Compression of Tunnel Spoil at Venemo Dam

Compression des matières de rebut du tunnel du barrage de Venemo

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SUMMARY

This paper presents some results of indirect measurements of compression of tunnel spoil measured by crossarms at the Venemo Dam, and also the results of an oedometer test on the same material. The measurements on the crossarms were carried out during the construction of the fill which took place during two summers and one winter season from 1962 to 1963. At the time of writing (June, 1964) the reservoir has not yet been filled.

SOMMAIRE

L'article présente quelques résultats mesurés par la méthode des bras croisés et des essais œdométriques dans le remblai. Le matériel était obtenu à l'occasion du perçage d'un tunnel. On a effectué ces essais pendant la construction dès l'été 1962 jusqu'à l'été 1963. À ce jour (juin, 1964) le réservoir n'est pas encore plein.

VENEMO DAM is a part of the Tokke Hydro-electric Project located in the western part of southern Norway. The dam is owned by the Norwegian Watercourse and Electricity Board who also did the major design and construction work. The Norwegian Geotechnical Institute acted as the consultant to the owner on special matters. Venemo is a 357,000 cu.m. rockfill dam with an impervious membrane of asphaltic concrete on the upstream slope. The main contractor for the asphaltic work was S. Hesselberg, Oslo. The maximum height of the dam is 64 m. and the length along the crest is 238 m., the axis being convex upstream, with a radius of 1000 m. (Fig. 1). The upstream and downstream slopes have inclinations of 1:1.7 and 1:1.4, respectively.

CONSTRUCTION

The supporting fill is constructed of tunnel spoil from two 27 sq.m. tunnels passing through rock of granitic gneiss with zones of amphibolite. The grain size distribution of the tunnel spoil is given on Fig. 2. The compressive strengths of four rock samples were 422, 952, 1470 and 2175 kg/sq.cm.

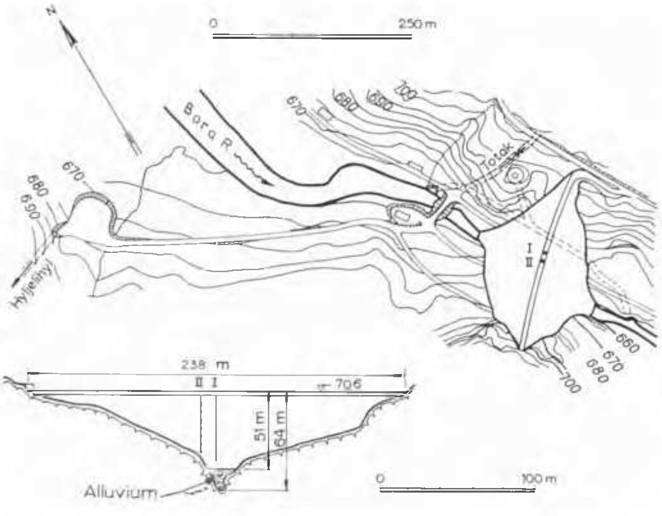

FIG. 1. Layout of Venemo Dam.

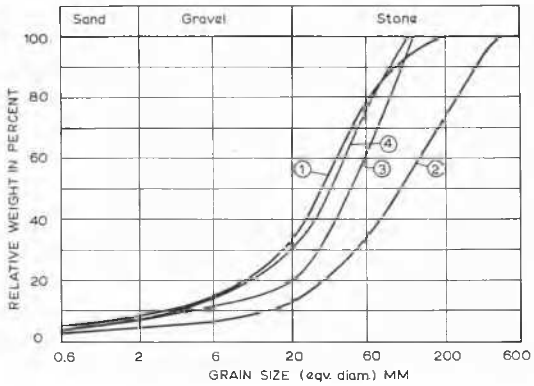

FIG. 2. Grainsize distribution of tunnel spoil. (1) from top of compacted layer, (2) from Totak tunnel, 27 sq.m., (3) placed in oedometer, (4) after completion of oedometer test.

