conditions allow increased quantities of water to penetrate with a consequent increase in damage.

The entrapment of water within steel members can cause extensive damage if allowed to freeze. Hollow Structural Sections have been seriously damaged by the freezing of entrapped water due to the failure of steel detailers and fabricators to provide drainage holes.

3.4 Effects of Corrosion By Melt Water

Linked with the damage done by water penetrating the fabric of the structure and freezing, and possibly still more destructive, is the internal and external corrosion caused by the acidic nature of solutions resulting from the use of de-icing chemicals. In North America, calcium chloride is commonly used to melt ice and snow on northern and high altitude highways. The useful life of structures exposed to the effect of such chemical ice and snow control methods can be shortened significantly unless expensive and continuing maintenance and repair procedures are adopted. Roadway bridges are the obvious victims of such corrosion and evidence of corrosion damage caused by de-icing road salts can be found in practically any cold climate area of this continent.

In concrete structures the attack commences with the corrosion of embedded, steel reinforcement and pre-stressing tendons. The resultant oxidation produces expansive forces greater than the concrete cover can resist, thus producing cracking and spalling which, in turn, allows increased quantities of acidic solution to penetrate the member. Structural steel girders and other members are also affected by similar action, particularly where dust and dirt can collect to form a poultice which remains damp and in continuing contact with the steel surface.

Although the exposure may not be so great, parking garages, both indoor and outdoor varieties, have been found to suffer in a similar manner to bridges. In this case the acidic solution is transported to the floor surfaces of the garage by the vehicle's tyres and by ice and snow which have collected on the automobile. Because such structures are usually designed under the provision of Building rather than Bridge Codes, the effect of corrosion often becomes critical earlier in the life of the structure. Parking garage structures, particularly those for automobiles, are generally much lighter than bridge structures, due to the relatively light loading and modest depth of cover for reinforcement required by many codes. Melt water therefore, need penetrate a shorter distance to come in contact with reinforcing or pre-stressing tendons. Because the reinforcement tends to be relatively small in cross-section due to the light loading, the reduction in effective area due to even modest corrosion can, in fact, represent a significant percentage of the total cross-sectional area. The cost of repairing damage, and maintenance in general, can be very high.

3.5 Effects of Frost in the Soil

Structures located in cold climate areas must also take into account the presence of ice (frost) in the soil. The expansion forces created when water freezes in the ground can impose quite irresistible lifting forces on structural foundations and walls. By the same token, foundations placed on frozen ground can suffer serious settlement if the frozen supporting soil is allowed to thaw. In both cases cracking and damage to the superstructure can result from such foundation movement.

Care must be taken by the designer to identify locations around structures where wind scour or snow-clearing will prevent the normal accumulation of snow. Deprived of this (snow) insulation, frost can penetrate much deeper than normal.

It has been established that ground frost can develop very significant bond to the vertical surfaces of foundations such as pilings and walls. Under some conditions of repetitive freeze-thaw, this bond strength is sufficient to cause very significant lifting and movement of driven piles and foundation walls, particularly those constructed of jointed masonry. In those areas where the climate is sufficiently cold that the ground remains either completely or partly frozen throughout the entire year, this effect of ground ice must be carefully considered.

4. CONCLUSIONS

This dissertation has attempted to identify in a general way, the various effects which ice and snow have on structures. As stated, some of the effects are direct - others are secondary in the sense that they result from attempts to control the direct effects.

Not all of the control methods have deleterious effects on structures. Designers have developed numerous methods for minimizing ice and snow effects and producing cost effective, relatively maintenance free structures. As stated earlier, continuing study and research, including model testing in wind tunnels and water flumes, has allowed quite accurate forecasting of snow accumulation tendencies for a given structure in a specific location. As a result designers can adjust buildings' shapes and orientation to minimize the effect of snow drifting. The improvement in electrical control systems has allowed the integration of heating systems and insulation to control the build up of snow and ice at critical times, without invoking high costs when less critical conditions prevail.

Designers also have learned more fully, the response of structures to the various influences imposed on them by their environment. Of primary importance in this regard is the appreciation of the effect of structural movements resulting from temperature changes, foundation settlement, shrinkage and creep. This awareness of structural movement has led to great improvement in crack management and control. As a result designers can forecast in a rational way, the optimum location of control joints and the likely movements which will occur at them. This knowledge, together with the improved sealants available today, leads to a marked reduction in the entry points available for melt water to penetrate the skin of the structure, thus causing a marked reduction in potential damage due to corrosive and icing effects.

