Frost Cracks in Roads

Fissuration des routes par le gel

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Summary

During recent years longitudinal cracks have appeared in many roads in North Sweden. These cracks are formed early in the frost period and mainly in modern roads with asphalt pavement. The cracks are not due to overloading during the break-up period, but to frost heave. The frost penetrates deeper under the bare pavement in the middle of the road and causes a differential frost heave that ruptures the road.

A test road was built, using various cross sections designed to reduce frost heave and to study the frost penetration into different types of construction. These included many modern forms of construction, and two with peat and sand respectively below the sub-base.

The tests were run for two frost periods, 1957-58 and 1958-59 and are still going on. Durint the test, recordings were made of rainfall, air temperature, frost penetration, the amount of frost heave, the ground water table levels and the moisture content of the soils.

Test results indicate that two particular forms of construction achieved the best results, and that frost heave is more uniform across the width of a road. The other test sections still displayed longitudinal cracking.

Sommaire

Au cours des dernières années de nombreuses fissures longitudinales se sont produites sur les routes, principalement dans le nord de la Suède.

Ces fissures dues à l'action du gel se forment généralement au début de la période de gelées et se produisent, dans la plupart des cas, sur des routes nouvellement construites et recouvertes de revêtements bitumineux. Elles ne sont donc pas occasionnées par une surcharge de la route au cours de la période de dégel, mais au contraire sont le résultat de soulèvements dus au gel.

Le gel pénètre plus profondément dans la partie médiane de la route, non recouverte de neige, que dans les accotements, produisant ainsi un soulèvement variable transversalement qui provoque la fissuration longitudinale de la chaussée.

Une route d'essais a été réalisée avec différents types de chaussée, dans le but de réduire les soulèvements différentiels et pour étudier la pénétration du gel dans les différentes sortes de chaussée. Celles-ci comprennent : a 12 : type de chaussée normal ; a 24 : type ancien de chaussée; a 31 : type de chaussée caractéristique pour routes élargies; b 42 : type de chaussée normalement employé avec sous la couche de fondation des fouilles en forme d'entonnoir remplies de tourbe ; c 42 même construction comme sous b 42 mais avec dans les fouilles, du sable à la place de tourbe.

Les essais qui ont duré depuis deux saisons de gel, 1957-58 et 1958-59, continuent. Pendant ce temps sont notés : les précipitations et les températures, la pénétration du gel, l'amplitude des soulèvements dus au gel, les niveaux de la nappe phréatique de même que les teneurs en eau du sol.

Les mesures faites jusqu'ici ont montré que les types b 42 et c 42 ont donné les meilleurs résultats en ce sens que les soulèvements transversaux dus au gel ont été moins irréguliers pour ces deux types que pour les autres types de chaussées. Par suite le risque de fissuration a diminué.

Introduction

Swedish roads, particularly those in the northern parts of the country, have in recent years been subject to longitudinal frost cracks (Fig. 1) on a large scale. In these areas, the frost usually penetrates the ground to a depth of some 2 metres. The cracks, which have generally appeared in newly built roads with bituminous surfacing, are usually formed fairly early during the frost period, i.e. in January or even as early as the latter part of December. Thus they are formed during that part of the year when the roads are frozen and consequently have great bearing capacity.

However, these cracks should not be confused with cracks which may arise from excessive traffic blow during the thaw period, when the roads have minimum bearing capacity. The cracks which have been investigated, i.e. frost cracks, increase in width and length as the frost penetrates into the subgrade and reach their maximum dimensions at the end of the frost period. In extreme cases, the width of the cracks may be 20 or even 25 cm and the length can be some hundreds of metres. The cracks generally run along the approximate centre of the road or to one side or the other of the centre. The depth of the cracks does not appear to

Fig. 1 Frost crack in a road near Ersnäs, Sweden.
Fissure sur la route d'Ersnäs, Suède.

exceed the total thickness of pavement, base course and sub-base and thus does not appear to penetrate into the subgrade.

The types of cracks described here seem to appear also in Germany. In Strasse und Autobahn (No. 3, 1956), A. Dücker writes on page 79 : "Zwar handelte es sich hierbei nicht um Frostaufbrüche, sondern um längsgerichtete Frostrisse. .... diese während der Frostzeit entstandenen Schäden ...." (Fig. 2).

Fig. 2 Frost crack in a road, Germany (after A. Dücker).
Fissure sur une route allemande (d'après A. Dücker).