The samples (approximately 5 by 5 by 14 cm) were tested after saturation in a waterbath. The most likely explanation of the rather low strength of two of the samples is thought to be due to the sticks going through the samples along which a failure plane developed.

The downstream fill was partly built up by dumping the rock in lifts of a few metres to approximately 20 metres in height, the rock being sluiced during dumping. The ratio of water to rock (by volume) is thought to be higher than four. In the upstream part of the dam the rock was placed in layers and compacted by an eight-ton vibrating roller. During the summer time the layers were 1.5 m thick, the rock was sluiced and 10 passes by the roller were made. During the winter the rock could not be sluiced because of frost, and the layer thickness was reduced to 1.0 m, while the number of passes was increased to 15. All snow and ice was removed from the fill before placing a new layer. After the winter season the fill was flushed by water from open tubes placed on top of the fill. Typical stages of construction are shown in Fig. 3.

The porosity of rock placed during summer was measured in an excavation to a depth of 1.0 m. The following results

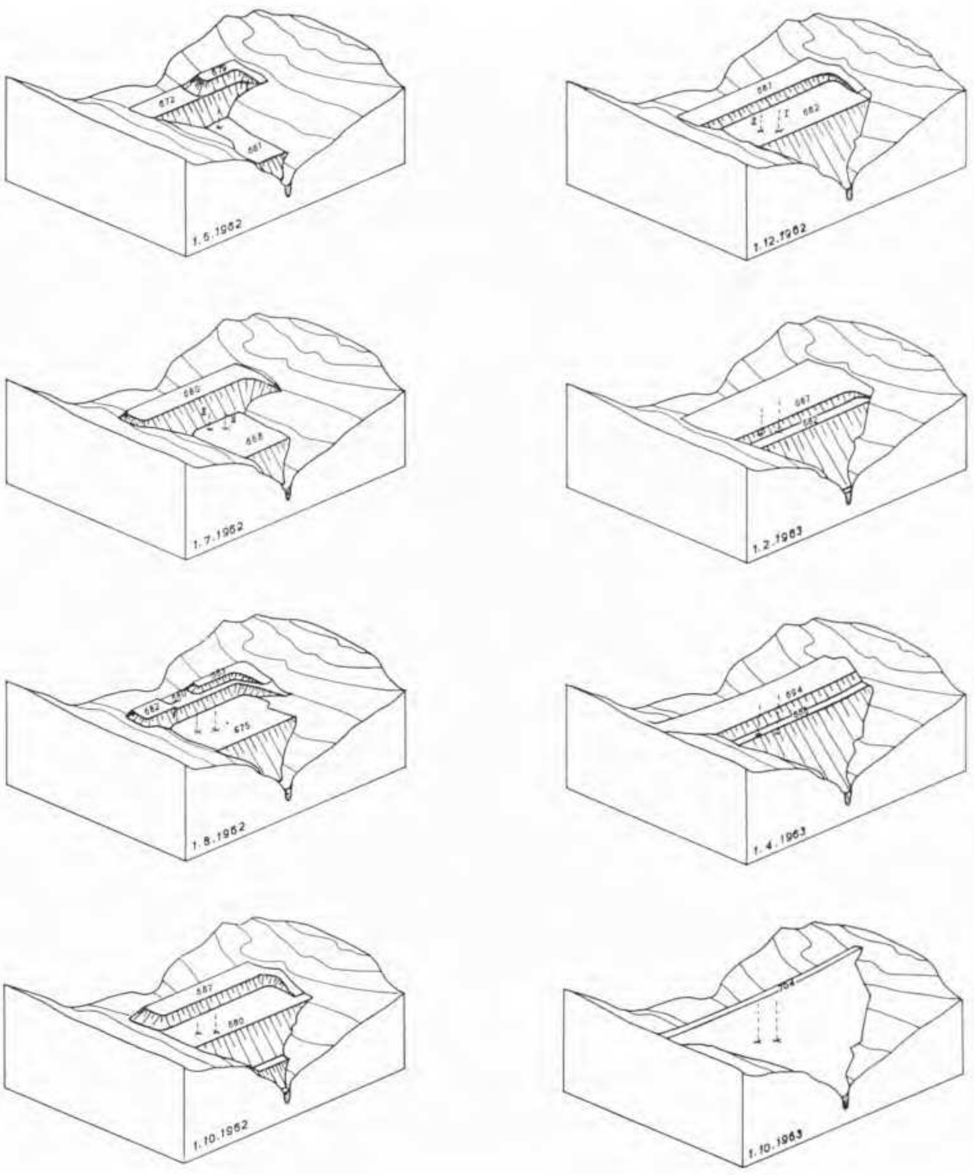

FIG. 3. Stages of construction.

were obtained; at the surface the porosity was 23 per cent. For material down to a depth of 0.4 m the average porosity was 25 per cent, and between 0.4 m and 1.0 m 35 per cent. Specific gravity of the rock was 2.70 tons/cu.m.

The grain size distribution of the sample taken from top of the layer is shown on Fig. 2. As seen, the material deviates slightly from that taken directly from the tunnel. The reason for this is perhaps a natural deviation; it is also thought to be due to crushing of material during compaction, but mainly to segregation of material even when placed in layers.

