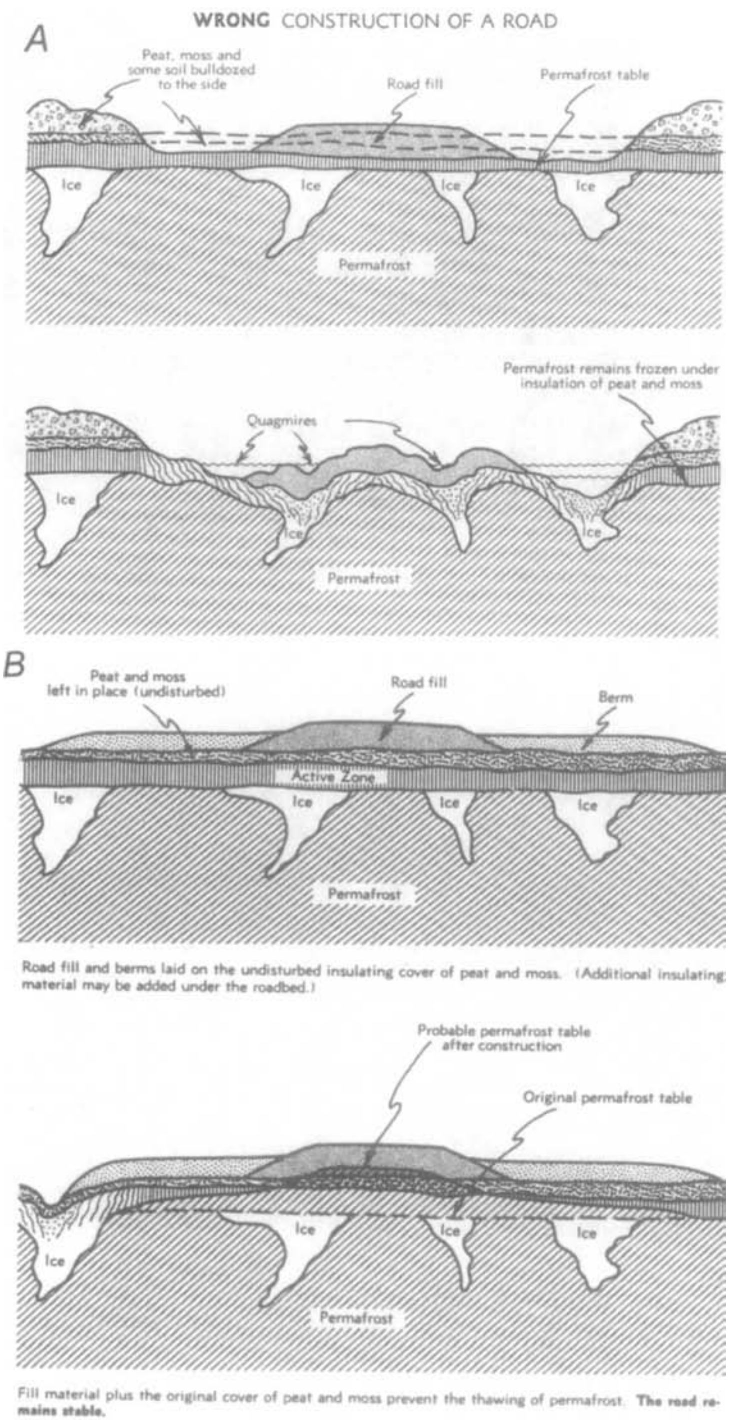
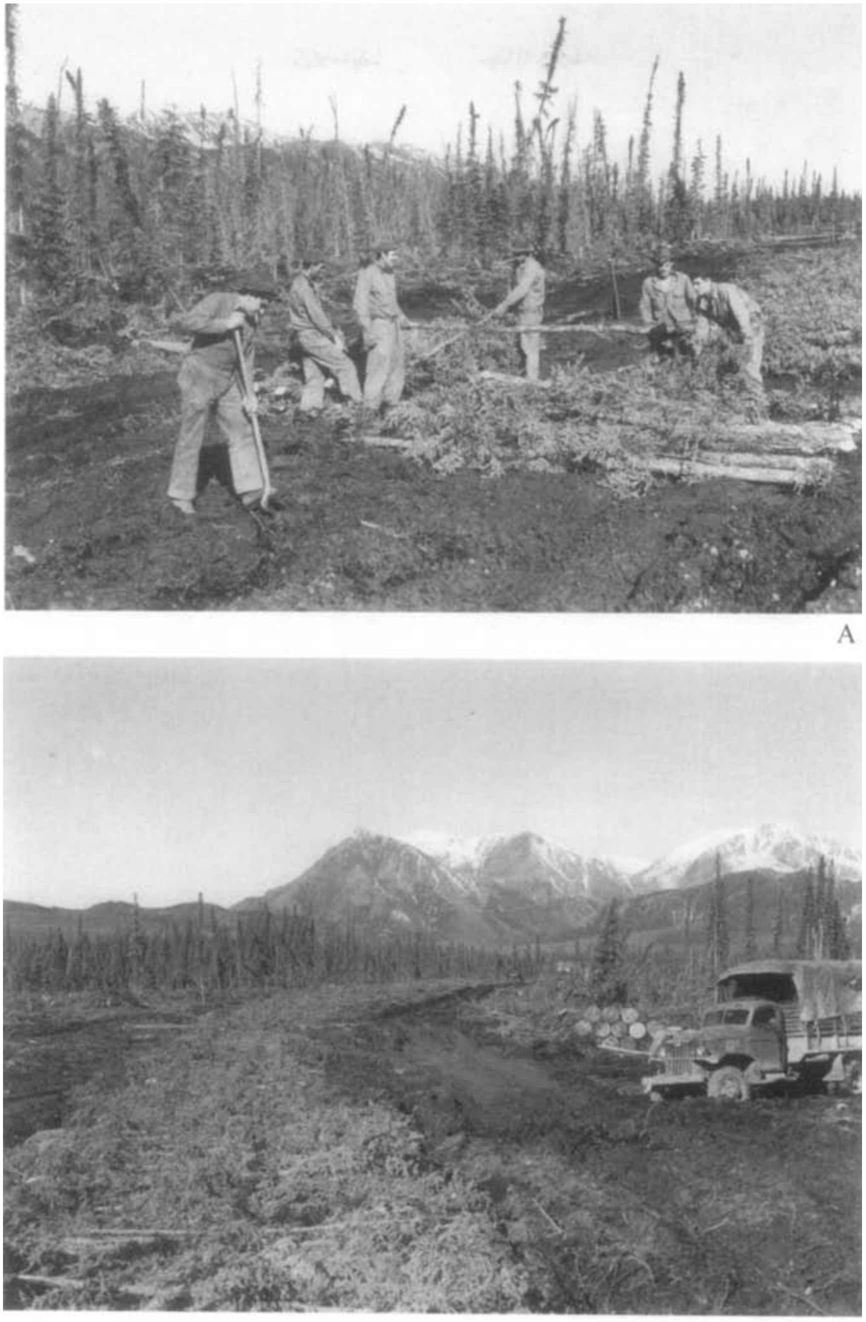


