FROST DAMAGE TO ROADS IN GREAT BRITAIN*

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In Great Britain low temperature conditions sufficiently prolonged to cause serious damage to roads rarely occur. Potential damage by frost is not therefore a factor which is always taken into account in the design of highways. Nevertheless during occasional very severe winters widespread damage does occur, often attended by a temporary dislocation of traffic.

The mean sea level temperature of the British Isles in January, approximately 40 F., is higher than that of all the central and northern United States. Periodically, however, winters occur during which one or more months have an average temperature of the order of 30 F., and it is during these winters that serious damage to roads may occur.

It is found in Great Britain, in common with other countries, that the severity of a frost period (as indicated by the mean air temperature) is broadly related to its duration, i.e., the longer the cold period the lower the mean air temperature. In view of this, and the fact that most forms of frost damage to roads entail some penetration of freezing into the surface, the severity of the damage depends more on the duration of the cold period than on the actual air temperatures.

Experience in the last 20 years indicates that in Great Britain the air temperature must remain at or about the freezing point for some 40 consecutive days before roads suffer serious damage. Temperature records taken over the last 100 years show that on this basis serious damage to roads (as at present constructed) would have occurred during 9 winters, of which 5 occurred in the 22 years 1874-1895 and three in the period 1929-1947.

At several stations in the British Isles soil temperatures are recorded at depths down to 4 ft. below grass cover. The records indicate that during prolonged frost, freezing occurs down to depths of approximately 18 in., although there is evidence that this figure is exceeded in the case of roads on high exposed ground.

Damage to roads caused by frost may occur in the surfacing only, in the surfacing and the base, or in the surfacing, base and subgrade.

Damage to Surfacings

The most common form of frost damage to concrete when used as a road surfacing, is spalling arising from the expansion on freezing of the water contained in the upper voids of the concrete. An example of this type of damage is shown in Figure 1. Spalling is most likely to occur in concrete made with a high water to cement ratio (above 0.7 by weight), which favors the formation of a surface laitance.

Damage to bituminous surfacings may arise due to stripping of the aggregate with the result that local areas of the surfacing disintegrate under traffic. This is particularly liable to occur when half-melted snow is allowed to lie on the road surface for long

Figure 1. Surface Spalling Due to Frost (Concrete Construction).

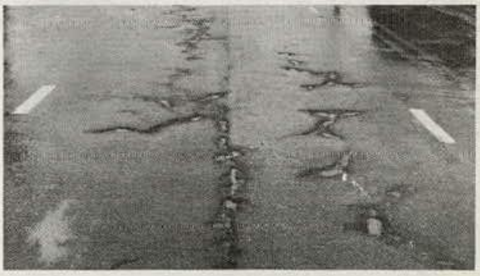

Figure 2. Separation of Two Courses of 2-Coat Asphalt Due to Frost Action.

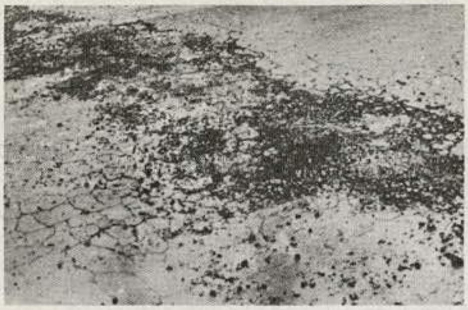

Figure 3. Breakup of Surface Due to the Entry of Water into a Low Quality Base.

periods. Frost can also cause the separation of the upper layers of compound bituminous surfacings. This also leads to failure of local areas under traffic (Fig. 2). Freezing of water at the interfaces between the layers is probably the original cause of separation.

Damage by the Entry of Water Through Porous Surface

When the rainfall on a pervious surfacing is not large, and adequate surface drains are provided, only a small proportion of the water percolates through the surface, and any damage which results to the road structure usually occurs only after a fairly prolonged period. However, in the early stages of a thaw, the surface drains are often blocked by ice, and in these circumstances large quantities of water from melting snow may enter the base or subgrade causing the immediate failure of the road. This form of damage frequently occurs where a base material containing an appreciable quantity of particles passing the No. 7 B. S. sieve has been put down and rolled dry during the construction of the road. The sudden ingress of water during the thaw encourages additional compaction of the base under traffic. Figure 3 shows damage of this type which arose from the entry of water into a brick rubble base after a sudden thaw in 1947.

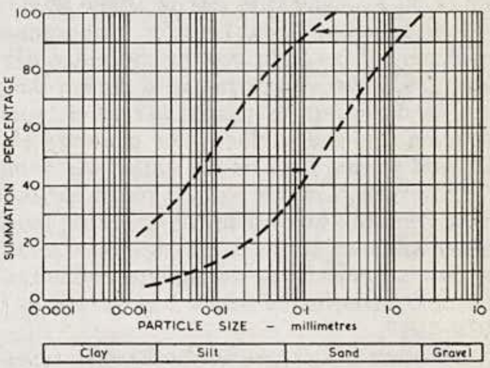

Figure 4. Particle-Size Limits Within Which Soils are Likely to be Frost Susceptible (Based on Investigations in So. England.)

Figure 5. Frost Heave on Country Road in Southern England.

Damage from Frost Heave in Subgrade

Heave in the subgrade gives rise to the most serious form of frost damage to roads. The extent to which a road is liable to heave depends both on the nature of the subgrade and on the thickness of non-frost susceptible material in the road structure. In Great Britain, if the thickness of construction is greater than about 18 in., the possibility of damage from frost heave is almost negligible. This means that highways falling within the Ministry of Transport classifications of Trunk, Class 1, and Class 2 roads, which together form about one quarter of the total length of roads in Great Britain, are largely exempt from the possibility of frost heave, due to their thickness. There is, however, one important exception to this - roads built

Figure 6. Damage Caused by Frost Heave in Chalk Fill.