During the construction of the fill, crossarms of the type introduced by the U.S. Bureau of Reclamation were installed at the two locations shown on Fig. 1.

RESULT OF CROSSARM MEASUREMENTS

The results of the crossarm measurements up to the time of writing are shown for installations I and II on Figs. 4 and 5, respectively. A section through the dam, on which dumped and rolled fill is indicated, shows the location of the crossarms. The compression of the fill between crossarms is plotted against both time and overburden. The compression is given in centimetres and as a percentage of initial distance between the crossarms; the percentage is only approximate, as the initial distance between the crossarms deviated a few centimetres from the average of 5.3 m. In Figs. 4b and 5b the progress of fill at the location of the crossarm is shown by the elevation of fill curve. On the same diagrams it is also indicated when fill was placed during wintertime and when it was flushed afterwards. As a matter of course, the diagram shows that the fill at the bottom of the dam is more compressed than at the top, and that the compression at the bottom of the dam is as high as 5 per cent, or, in other words that the distance between the lower crossarms which was originally approxomately 5.3 m is reduced by more than 25 cm.

Figs. 4c and 5c give the compression *versus* the pressure due to the overlying fill, assuming an average density of fill of 2.0 tons/cu.m. The compression curves include a correction approximating the compression of the layers which occurred before the installation of the crossarms. From these diagrams it is clear that except for a marked bump in all curves the compression/load graph is fairly linear. The distinctive bump in all curves coincides with the

