Design of Swiss Roads Against Frost Action

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This paper describes the topography and climate of Switzerland in relation to road design. Development in highway technology, particularly during the last 20 years, is traced. Methods for assessing road stability on the basis of soil type, ground water conditions, and frost penetration are discussed. Empirical curves for pavement design are shown.

• SWITZERLAND, in the center of central Europe, occupies a surface of 41, 295 km^2. The greatest extensions of this small country are only about 220 km in the north-south direction and 348 km in the east-west direction. More exciting is the vertical scale, from an elevation of 193 m above sea level at the surface of the Lago Maggiore in southern Switzerland, to 4, 634 m above sea level at the top of the Dufourspitze in the Monte Rosa Massif near Zermatt. These differences are an indication of the intense vertical structure of this country.

The climate of Switzerland falls between the atlantic-oceanic climate of western Europe and the continental climate of eastern Europe. The precipitation is about 120 cm/year on a 40-year average. Rather dry parts are found in the deep valley of the Rhone in the Wallis with an average of 60 cm of precipitation per year, whereas the Alps of the Bernese-Oberland and of the Canton of Claris are rather wet, with an average of 320 cm/year and more. Precipitation is fairly well distributed over the whole year with some predominance in the South during spring and autumn, and in the North during summer. The mean annual temperature varies, depending on the elevation and the latitude, between +10 to 12 C in southern Switzerland and near the Lake of Geneva to about +1 to +2 C on the highest alpine roads. It is typical for the country that even in the South there may be several frost periods in some years. Therefore, frost action in roads must always be considered.

ROADS AND ROAD STUDIES

Switzerland, with its population of 5, 429, 061 has at its disposal a network of 50, 000 to 60, 000 km of roads for motor traffic. Some of the present roads date back to the time when the Romans occupied the country, and others to the Middle Ages. Most of the roads, however, have been built within the last 100 years by municipalities and cantons. Although the greater part of them are located in valleys and plains, there is still a considerable number that cross the mountains of the Alps and the Jura. Design, construction and maintenance of this rather dense network of roads are administered by the public works departments of municipalities and cantons.

At the present time, Switzerland plans a new network of 1, 680 km of so-called National Roads, most of which will be open to motor vehicles only. In this case, it is the Federal Government that is responsible for planning and the co-ordination of this national undertaking. The Federal Government will contribute, on the average, 83 percent of the cost; the balance to be paid by the cantons and the municipalities. In July 1962 only 136 km of these National Roads were completed and 206 km were under con-

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struction. By the end of 1966, it is hoped that about 677 km (about 40% of the total) will be in use.

The design of the roads which have been constructed by the municipalities and the cantons has varied a great deal and depends on local tradition, financing methods, and designers. In order to develop more basic design information, the Swiss Federal Institute of Technology at Zürich and the Ecole Polytechnique de l'Universite de Lausanne are doing research work, especially on frost problems. Many of their papers are published in the Proceedings of the International Society of Soil Mechanics and Foundation Engineering, the Association Internationale Permanente des Congres de la Route, or in the periodical of the Association of Swiss Road Engineers, entitled "Strasse and Verkehr."

STUDIES ON FROST PROBLEMS

Damage due to frost action including thawing in the subsoil of the roads in Switzerland has been recognized for many years. Many case records have been published (4-6, 10-12). The theoretical aspect of the problems has been treated by Ruckli (8) and

