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Please note

Most houses in Canada are roofed with overlapped shingles and sloped to shed water. Some industrial buildings are roofed with overlapped corrugated metal or asbestos cement, and also sloped to shed water. Most other roofs are designed to be entirely flat and are waterproofed, although a completely flat roof is seldom a design necessity and can never be achieved in practice because of normal construction inaccuracies and structural deflections. A completely watertight membrane is extremely difficult to construct and difficult to keep watertight in service when exposed to the full onslaught of the weather experienced in most areas of Canada.

Every discontinuity of or penetration through a roof is a potential source of imperfections at the flashings. The amount of water penetrating any imperfection in such a roofing membrane is directly proportional to the time during which the imperfection remains covered with water; that is, generally, the time that water remains ponded on the roof of the building. Shallow pools that form in depressions on the roof expose the membrane to the combined attack of moisture and sunshine at the edges of the pools in summer and to ice action in winter. For these reasons it is most desirable to provide slopes to drains on roofs so that water does not collect in pools but drains away almost as fast as it falls.

Few structural failures of lightweight roofs are known to have occurred in Canada as a result of ponding, but several have been reported from the United States. Water falling on these roofs in heavy rainstorms caused progressive deflection and accumulation of water until the loading collapsed the roofs. Usually in Canada the snow load requirement produces a sufficiently strong roof to preclude any possibility of such failure. The designer should however, keep this possibility in mind and provide sufficient roof slope to avoid deflection from ponded water on lightweight roofs.

Steeply Sloped Roofs

When overlapping units such as shingles are used for roofing, the minimum slope is about 4 to 5 inches vertical rise to 1 foot horizontally. Asphalt shingles are used on lower slopes when solidly cemented, but this is essentially a waterproofing type of application. The penetration of water at the overlaps of uncemented shingles or tiles is related to the roof slope and the amount of overlap. Wind forces and capillary suction tend to drive water up under the lap and gravity flow tends to carry it out. If water is not to penetrate, the force tending to cause outward flow must be greater than the forces causing inward flow. Minimum slopes and overlaps are based for the most part on experience. Most codes and standards state a maximum exposure of underlying units that varies with the length of the unit and the slope. For double coverage units without sidelaps this is sometimes based on a minimum headlap of 3 inches, so that exposure would be the length of the shingle less 3 inches divided by two.

Low Sloped Roofs

A slope of 1 inch in 4 feet is about the minimum practicable slope, and even with this it is probable that for large surfaces there may still be depressions where some water will pond. Studies on drainage channels by Martin and Tilley in Australia in 1968 showed that the relative discharge capacity of a roof increases by 50% when the slope is changed from zero to 1 inch in 5 feet.*

Slopes on roofs can be achieved in a variety of ways, the most desirable from a roof design standpoint by providing slope in the structural framing, or by varying the thickness of the structural roof deck. If this is not acceptable in relation to the other design requirements for the building, it is possible to add a sloped fill, to slope the top surface of the insulation, or to provide a sloped superstructure. All these methods are widely used but practicability and cost have to be considered in relation to specific solutions.

For complete water control it is necessary to consider all of the details as well as to provide slope on the main roof surfaces. One of the major sources of leaks in flat and low-slope roofs is faulty flashing at the termination of the roofing membrane where it meets movement joints, parapets or other wall and building features higher than the roof surface, and where vent pipes and ducts penetrate the roof. If imperfections occur at such locations because of design or application omissions and water is allowed to cover them, penetration will almost certainly take place.

All such details should be arranged, if at all possible, to be above the general level of the roof so that they are not covered with water, and slopes should be provided so that water will drain away from the flashings. Even if the details are not perfect, water will probably penetrate only when conditions are extreme, as might occur from flooding or during high winds. The cover or counter flashings at all flashing details should be designed with slopes to shed water. This includes individual pipe or duct penetrations as well as movement joints and parapet walls.

Parapet walls are merely extensions of the walls of a building and need roofing that must be linked to the main roofing for the building. Parapet cappings, whether of concrete, stone or metal, should be sloped to shed water although they cannot be relied upon to provide complete water control at the end joints. A roofing membrane (or through wall flashing) is required below the capping to intercept and lead away any water that penetrates the joints of stone, concrete or tile cappings. For metal cappings this may not be necessary, but it is desirable to provide upstanding end joints as well as sloped surfaces to assure that there is no water penetration. Even when perimeter slopes are used to put base flashings above the main roof level, water may still be blown under counter flashings and penetrate unless the flashings are carried well up the vertical walls.

Sizing and Location of Drains

External gutters and downpipes are sometimes used at the eaves of sloped residential type roofs to direct water away from foundation walls and to protect entrances and foundation planting. They frequently fill with ice in the winter and when build-up is severe are sometimes torn from their supports. The size of such gutters is seldom a matter of design, and generally only a single size is available from the building material suppliers.