Figure 46. Road construction (1): (A) Wrong construction method; (B) right construction method.

A

B

Figure 47. Road construction (2): (A) Shallow rooted trees are easily felled by bulldozer in clearing ground for road construction. The turf and top soil are also scraped, thereby exposing and allowing underlying permafrost to thaw. (B) Denuded of the insulating vegetative blanket, the melt of ground ice turns the road into an impassable quagmire (both photos courtesy of Bureau of Public Roads).



A

B

Figure 48. Road construction (3): (A) Vegetation on the path of a road is cut (not bulldozed) and spread over the ground to insulate and thus prevent the thaw of underlying permafrost. (B) Vehicular traffic at this stage of construction should be kept to a minimum (both photos courtesy of Bureau of Public Roads).

A

B

Figure 49. Road construction (4): (A) Non-frost-active basecourse aggregate (gravel) is dumped on the vegetative blanket; (B) Additional fill on shoulders insures better stability of the road. More fill should be placed on the shoulder than is shown in the picture and the material (berm) should be graded to facilitate proper functioning of snow-removing equipment (both photos courtesy of Bureau of Public Roads).

perceptible sign of settling. Therefore, in the long run, building roads with 5 feet of fill is more economical and dependable than with a fill of only 2 ft. This pragmatic design requires detailed analytical study to arrive at the most rational and economic thickness of fill.

The effect on permafrost by road-fill composed of non-frost-acting coarse aggregate depends on its thickness and varies with climatic conditions, as well as with the initial thermal balance of the ground. If the fill is thin and the insulated cover has been compacted to the extent that the flow of heat into the ground has increased, permafrost will thaw. If the fill is thick, the balance of the heat flow will be out of the ground and, over the course of several years, the permafrost table may rise and penetrate the lower part of the fill (Figure 50A).