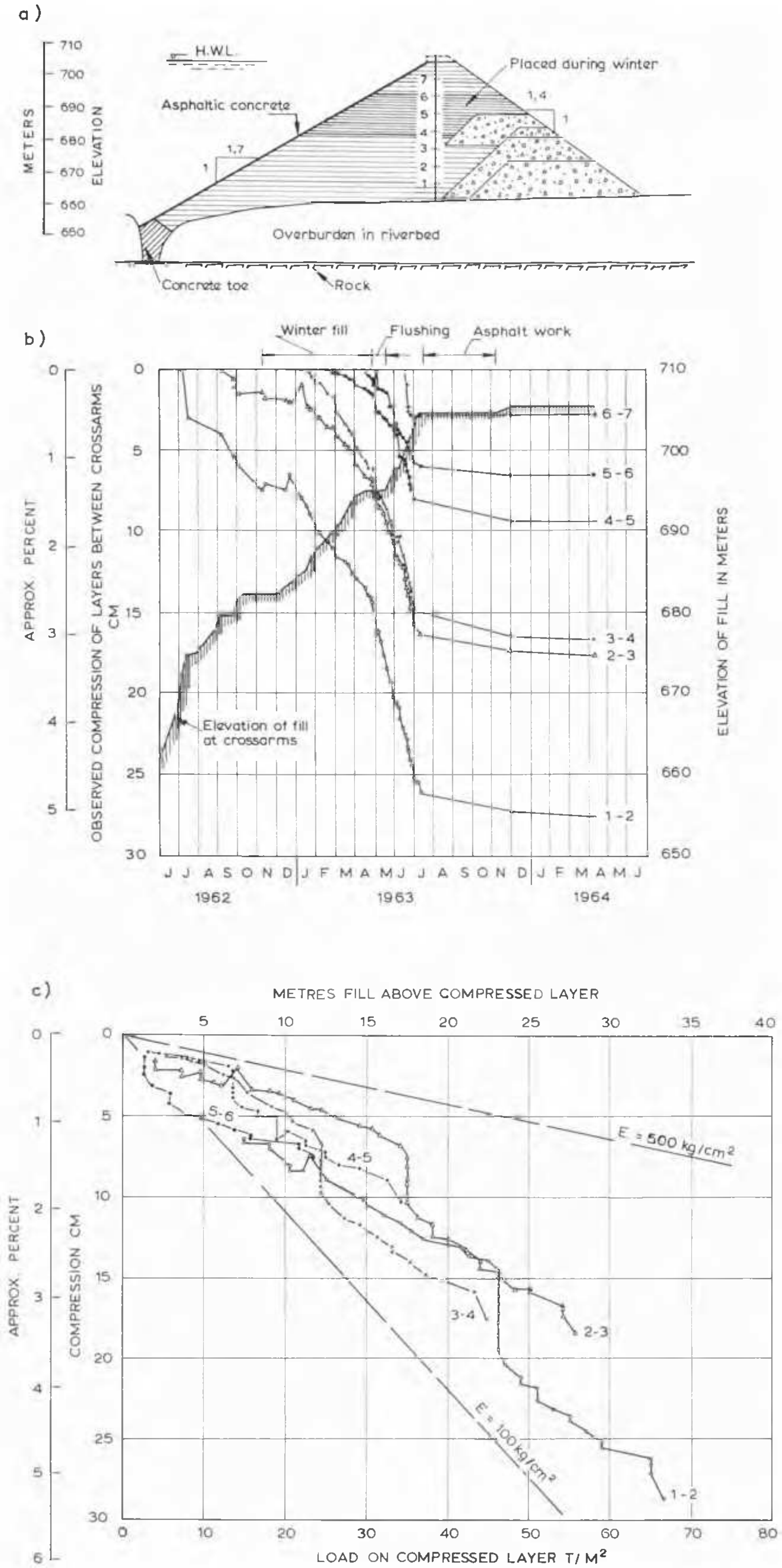

FIG. 4. Compression of layers at Installation I. (a) section through dam, (b) compression of layers between crossarms against time, (c) compression of layers between crossarms against pressure of overlying fill.