The more usual drainage system for flat and low-slope roofs consists of drains on the main surface of the roof connected to internal downpipes (or leaders) leading to storm sewers or discharged at ground level to drain into open drainage ditches. The number and size of drains for these roofs are based on rainfall information for the geographic area and on drainage information for drains and leaders. Such information is available in civil engineering handbooks, drain manufacturers design manuals and building codes.

Information on rainfall intensity can be obtained from Supplement No. 1 of the National Building Code 1970 that gives climatic information for building design in Canada. The rainfall data are shown graphically in Chart 6, and tabulated as well under design data for selected locations. (The design data are also reprinted in Part D, page 613, of Supplement No. 4, titled Canadian Structural Design Manual 1970.) Roof drainage systems are usually designed to carry off rainwater from the most intense rainfall that is likely to occur. A certain amount of time is required for the rainwater to flow across or down the roof slope before it enters the drainage system, and this tends to smooth out the most rapid changes in rainfall intensity. The drainage system therefore need cope only with the flow of rainwater produced by the average rainfall intensity over a period of a few minutes. This can be called the concentration time and is usually much less than 15 minutes, at least for small roofs. It has been customary in Canada, however, to use as the basis of design the 15-minute maximum rainfall that will be exceeded on the average once in 10 years.

Table I. Leader Size and Hydraulic Load

Leader Size, in	Hydraulic Load, sq ft
2	720
2½	1300
3	2200
4	4600
5	8600
6	13500

The choice of leader size or the number of leaders of a specific size for a particular roof area can be determined by reference to Table 7.4.11.G, which forms part of Article 7.4.11.12 of the NBC 1970. In this table, partly reproduced in Table I, the diameter of the leader in inches is related to the hydraulic load from the roof. The hydraulic load from the roof in square feet is defined in Article 7.4.11.5 of the NBC 1970 as the maximum 15-minute rainfall in inches multiplied by the sum of:

a. area in square feet of the horizontal projection of the surface that is to be drained, and
b. one-half the area in square feet of the largest adjacent vertical surface.

Although rainfall and drainage information are the basis for sizing and determining the required number of drains, other considerations are necessary in achieving a satisfactory system. The shape of a roof, penetrations through it, and superstructures above it that provide obstruction to drainage may well be overriding considerations. Where one drain might be sufficient in relation to roof area and rainfall, it may be necessary to specify two or more to assure adequate drainage in such cases.

On roofs that do not have slopes to drains the drains should not be located at columns. These locations will become high points on the roof when structural deflections occur between the columns. If drains are located at the centre of bays between columns, any structural deflection will produce slopes to the drains, but allowance must be made in the leader connection to the drain for any vertical movement resulting from the structural deflection.

Drains should not be located so close to parapet walls, movement joints, or the walls of higher building elements that installation and waterproofing will be difficult to achieve. It is generally good practice to locate them several feet from roof edges and walls.

Emergency overflow drains or scuppers should be provided for parapet type roofs. They should be installed slightly below the level at which collected water would impose the design loading for the roof if the drains were blocked for any reason. Base flashings should extend above this level for obvious reasons.

Controlled Flow Drainage

From the standpoint of roofing alone it is desirable to drain rainwater as fast as it accumulates. If no water is present it obviously cannot penetrate any imperfections in the roof, and even with water running over a roof there will probably be only slight penetration since there is little head to cause entry. As water is a principal agent of deterioration of materials, deterioration will also be slowed down if the materials are kept dry except when rain is falling or snow is melting.

The designer, however, may be faced with several additional considerations. Underground storm drainage in the area where the building is to be located may sometimes be overloaded by rapid run-off of rainwater from large roofs during flash storms. This can cause flooding of basements or surface flooding and considerable damage to property. It may be necessary to dispense with immediate drainage of rainwater and consider controlled flow drainage.

With this approach, water is allowed to build up to some depth on the roof during flash storms, to be drained at a controlled rate over a longer period. Smaller drain piping and fewer drains may be used for such systems, thus reducing over-all cost of the drainage system. Cost by itself, however, is seldom justification for its use because water on a roof always constitutes a hazard.

Even when controlled flow drainage is to be used roof surfaces should be sloped to drains. Although allowance is made for longer draindown times during heavy rainstorms, for most of the time the roof will be clear of water. For flat roofs with no intentional slopes controlled flow drainage adds to the hazard for the roofing since water will be lying in the depressions of the roof for much of the time.