Preliminary investigations have shown that a condition for frost cracks to appear to be that the road is built on a sub-base liable to frost heave, and that frost have is greater at the centre of the road than at the sides. It has even been shown that the reasons for uneven frost heave are often due to the fact that the sides of the road are insulated by snow during the winter, the frost penetrating deeper down at the centre of the road than at the sides (Fig. 3). These conditions, which result in heavier frost heaving at the centre of the road, may cause bending and tensile stresses in the pavement, base course and sub-base, with the risk of cracking. This seems to be the case particularly when the sub-base consists of coarse-grained gravel, which does not retain any water in the pores and therefore lacks adequate tensile strength in both its frozen and unfrozen condition.

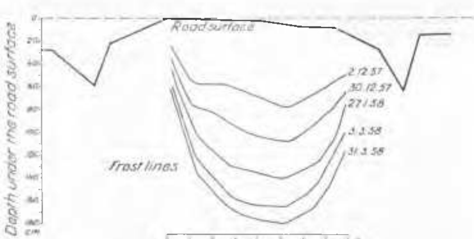

Fig. 3 Frost lines at different dates during the frost period 1957-58 in a road near Rutvik, Sweden.
Pénétration du gel à différentes époques au cours de la période de gel 1957-58 sur la route de Rutvik, Suède.

Test road

In order to study frost penetration and frost heave in roads more closely and to examine the possibilities of preventing cracking, a test road was built in 1957 at the village of Ojebyn in Northern Sweden. The intention was — in addition to general studies of the penetration of frost into the ground — to try by varying the construction of the sub-base to increase the rate of penetration of the frost at the sides of the road and to lessen it in the centre, and thereby to bring about a constant frost depth over the entire width of the road. In this way the transverse frost heave may be equalised and consequently the risks of cracking substantially reduced.

The subgrade of the test road consists of sedimentary strata down to a depth of 2·50 m or more, which are highly sensitive to frost below them being moraine. The ground water level is at a depth of 70-100 cm below the road surface.

Five different types of sub-base were tested during the investigation (Fig. 4); two sections of each type were tested.

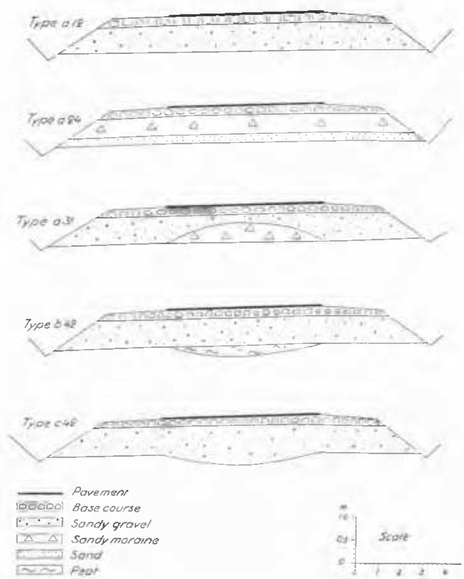

Fig. 4 Road cross sections with different types of sub-bases tested on the test road Öjebyn in 1957.
Differents types de couche de fondation employés dans les chaussées de la route d'essais de Öjebyn 1957.

The total thickness of pavement, base course and sub-base for the different types was 80 cm, with the exception of type *b* 42 and *c* 42, the thicknesses of which were progressively increased towards the centre of the road until reaching

105 cm. This grooved part of the sub-base was in the case of type *b* 42 filled up with peat and in the case of type *c* 42 with sand. The purpose of this method of construction was to have under the centre of the road a saturated material not subject to frost heave and highly resistant to freezing, (particularly the peat), in order to decrease the rate of frost penetration at the centre of the road. Type *a* 12 represents the usual type of modern Swedish road construction and type *a* 24 a previously used form, the strengthening layers of which consisted of capillary breaking sand layers at the bottom with overlying moraine material; the latter holds moisture and therefore has high tensile strengt when frozen. Type *a* 31 has been included for the further testing of the effect of fine-grained mineral soil on the penetration of frost into the ground. This type also represents a case where an old road in widened and strengthened.

Throughout the tests the temperature of the air was taken with automatic recording instruments. The penetration of frost into the ground and its disappearance were read once a week using the frost indicator of Statens Väginstitut, which has been described in Proc. of the Fourth Int. Conf. on Soil Mec. and Found. Engin., 1957 1 (a)/8. Vertical movements of the road surface during the frost season were measured by means of this frost indicator and checked by levelling. The movements of the subsoil water table during the frost season were noted by measuring with a subsoil water-level tube. Furthermore the moisture content of the ground at various levels and at different times was determined by tests and the moisture content determined from samples taken.