Landslides and Slumps. Seasonal thaw in road-fill will penetrate somewhat deeper than in surrounding ground, especially on its south-facing side (Figure 50B). The deeper thaw on the south side commonly produces a slight depression in the permafrost table just below the south-facing shoulder. Excessive moisture may accumulate in this depression and cause a landslide. This can be prevented by surfacing the south slope of the fill with a layer of material with low heat conductivity, such as sod, peat, and, wherever available, slag. Peat, being inflammable, should be covered with sod. A protective layer of sod is also recommended for nonflammable porous materials to reduce the convection of warm air.

Seasonal freezing and thawing of ground affects roadcuts seriously, especially where the cuts are made in unconsolidated material. Frost heave during winter lifts the ground in a direction normal to the surface of the cut, whereas during thaw, settling takes place in a vertical direction. Thus, there is an annual downslope movement of materials. Ground composed of pebbly material in silty matrix shows this process in an exceptionally striking manner. During freezing, individual pebbles are lifted on ice pillars in the direction normal to the surface of the ground; during thaw they drop down vertically and may even roll down the slope, bringing about accelerated mass-movement of the material.

During spring thaw of the surface of roadcuts, or of road shoulders, downward percolation of water from thawed ground is obstructed by the still-frozen impervious part of the active zone. An excessive amount of such water may cause landslides and erosional gullies. Such damage is especially common along steep road and railroad embankments but does not generally affect runways, which are built on level terrain with no significant bordering slopes.

The hydrologic regime of an area traversed by a newly constructed road-fill may also be affected by the fill. This effect may be very slight if the direction of the fill coincides generally with that of surface and groundwater flow. On the other hand, if the fill runs at a right angle to the direction of water flow, the effect may be quite marked. One such situation is illustrated in Figure 50. Here, the swampy condition is intensified on the uphill side whereas, on the downhill side, the swamp is more or less thoroughly drained. The drying of the swamp on the downhill side causes lowering of the permafrost table and thaw of previously frozen ground. This over-saturated ground becomes plastic, or even fluid, on thawing and seriously impairs the stability of the fill. In contrast, water accumulating on the uphill side starts to move

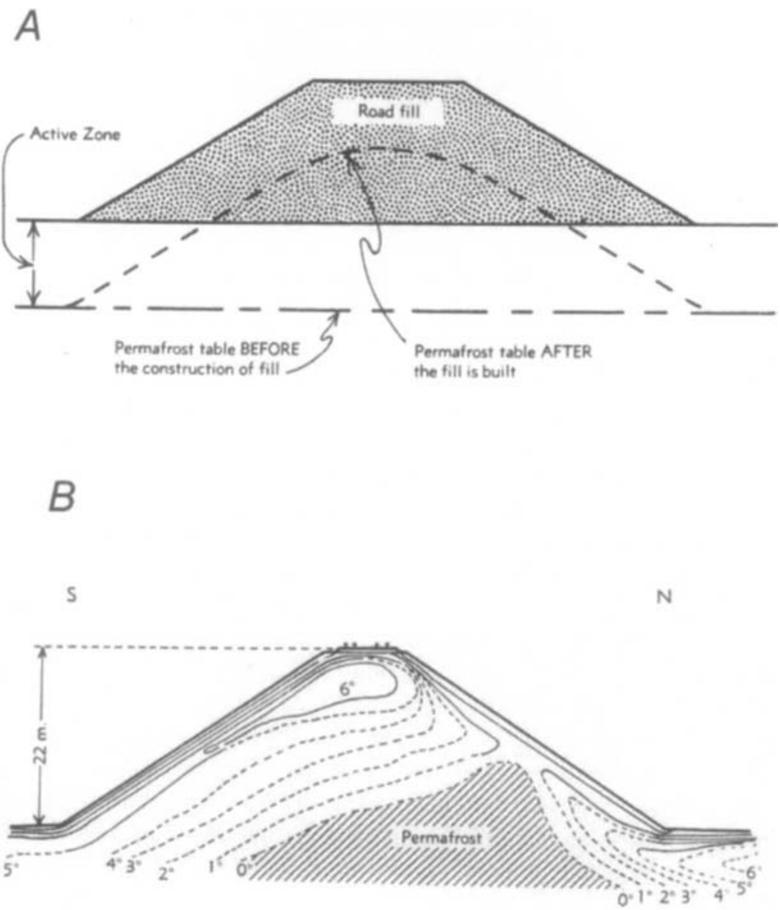


Figure 50. Thermal effects of roads: (A) The effect of road fill on permafrost table; (B) Diagram of ground isotherms in road fill in September shows deeper thaw on the south side than on the north side (from Sumgin 1940).