Figure 7. Differential Frost Heave Between Construction Strip and Concrete Slabs.

on chalk subgrades; these are discussed later. Frost heave is largely confined to Class 3 roads (one quarter of the total mileage), and unclassified roads (one half of the total mileage).

Figure 4 shows the approximate limits of particle-size distribution for soils which are frost susceptible under British climatic conditions. These curves are based on a number of subgrade investigations carried out during the very cold winters of 1940 and 1947. It will be seen that the upper curve indicates a total clay and silt content much greater than is usually associated with frost susceptible soils. In fact, the particle-size distribution of most of the soils tested were close to the lower limiting curve. In a few cases, however, where the free-water table was close to the surface of the subgrade, soils having a clay content approaching 30 percent were found to exhibit appreciable heave. In such soils it is probable that lowering the water table would have entirely prevented heave. In the case of many of the coarser subgrades investigated, the water table was at a considerable depth and it was clear that the water required to promote ice segregation was being drawn from the soil immediately beneath the frozen zone rather than directly from the water table. Figure 5 shows typical damage to an unclassified road in southern England. For generations prior to the advent of the tar surfacing, such roads were kept open in winter by the tipping of any available granular material into the deep ruts caused by iron-tired vehicles. There tends therefore to be a considerable thickness of frost-resistant material near the edges and only a comparatively thin layer at the center of the road. This accounts for the heave and subsequent breakup being confined largely to the crown of the road.

Chalk, which occurs near the ground surface over considerable areas of S. E. and E. England, is a particularly troublesome subgrade material from the point of view of frost heave. The upper few feet of the chalk are generally intersected by weathering and temperature cracks between which ice lenses form when freezing occurs, the necessary water being drawn from the chalk beneath. When the subgrade of a road consists of compacted chalk fill the heave is likely to be much greater than in the case of natural (undisturbed) chalk subgrades. Figure 6 shows the breakup subsequent to thawing to a suburban road where a compacted chalk subbase about 8 in. in thickness was used on a heavy clay (non-frost susceptible) soil. The road structure in this case consisted of a tar-macadam surfacing on a base of compacted brick rubble 8 in. thick.

Except under freezing conditions, chalk, being in effect a soft rock, provides a particularly stable subgrade material on which only a few inches of surface construction are required to carry even the heaviest traffic loads. In the past, therefore, it has been usual to make roads on chalk with a much thinner structure than is possible for highways of the same class on other subgrade materials. The result is that in very severe winters even trunk roads on chalk may be affected by frost heave. Figure 7 shows a modern concrete road consisting of an 8-in. slab placed directly on compacted chalk, photographed during the severe frost of 1947. The central construction strip which was laid on a narrow concrete raft and had a total thickness of 18 in. did not move, whilst the slabs on either side heaved almost uniformly by about 1 to 2 in.

After the thaw the surface of this road returned to normal level with very little permanent damage. Traffic was not restricted during the thaw.

Measures Taken to Minimize Frost Damage

The type of frost damage which affects the surfacing only can largely be avoided by cooperation between the research worker and the engineer responsible for the road construction. Research in progress at the Road Research Laboratory into the laying and compaction of dry concrete mixes and into the stripping of the aggregates used in bituminous carpets should go a long way towards the prevention of purely surfacing damage. Research is also being undertaken into the stability of base materials, particularly low cost materials such as brick rubble and colliery shale.

The problem of frost heave, is however, a more difficult matter. In the case of new roads constructed on chalk subgrades, attention is now generally being paid to the frost question, and the depth of possible frost penetration is accepted as the design criterion rather than the normal high strength of the subgrade. The comparatively rare occurrence of serious frost in Great Britain precludes on economic grounds either the wholesale reconstruction of existing roads known to be affected by frost heave, or the construction of new roads, other than those falling in the Trunk and Class 1 categories, to completely non-frost susceptible standards. During the last few years, however, the counties and other authorities responsible for road construction and maintenance have become increasingly conscious of the frost problem. As soon as the thaw sets in after a bad frost, affected roads are, as far as possible, closed to traffic until subgrade moisture conditions have returned more nearly to normal. This frequently prevents any extensive breakup of the surface. It is usual too for authorities to keep plans of their areas on which stretches of road susceptible to frost heave are marked. In this way the lengths most liable to give trouble are located and the economies of remedial measures can be considered in relation to these sections only.

Acknowledgement

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LOAD CARRYING CAPACITY OF ROADS AS AFFECTED BY FROST ACTION

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For a number of years, highway engineers have known that a general weakening of the road structure occurs during and after the spring thaw. This loss in supporting value manifests itself in two forms the most obvious of which is the notorious "frost boil" where complete breakdown of the pavement structure results in sections of the road becoming impassible or practically so. The soil conditions causing this type of failure are readily identifiable as to soil types and proper corrective treatments made during grading operations will eliminate their occurrence.

The correction of these localized failures, however, has not eliminated the less spectacular, but still serious progressive failure which accumulates over a period of years. This is the reduction in load-carrying ability of the road structure resulting from the detrimental effect of frost action. Field observations have consistently shown that the weakening occurs during and two or three months following the spring thaws. Recognition of this phenomenon has led to the practice in Minnesota of restricting axle loads to values below the legal 9-ton axle load limit on all types of pavement structure, excepting concrete pavements. In Minnesota the degree of restriction has, in the past, been based on the considered opinion of the District Maintenance