Test results

Using the temperatures recorded as a guide, a freezing index for the actual frost season was calculated and freezing index curves drawn (Fig. 5). From this it appears that the freezing index for the 1957-58 frost period amounted to 1 220 degree-days (C° · *d*) and for the 1958-59 frost period to 880 degree-days (C° · *d*). This means that the test area

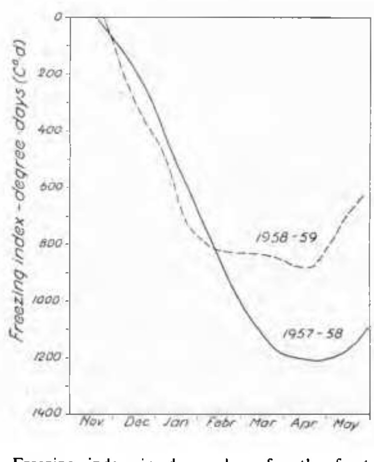

Fig. 5 Freezing index in degree-days for the frost seasons 1957-58 and 1958-59 on the test road Öjebyn 1957.
Intensité du gel exprimée en jours-degrés C pour les périodes de gel de 1957-58 et 1958-59 sur la route d'essais de Öjebyn 1957.

has an average freezing index of some 1 050 degree-days (C° · *d*), the 1957-58 winter was cold throughout, whereas the winter of 1958-59 was mild. The difference in the freezing index for the two frost periods, which were of approximately the same duration amounted to 440 degree-days (C° · *d*). Furthermore, Fig. 5 shows that the first half of the two frost periods, i.e. from their beginning and until early February, had the same freezing index and were thus equally cold. The second half of the frost period of 1957-58 was, on the other hand, considerably colder than the corresponding frost period of 1958-59. These circumstances are reflected in the rate of frost penetration, the frost depth frost heave and the greater elevation of the centre of the road than at the edges during the frost period and also in the changes in the level of the ground water during the winter and in the extent of moisture concentration in the frozen part of the sub grade. However, these particular results are not yet available.

The penetration of the frost into the road and the subgrade during the frost periods 1957-58 and 1958-59 with type a 12 are shown in Fig. 6. Here it can be seen that the

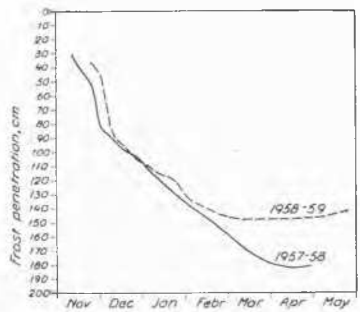

Fig. 6 Frost penetration during the frost periods 1957-58 and 1958-59 (test road Öjebyn 1957, subbase type a 12).
Pénétration du gel pendant les périodes de gel de 1957-58 et 1958-59 (route d'essais de Öjebyn 1957, couche de fondation type a 12).

rate of frost penetration has been about the same up to the beginning of April for each frost period. Then the frost in both cases has penetrated to a depth of about 140 cm beneath the road surface. After this time, the frost penetrated considerably more quickly and more deeply in 1957-58 than in 1958-59. Thus the frost depth increased after this time by about 40 cm during the first mentioned frost period and by only about 10 cm during the latter. The reasons for this are that the freezing index during the latter half of the frost period of 1957-58 were considerably greater than during the corresponding period of 1958-59, as can be seen from Fig. 5. A comparison between Fig. 5 and Fig. 6 shows that there is a good correlation between the freezing index and frost penetration.

The maximum frost depth reached by the end of each frost period, is, as can be seen from Fig. 7, greater throughout the 1957-58 frost period than in 1958-59. On average the maximum frost depth at the centre of the test road during the first mentioned period reaches 170 cm, while during the latter it is only 144 cm. Examining the maximum frost depth for the different test sections it can be seen from Fig. 7 that during the two frost periods this is least at the two outer sections, i.e. the sections where pave-

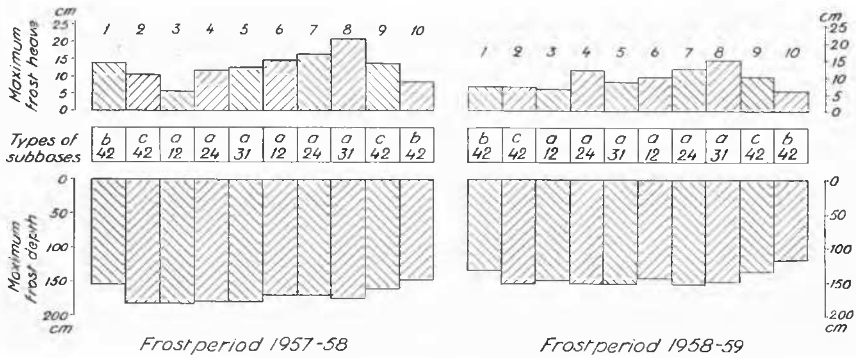

Fig. 7 Maximm froust depth and maximum frost heave at the different sections of the test road Öjebyn 1957 during the frost periods 1957-58 and 1958-59.