along the fill and causes sagging in the permafrost table directly under it. At the same time, the permafrost table beneath the fill rises slightly. This situation, favorable for landslides and erosion of the fill, can be prevented by a drainage canal. Protective benches (berms) on both sides of the fill check the lowering of the permafrost table near the fill (see Figure 51). The berms should be made of material that is a poor conductor of heat. Properly located culverts will also eliminate some of the undesirable conditions described above.

Except where excavation is made in bedrock, roadcuts present great difficulties. The material in the active zone is usually either partly or completely removed. Frequently, even the permafrost is penetrated. This causes a substantial lowering of the permafrost table, and the ground that was formerly frozen and firm thaws and changes into a less-

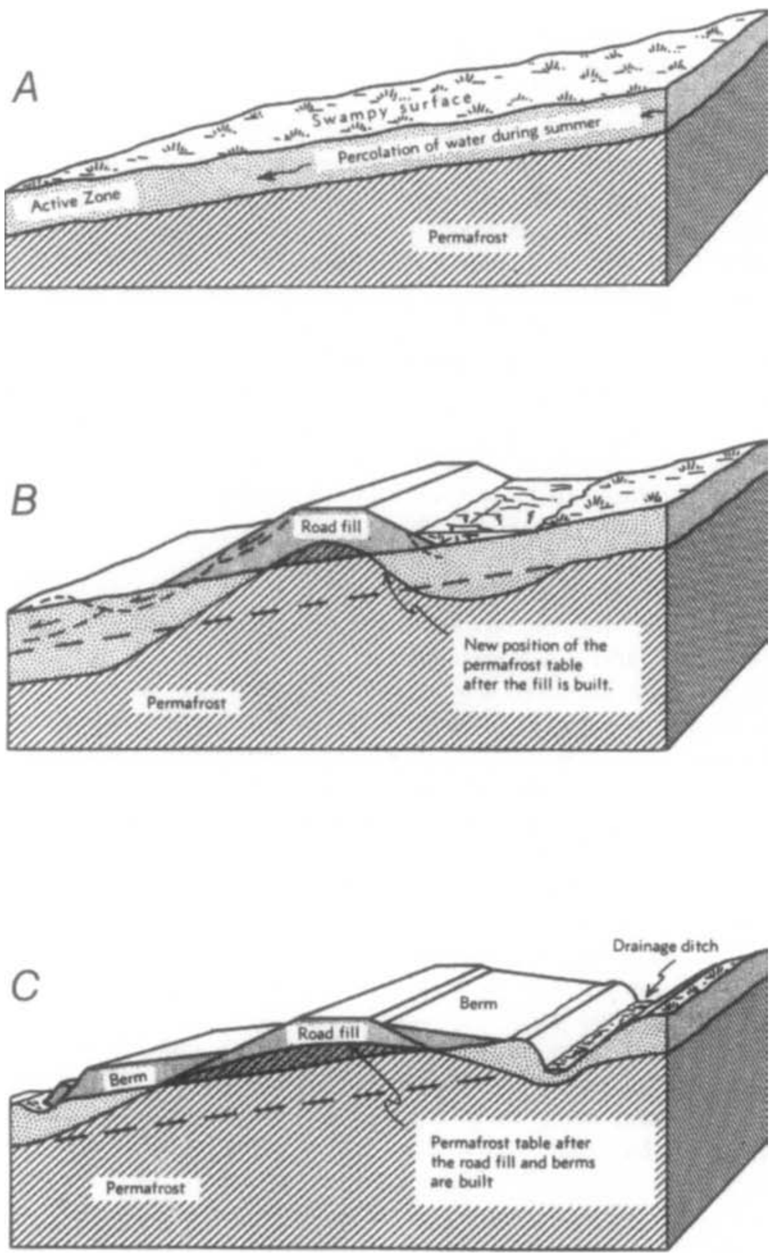


Figure 51. Diagrams to illustrate varying hydrologic regime of terrain when traversed by a newly constructed road: (A) Sloping terrain prior to construction; (B) Thawing of permafrost under shoulders causes sloughing of road bed; permafrost bulge beneath road bed blocks subsurface drainage and causes icing in late winter; (C) Permafrost rises under berm; road bed remains stable; subsurface drainage intercepted and carried away in ditch.

stable plastic or freely flowing material. This gives rise to numerous landslides and slumps. The only solution to this problem appears to be replacing unstable ground with more suitable material. This can be costly. In summary, roadcuts should either be avoided or kept to a minimum in permafrost areas.