TABLE 1

FREEZING INDEX, MEAN ANNUAL TEMPERATURE AND MEAN TEMPERATURE OVER THE DURATION OF FROST PENETRATION

No.	Measuring Stations	Height Above Sea Level (m)	Exposure of Meas. Station[a]	FI_{10} Avg. Freezing Index of 10 Successive Years (°C-days)	FI_{30} Avg. Freezing Index of 3 Coldest Winters in 30 Years (°C-days)	Mean Annual Temp. of 10 Successive Years (°C)	δ_0 Mean Annual Temp., Cold Year 1929 (°C)	δ_S Mean Temp. over Duration of Frost Pen.[b] (°C)
1	Aarau	406	T	96.7	297.5	9.24	7.9	-4.8
2	Adelboden	1,345	H	226.0	468.9	6.04	5.0	-5.5
3	Airolo	1,170	H	171.9	326.3	6.57	6.2	-3.6
4	Altdorf	456	T	61.3	223.4	9.63	8.8	-4.6
5	Andermatt	1,442	T	564.6	872.7	3.50	2.9	-6.5
6	Basel	318	Te	93.7	292.3	9.80	9.7	-4.7
7	Bellinzona	236	T	21.6	65.9	11.98	11.4	-2.4
8	Bern	572	Te	117.4	320.9	8.91	7.9	-4.4
9	Château-d'Oex	994	H	259.9	484.1	6.44	6.1	-4.5
10	Chur	609	T	113.9	318.7	8.92	8.2	-4.3
11	Davos-Platz	1,561	H	623.7	872.8	3.42	2.8	-6.8
12	Engelberg	1,018	T	257.2	509.8	6.03	5.4	-5.5
13	Frauenfeld	432	Te	119.1	333.1	9.02	7.9	-4.6
14	Fribourg	670	H	127.1	323.9	8.58	7.6	-5.9
15	Genève	405	K	48.2	173.5	10.74	9.7	-4.2
16	Glarus	503	T	154.9	391.0	8.28	7.1	-6.8
17	Interlaken	568	T	83.3	229.4	8.89	7.9	-4.2
18	Kloten	440	T	116.2[c]	289.6[d]	8.60	7.2[e]	-3.6
19	Kreuzlingen	445	H	115.9	326.3	8.87	8.3	-4.4
20	La Brévine	1,060	T	375.5	654.2	4.87	4.6	-6.8
21	La Chaux-de-Fonds	990	K	187.1	422.6	6.95	5.9	-3.7
22	Lausanne	589	H	69.2	206.0	9.99	9.2	-4.6
23	Luzern	497	H	91.8	277.2	9.65	8.4	-5.9
24	Neuenburg	487	H	82.2	240.8	9.71	9.0	-5.2
25	Sargans	510	H	104.8	317.7	9.51	8.6	-6.1
26	Sarnen	474	T	88.9	278.4	9.19	7.6	-5.4
27	Schaffhausen	448	H	115.2	358.1	8.96	8.0	-4.3
28	Schuls	1,253	H	483.0	736.1	5.42	4.3	-6.3
29	Sitten	549	H	71.6	210.4	10.52	9.8	-3.3
30	Solothurn	470	H	99.3	283.8	9.28	8.3	-4.0
31	Splügen	1,500	H	527.0	788.3	3.89	3.3	-6.5
32	St. Gallen	664	until 54:H later :T	170.0	401.6	7.63	6.9	-4.8
33	St. Moritz	1,853	H	632.8	338.7	2.59	0.5[e]	-6.7
34	Zermatt	1,610	T	505.3	593.2	3.91	3.7	-5.4
35	Zürich (MZA)	569	H	108.6	288.0	9.26	8.5	-6.3

[a]Exposure of measuring station: T = valley bottom; H = mountain slope; K = round hilltop; Te = terrace.

[b]Mean value calculated from the freezing indexes and the respective number of days of the 3 coldest winters in 30 years.

[c]Mean from 9 years, of measurements since 1949 only.

[d]Freezing index of the coldest winter in 10 years (1955/56).

[e]Mean annual temperature in 1956.

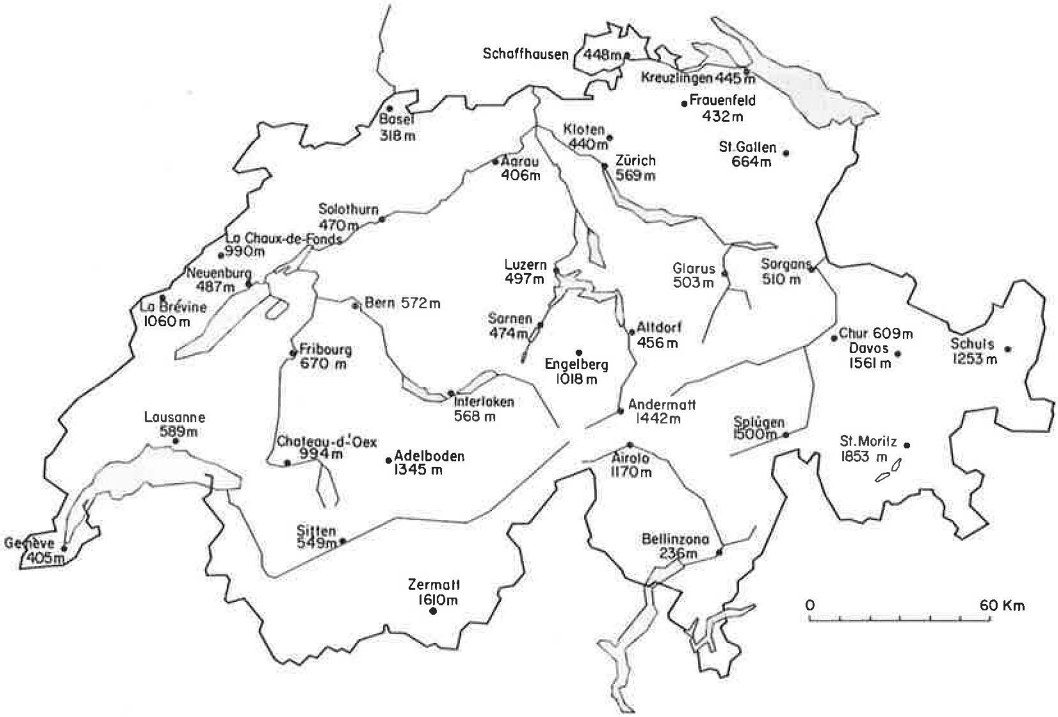

Figure 1. Distribution of the places in Switzerland where the freezing index, the mean annual temperature and mean temperature over the duration of frost penetration has been calculated (Table 1). Altitude above sea level is in meters, after Schnitter and Zobrist.

more recently by Balduzzi (2), who worked out a theory of the development of ice lenses and constructed very effective apparatus for the measurement of frost penetration, frost heaving and the heaving forces in the laboratory.