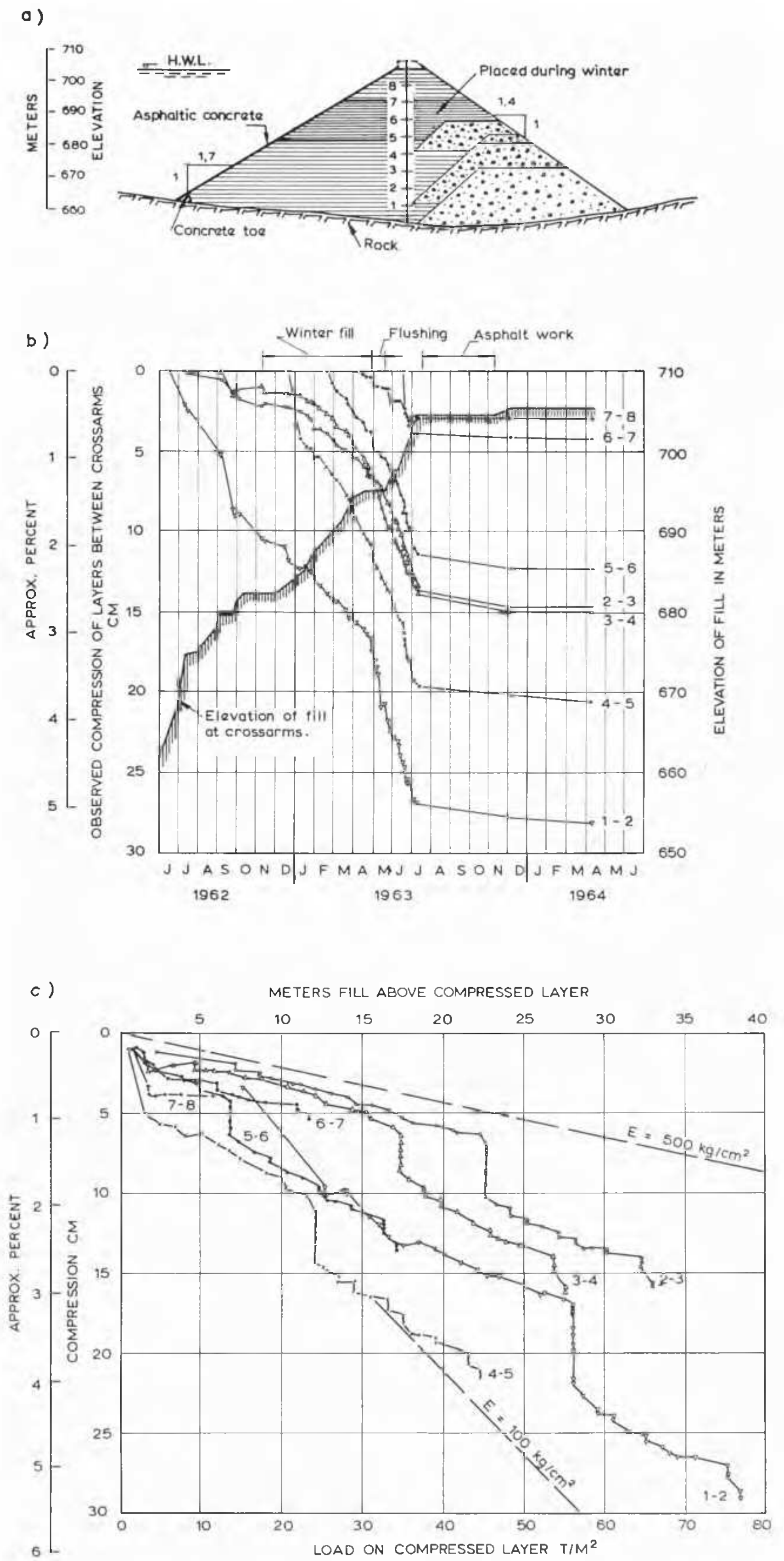

FIG. 5. Compression of layers at Installation II. (a) section through dam, (b) compression of layers between crossarms against time, (c) compression of layers between crossarms against pressure of overlying fill.

flushing of the fill in the spring of 1963. The compression of the fill as a result of flushing is greater for the fill under high load than for a lower load. The slope of the compression curve after compression due to flushing does not seem to have decreased, as may be expected. It is to be noted however, that the compression of the fill increased at a rate of a few millimeters up to approximately 15 mm a week when filling was restarted after flushing, compared with a rate of compression of up to 10 mm over a period of approximately 5 months, when no fill was placed during asphalt work. The slopes of the curves correspond to a tangent modulus of $E = 200$–400 kg/sq.cm.

From Figs. 4 and 5 it is not easy to determine if fill placed during winter is compressed more than fill placed during summer. Correlation of the compression of fill placed in winter and summer is therefore given in Fig. 6, where the compression of fill due to flushing is plotted against the load that the fill was exposed to, at the time of flushing. The effect of flushing clearly depends on the loads. Under a load of approximately 50 tons/sq.m. the compression is approximately 1 per cent. Plotted points of compression representing winter and summer fill indicate no remarkable difference in compressibility for different methods of placing. If anything, the winter-placed fill is slightly more compressible than summer fill.