Erosion along Drainage Ditches. Drainage ditches and canals are subject to active erosion in depth as well as in width, causing a lowering of the permafrost level. Successive erosion of drainage ditches with gently sloping sides may be checked by lining the bottom and sides with sod or peat, provided the flow of the water is not very strong. Ditches have also proved effective in checking excessive erosion when lined with burlap soaked in tar or oil. Wide and shallow drainage ditches are, as a rule, less subject to erosion and slumping than narrow and deep ones.

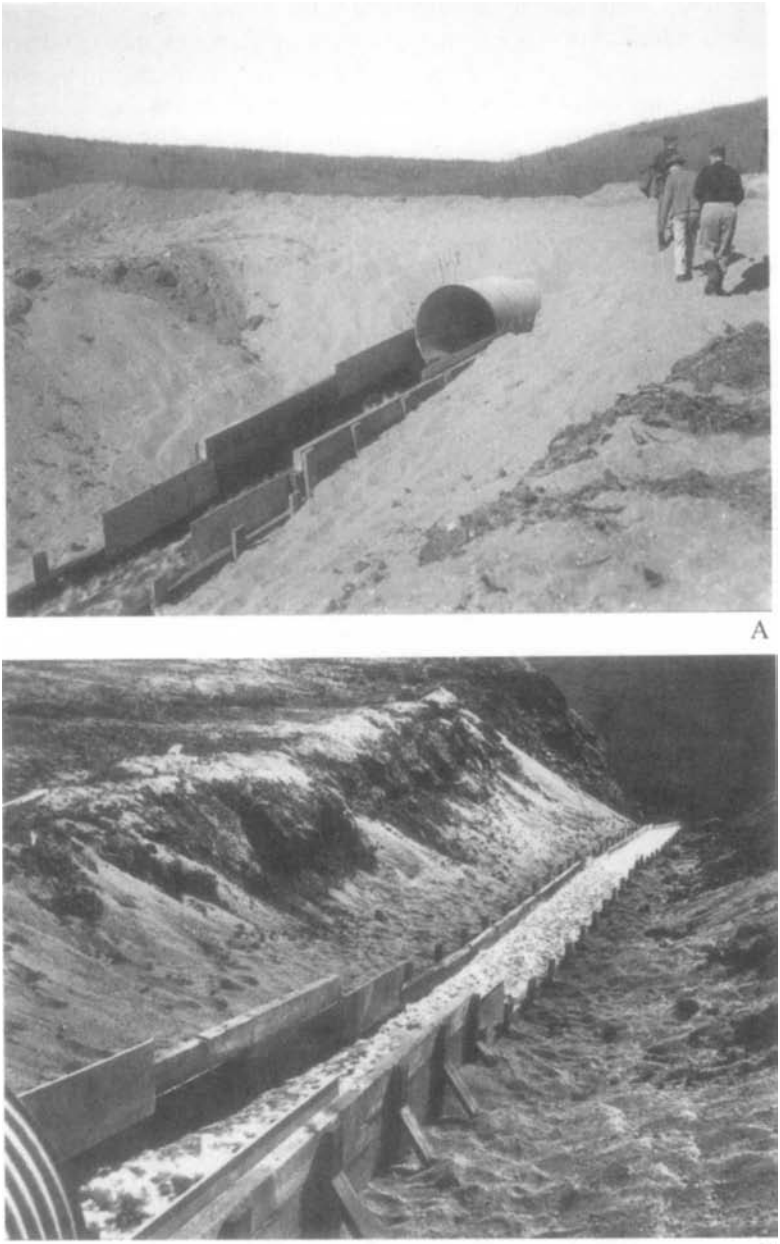
Ideally, drainage ditches along roads should be located at some distance from the traveled part of the road, and the shoulders between the road and the ditch should have a protective insulating cover (berm) to prevent the thaw of permafrost in the area immediately adjacent to the road. Extended spillways are recommended for outflow from road gutters to prevent headward erosion of drainage ditches and possible damage to the road (Figure 52A/B).