Pénétration maxima du gel et soulèvement maximum sur les différentes sections de la route d'essais de Öjebyn 1957 pendant les périodes de gel de 1957-58 et 1958-59.

ment, base course and sub-base have beneath them a layer of peat type *b* 42. This could reasonably be expected because the peat is more highly reisstant to freezing.

Maximum frost heave at the centre of the road is greater for 1957-58 than for 1958-59, as can be seen from Fig. 7. Thus, the maximum frost heave at the centre of the road averages 12·9 cm during the first-mentioned period and 9·5 cm during the latter. As to the frost heave on the different sections, it is noteworthy that this is a maximum (i.e. 21·2 cm in 1957-58) on section 8, which first of all seems to depends on the condition of the subgrade, and is not completely uniform along the entire test road.

Fig. 8 shows the difference between the various test sections during the two frost periods in question; the difference is partly between the maximum frost depth at the centre of the road and at the sides, and partly the corresponding difference in the maximum frost heave. As far as these two differences are concerned it is a fact that for all the sections these differences are greater for the colder frost season of 1957-58 than for 1958-59, when the freezing index was less.

The greatest difference in the maximum frost depth at the centre of the road and the edges amounted to 23 cm on test section 8 during the 1957-58 frost period, as is shown in Fig. 8. As can also be seen from this, the corresponding differences were particularly low for the two outer stretches. For one of them, the difference was negative, i.e. the frost penetrated somewhat deeper at the sides than at the centre of the road.

The greatest difference between maximum frost heave at the centre of the road and the sides measured 4·5 cm on the test section 7 during the 1957-58 frost period. As can be seen from Fig. 8, the corresponding difference in frost heave is a maximum on test sections 5-8; this applies to both the frost periods. For 1958-59 it is particularly noticeable that the difference in the maximum frost heave at the centre of the road and the sides is negative on the test sections 1, 2, 9 and 10, which means that frost heave was greater at the sides than at the centre. In all these sections the terracing is of trough shape. Thus, with this form of construction, reduced frost heave at the centre of the road was achieved,

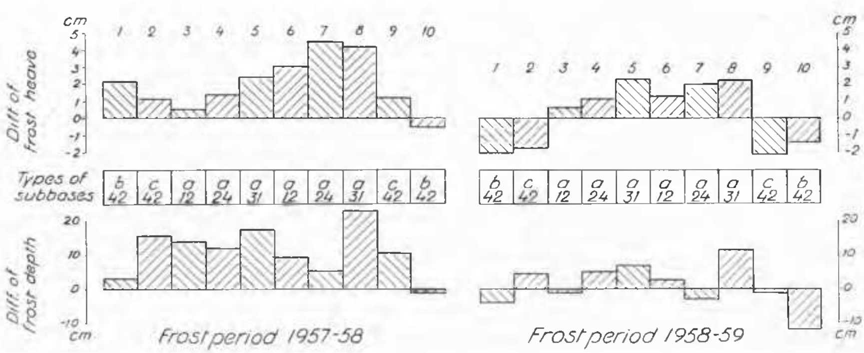

Fig. 8 The difference between the maximum frost depth at the centre of the road and at the edges and the corresponding difference in the maximum frost heave at the different sections of the test road Öjebyn 1957 during the frost periods 1957-58 and 1958-59.

Différence entre la pénétration maxima du gel au milieu de la route et sous les accotements, ainsi que différence correspondante du soulèvement maximum dans les différentes sections de la route d'essais de Öjebyn pendant les périodes de gel de 1957-58 et 1958-59.

by which the bending and tensile stresses in the pavement, base course and sub-base are lessened. The risk of cracking is also reduced.

Typical longitudinal frost cracks have appeared on test sections 5-8, i.e. those sections where the difference between the maximum frost heave at the centre of the road and at the sides is a maximum. Also on section 9 and extending into section 10 is a crack. However, this crack is situated along the side of the road. As the trough-shaped excavation of the sub-base of the two latter test sections finishes at the edge of the pavement (Fig. 4), the crack appearing here may owe its occurrance to this.

The results so far obtained are preliminary and investigations are continuing.