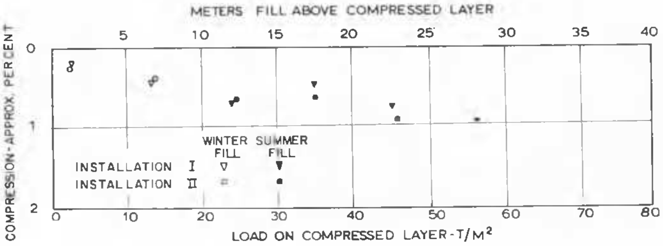

FIG. 6. Compression of layers between crossarms as fill is flushed with water against overburden.

RESULT OF OEDOMETER TEST

For the sake of interest oedometer tests have been carried out on the tunnel spoil from Venemo. The diameter and height of the oedometer cylinder were 50 cm and 25 cm, respectively. Load on the sample was obtained by a jack. From previous testing the wall friction was assumed to be 20 per cent of the jackload (Kjaernsli and Sande, 1963).

The results of one oedometer test are shown on Fig. 7 where compression is given against load. In general the rate of loading was a daily increase of 2 kg/sq.cm.; the first and last recorded compression is given for each load. Along the compression curve the time in days passed from the beginning of the test and also the submerging of sample is recorded. The results of the measurements on the crossarms in the dam are indicated.

Under a load of approximately 5 kg/sq.cm. the sample was given time to settle until no further compression was recorded (eighteen days). A further eighteen days were required before the sample came to rest after submergence. Keeping the load constant and letting the sample settle for 36 days, being submerged half of this time, resulted therefore in a compression of approximately 3 per cent. This was equal to the compression which might have been obtained by nearly doubling the load, with the rate of loading kept constant and with no submergence of the sample. At a load of approximately 27 kg/sq.cm. the sample was treated in the same way as under a load of 5 kg/sq.cm., the result being similar. During unloading a small rebound was observed. Reloading the sample up to the previous load of 27 kg/sq.cm. and further to 50 kg/sq.cm. gave only a small additional compression.

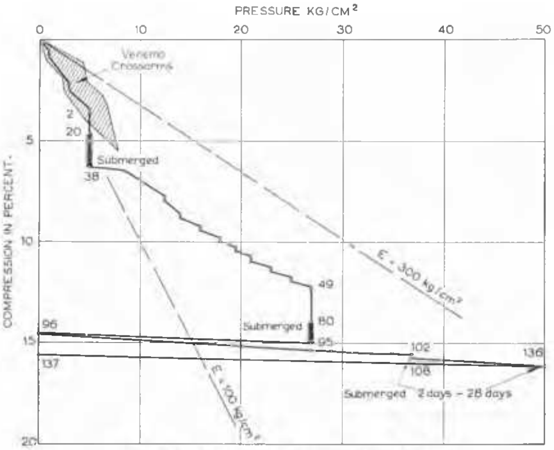

FIG. 7. Result of oedometer test.

The compression curve on Fig. 7 shows, as a matter of course, that the compression is a function of load. It shows, furthermore, that the compression under a constant load increases with time and that submerging of the sample is followed by compression. After being submerged and kept under a constant load for some time, the slope of the compression curve for the drained sample is flatter and approximately parallel to the recompression curve.

CONCLUSION

The main conclusion from the measurements might be that the rockfill built up of tunnel spoil is rather compressible, although this is not to say that tunnel spoil as such is more compressible than quarry-run rock. On the contrary, it is thought that well-compacted tunnel spoil would be less compressible than dumped rock of the same compressive strength.

The measurements have confirmed that the compression of rockfill under a constant load increases with time. Adding water to the fill results in a decrease of the compressive strength of the rock material which means that under constant load further compression results. If it was, therefore, necessary that an increased load on the fill should result in small deformations, it would be profitable to add water to the fill and allow it to have time to settle.

It is interesting to note that in a cold climate tunnel spoil may be placed during winter without sluicing (prohibited due to frost), and so obtain the same compressibility as for fill sluiced and placed during summer. However, more effort in compaction by reducing layer thickness and increasing the number of passes of compacting units is thought to be necessary. It should be noted that the fill must be kept free of snow and ice.

ACKNOWLEDGMENT

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