Much knowledge has been gained also in the control of air and water vapour. Modern materials and methods have been, and are being, developed to prevent more efficiently, the flow of interior air and water vapour through the interior surfaces of structures. Waterproof membranes and surface coatings have been, and are being, developed to protect the surfaces of structural materials against penetration by melt water resulting from ice and snow melting activities.

Despite improved performance, really dramatic advances are dependent upon continued and increased research. The present data base for snow information depends on tedious observation methods conducted by weather stations and other agencies at various locations. In Canada, current and past observations have been confined to measurements of ground snow and to some extent snow accumulation on roofs. The funding and actual snow measurement operations almost always are provided by and through Governmental Agencies. Possibly because of the non-dramatic nature of the subject, appropriate funds and assignments have rarely been provided. Information on snow accumulation is necessary in many more locations than are presently studied. Increased staffing by qualified personnel is required to assist in the measurement, and more importantly, in the recording and assessment of data coming from field observations. It is recognized that the allocation of funds for this work in economically depressed times is difficult to obtain. But the savings resulting from the reduction in structural damage caused by the direct and indirect effects of snow and ice, certainly would justify this expenditure.

Such studies would allow designers to improve their techniques in providing structural resistance to the effects of snow and ice. With this increased knowledge the provisions in Building Codes and other mandatory requirements could be modified to allow both the need for increased resistance in critical areas while at the same time allowing relaxation of requirements in other locations where the effects have been found to have no significance.

5. RECOMMENDATIONS

The persistent occurrences of structural failures, sometimes catastrophic, of buildings and structures due to snow and ice accumulations on their surfaces; the increasing maintenance and repair costs of bridges due to the popular demand by motorists for snow and ice-free roadways throughout the winter; the sometimes rapid deterioration of old buildings subjected to well intentioned, but ill conceived, energy conservation upgrading; the ever present temptation, for economic reasons, to reduce structural member sizes in accordance with increasingly accurate and reliable analysis and testing techniques; - - all these provide justification for the following recommendations.

5.1

Funds and personnel should be made available to expand the data on snow accumulations on the ground and on roofs, through increased field observations and accelerated data review and assessment activities.

5.2

Research relating the influence of the climatology (wind, precipitation, temperature) on snow accumulations in a given location and leading to statistical probabilities of snow drift loading occurring in specific areas on and around a structure, would allow significant cost savings to be realized. With such information, strength could be added efficiently in the proper locations without incurring the cost of strength in locations where there is little or no probability that heavy concentrations of snow can occur.

5.3

Development of wind tunnel testing techniques such that the action of snow and possibly ice accumulations on structures can be accurately scaled so that quantitative snow loadings can be determined in accordance with the climatology of the site in a manner similar to that which can already be obtained for wind loading.