Diversion ditches on the upslope side of the road should be constructed by up-building of ridges upon the undisturbed vegetative cover, rather than by excavation of the ground. The latter method commonly results in intensive erosion of the ditch, with consequent threat of damage to the road.

Icings. Icings are produced by seepage of groundwater or river water when normal percolation is partially or completely obstructed by freezing of the ground surface or the river channel. As freezing progresses through the winter, the maximum constriction of underground percolation channels occurs in late winter or early spring, usually between the months of December and May. At this time, groundwater is subject to considerable hydrostatic pressure and is forced to the surface through an unfrozen channel or by bulging and ultimately breaking the overlying frozen crust. Such breaks are occasionally accompanied by a loud sound, resembling that made by a cannon. Depending on local hydrological conditions, icings may be very small or may build successive sheets of ice up to several meters thick. The latter may cover an area of several square kilometers. The sheets of water spreading over a road may build up a thickness of ice that can seriously impede or completely obstruct traffic. Along the Alaska Highway for example, some icings at river crossings have built up ice thicknesses of more than 20 ft., completely submerging bridges. Cars stalled during the crossing of one such bridge were found the following day completely buried and frozen in the ice. Large icings are generally fed by water from beneath the permafrost or by water that normally percolates below the bed of a large stream. In large icings, the ice may persist throughout the entire summer.

Some icings, known as natural icings, occur perennially in areas that are not in any way disturbed by human activity. Their presence can be detected during initial survey, and they can be avoided in the planning of engineering projects. Icings that present the most serious problems in road building—and particularly in maintenance—are those induced by the construction of the road.

An unusual feature of man-induced icings is their appearance late in winter or



A

B

Figure 52. Two views (A, B) showing an extended spillway from a culvert on the Alaska Highway that was constructed in order to prevent road shoulders from accelerated erosion and damage (both photos by S. W. Muller).

early in spring. At this time the ground surface has already been frozen for several months. It is indeed a startling experience to observe the appearance of water on the surface and for more or less continuous seepage to occur when sub-zero temperatures have prevailed for many months. The explanation lies in the lag of the ground temperatures behind those at the ground surface. The reason for this relates to the typical progression of ground temperatures. For example, at Skovorodino they show that whereas the minimum air temperature in the area is in January, the minimum air temperature in the active zone at the contact with permafrost, 2.0 to 2.5 m below the surface, is in May. A comparable lag occurs with the maximum temperatures (Figure 53).

To the dismay of Arctic engineers, icings have a peculiar affinity to roads and bridges. For example, in Siberia on the new Amur-Yakutsk Highway more than 100 large icings have been recorded within a distance of about 700 km. Stretches of road, each several hundred meters in length, have been rendered entirely impassable by the icings. Another illustration is provided by the Alaska Highway in Yukon, Canada. During the 1943-44 winter between Dawson Creek and Whitehorse, a distance of about 900 miles, there were 92 places where icings presented serious maintenance problems. In addition, there were 57 other places where minor icings occurred.

During winter freezing of the active zone, percolating groundwater becomes progressively more confined to a thinner and thinner zone remaining unfrozen. With complete freezeup of the active zone, an obstruction is created to percolating water. This water is subjected to considerable hydrostatic pressure. If the quantity of trapped water is small and localized, the ultimate increase in pressure will produce an ice mound. However, where larger amounts of water are subjected to hydrostatic pressure, the water will break out to the surface and produce an icing (Figure 54A). This condition is generally produced on the upslope side of a newly constructed road where accelerated ground freezing is brought about by removal of the original insulating cover (Figure 55, see cross-section X).

Icings are also likely to occur along the brow of a roadcut, usually on the uphill side where normal subsurface percolation of water is obstructed or dammed by the deeper freezing of the exposed face of the cut. It must be stressed again that, in permafrost terrain, roadcuts should be avoided wherever possible or at least kept to the minimum.

Icings also form in response to construction of river crossings. Where terrain is undisturbed along a moderately large stream, water may percolate through pervious (thawed) materials below the river channel. Construction of the approaches, and of the bridge itself, changes the thermal regime of both the riverbank and the river channel. The compaction of the ground at the approaches and the possible removal of insulating vegetative cover, and placing bridge piers in the river channel, accelerate the flow of heat during winter and cause deeper than usual freezing of the ground. This constricts the channel of normal percolation of water. As a result, any backed-up water will break out to the surface on the upstream side of the road and may build successive sheets of ice, completely burying the road and the bridge and rendering them inoperative.

The behavior of an icing and its destructive effect on a road is well illustrated by