Flooded Roofs

It is often suggested that water on a roof can be used for evaporative cooling, and where air-conditioning is a factor in design it can usually be justified economically as a means of reducing the cooling load. This means keeping a roof flooded with water to a depth of several inches or using a continuous water spray. The latter gives the more effective evaporative cooling and can be used with a sloping roof. Water running over a sloping roof does not create as high a hazard since it produces only a very small head. Flooded roofs with a large supply of water and a relatively large head can cause a great deal of damage in the event of a leak. Flooded roofs also usually become stagnant pools that collect dirt and support algae growth. If used they should be capable of complete drainage for cleaning at intervals.

Roof Terraces

Drainage of surfacing materials on roof terraces requires special attention. Most terrace surfacing materials can be damaged or displaced by water or frost action. In addition to sloping the continuous membrane at the structural deck, it is usually necessary to provide a subsurface drainage or percolation layer through which water can run freely. Such a layer can be provided by a system of voids, uniform sized gravel, clean coarse sand, or no-fines concrete. The void system is the most preferable (**CBD 75**). Roof drains at the subsurface drainage level are essential, but surfacing may be made open or closed. Where joints between surfacing units are closed the terrace surface itself must also be drained (Figure 1). The joint in the surfacing at the perimeter of the roof terrace, especially at building walls, must be open in any case to prevent surface ponding against the building wall.

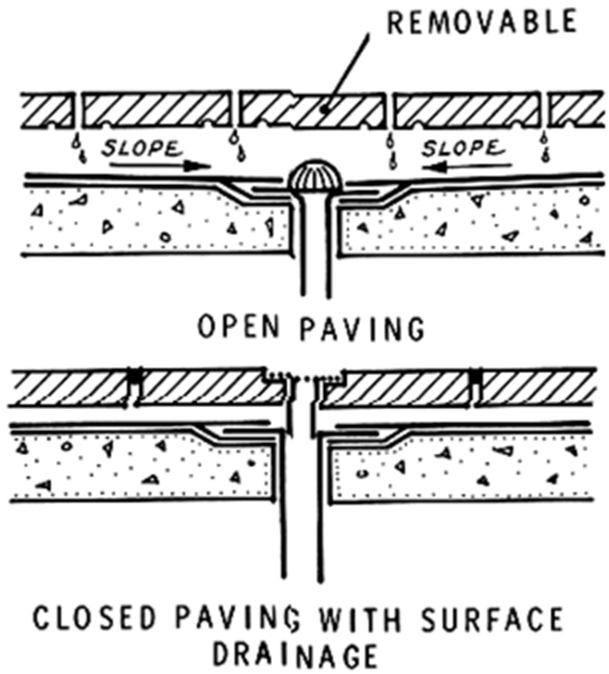

Figure 1. Drains for roof terraces.

Again, the details are important to the success of a roof terrace, and in some instances the walls of the building as well. Typical schematic flashing details are shown in Figure 2 where the membrane is arranged to carry water away from the walls.

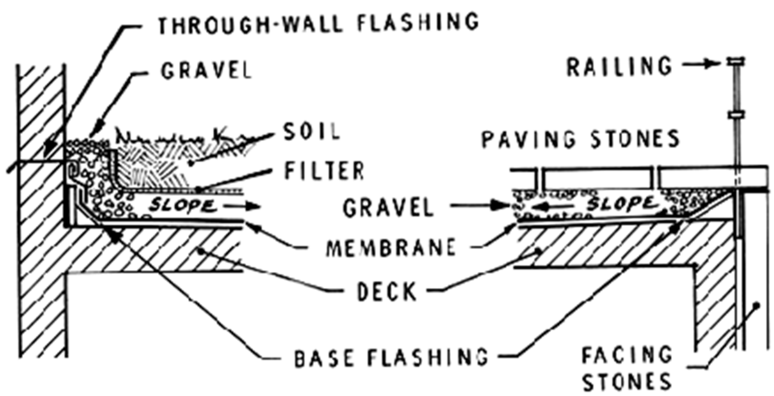

Figure 2. Roof terrace flashings.

Summary

A perfectly flat roof cannot be achieved in normal construction and slopes will inevitably develop owing to structural deflections. It is better to build in slopes to control water on a roof. The practicable minimum for main roof areas is about ¼ inch per foot, and greater slope is desirable. Where drainage is achieved by a folded plate type of arrangement crickets should be placed at the intersection of the larger slopes to direct water to the drains.

When controlled flow drainage or evaporative cooling are required on roofs, a sloping roof produces a less hazardous condition than a flat roof. For protected membrane type roofs the principal membrane at the deck below insulation and landscaping should be sloped, continuous and sealed round all penetrations.

* "The influence of slope upon the discharge capacity of roof drainage channels" by K.G. Martin and R.I. Tilley -- Division of Building Research CSIRO, Australia Report No. 02.2-32.