5.4

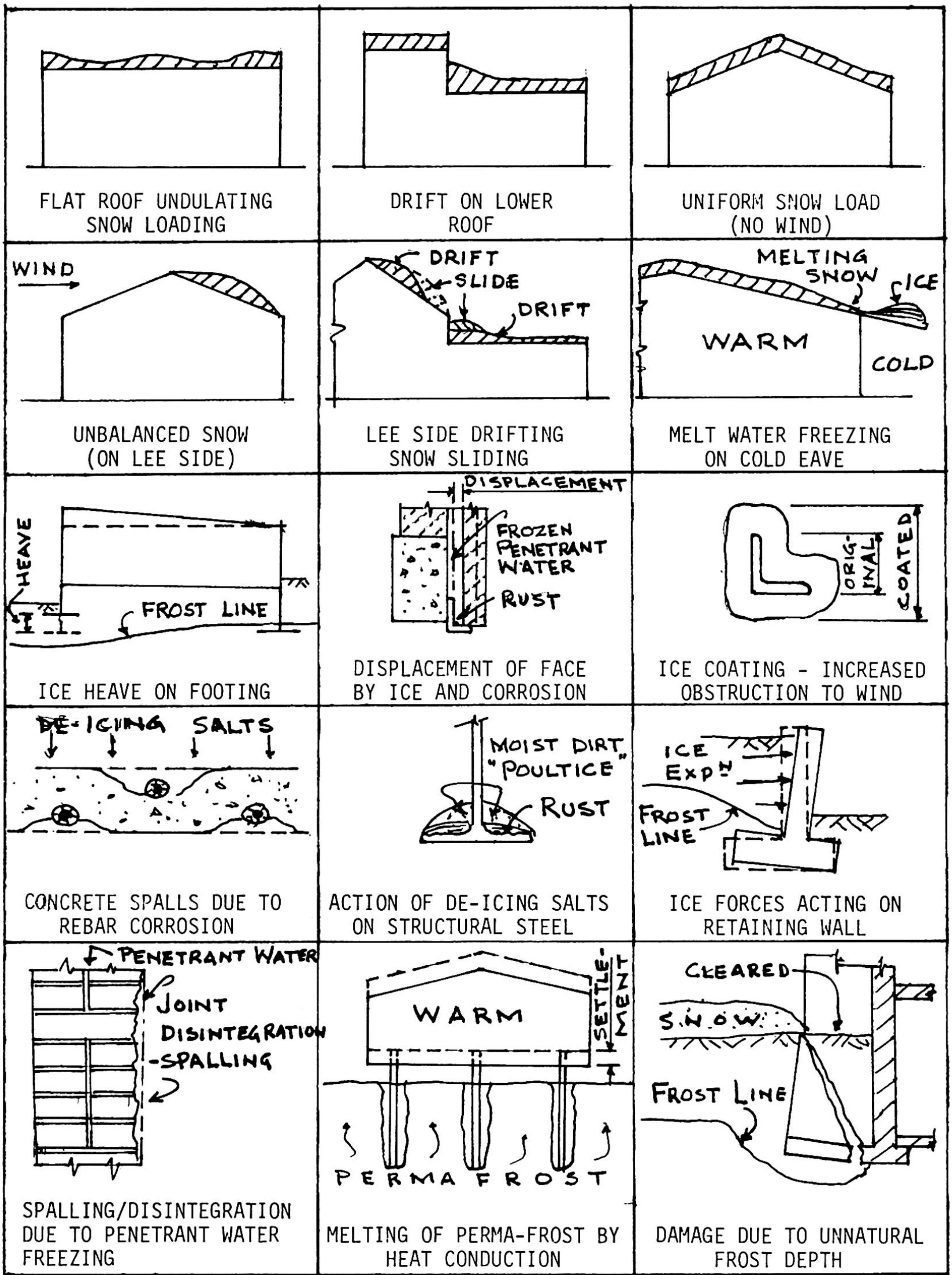
Continued research on protective measures which may be employed to combat the effects of corrosion and the formation of ice on and beneath the surface of structures and structural materials.

5.5

Development of ice and snow removal, chemicals and methods which do not produce by-products which are actively corrosive to structural materials.

5.6

Finally, and possibly most important, an increased international effort to integrate the knowledge and research information presently available only from the research and technical departments of individual Governments and private industries, so that methods to assess and control, more accurately and efficiently, the effects of snow and ice on structures can be universally developed.



FLAT ROOF UNDULATING SNOW LOADING

DRIFT ON LOWER ROOF

UNIFORM SNOW LOAD (NO WIND)

UNBALANCED SNOW (ON LEE SIDE)

LEE SIDE DRIFTING SNOW SLIDING

MELT WATER FREEZING ON COLD EAVE

ICE HEAVE ON FOOTING

DISPLACEMENT OF FACE BY ICE AND CORROSION

ICE COATING - INCREASED OBSTRUCTION TO WIND

CONCRETE SPALLS DUE TO REBAR CORROSION

ACTION OF DE-ICING SALTS ON STRUCTURAL STEEL

ICE FORCES ACTING ON RETAINING WALL

SPALLING/DISINTEGRATION DUE TO PENETRANT WATER FREEZING

MELTING OF PERMA-FROST BY HEAT CONDUCTION

DAMAGE DUE TO UNNATURAL FROST DEPTH

ILLUSTRATIONS OF DIRECT AND INDIRECT EFFECTS OF SNOW AND ICE ON STRUCTURES