The Soil Mechanics Laboratory of the Swiss Federal Institute of Technology at Zürich calculated the mean annual temperature, the mean temperature during the frost periods and the respective frost indexes of 35 locations in Switzerland (9). The results are given in Table 1, and the locations together with their elevation in meters are shown in Figure 1.

On this basis, the same laboratory calculated the theoretical maximal frost penetration for the above locations for a sandy gravel during the three coldest winters over periods of 30 years and of 20 years (9). The calculations are based on the theories of Aldrich and Paynter (1), using the modified Berggren formula. These results (Table 2) represent a welcome basis for the practical design of roads in Switzerland whose base is normally constructed of sandy gravel.

To get more information, the Association of Swiss Road Engineers sponsored in recent years the construction of test fields at Zürich 569 m a.s.l., Payerne 460 m a.s.l. in the Western Central plain of Switzerland and Davos 1,561 m a.s.l. in the Eastern Alps of Switzerland. These stations measure the frost penetration under different surfaces (concrete and flexible pavement of various thicknesses). These measurements are underway and have already given very helpful results for the future design of roads. At the same time, they offer a welcome comparison for different temporary measurements of frost penetration under airfields and roads in Switzerland.

Balduzzi (2, 3) published results of his studies on some typical fine-grained soils in the frost laboratory, especially their reaction under freezing and thawing with regard to heaving and shear strength. The recommendations in the following section were based on these results.

TABLE 2

CALCULATED DEPTH OF FROST PENETRATION IN BASE MATERIAL FOR 35 SWISS TEMPERATURE OBSERVATION STATIONS

No.	Station	Height Above Sea (m)	X_{30} (cm)	X_{10} (cm)
1	Aarau	406	129	71
2	Adelboden	1,345	189	125
3	Airolo	1,170	143	103
4	Altdorf	456	107	54
5	Andermatt	1,442	288	225
6	Basel	318	117	69
7	Bellinzona	236	46	27
8	Bern	572	133	78
9	Château-d'Oex	994	180	129
10	Chur	609	131	77
11	Davos-Platz	1,561	265	238
12	Engelberg	1,018	194	133
13	Frauenfeld	432	135	79
14	Fribourg	670	139	85
15	Genève	405	90	47
16	Glarus	503	157	96
17	Interlaken	568	112	66
18	Kloten	440	128	77
19	Kreuzlingen	445	131	78
20	La Brévine	1,060	231	171
21	La Chaux-de-Fonds	990	170	108
22	Lausanne	589	102	58
23	Luzern	497	124	70
24	Neuenburg	487	111	65
25	Sargans	510	132	75
26	Sarnen	474	128	69
27	Schaffhausen	448	140	77
28	Schuls	1,253	247	189
29	Sitten	549	94	55
30	Solothurn	470	122	70
31	Splügen	1,500	269	213
32	St. Gallen	664	158	100
33	St. Moritz	1,853	320	250
34	Zermatt	1,610	246	207
35	Zürich	569	127	78

X_{30}: average depth of frost penetration during the 3 coldest winters in 30 years. Calculated from:
- FI_{30}: average freezing index for the 3 coldest winters in 30 years;
- δ_0: mean annual temperature during the cold year 1929;
- δ_s: mean temperature over the duration of frost penetration.

X_{10}: average depth of frost penetration during 10 years. Calculated from:
- FI_{10}: average freezing index of 10 successive years;
- δ_{00}: mean annual temperature of 10 successive years;
- δ_s: mean temperature over the duration of frost penetration.

These calculated values of X_{30} and X_{10} are valid for the materials: GW to GP;

$\gamma d = 2.1\ t/m^3$; $w = 4$ percent

Studies by the same laboratory encouraged the possibility of stopping the formation of ice lenses in some soils by treatment with cement.

DESIGN

During the last 20 years, the Association of Swiss Road Engineers has created eleven working committees to establish standards or norms which usually are accepted by the public works departments of the municipalities, cantons, and the Federal Government for their respective road construction.

Design for Bearing Capacity

The association of Swiss Road Engineers has published two recommendations for the design of roads regarding bearing capacity.

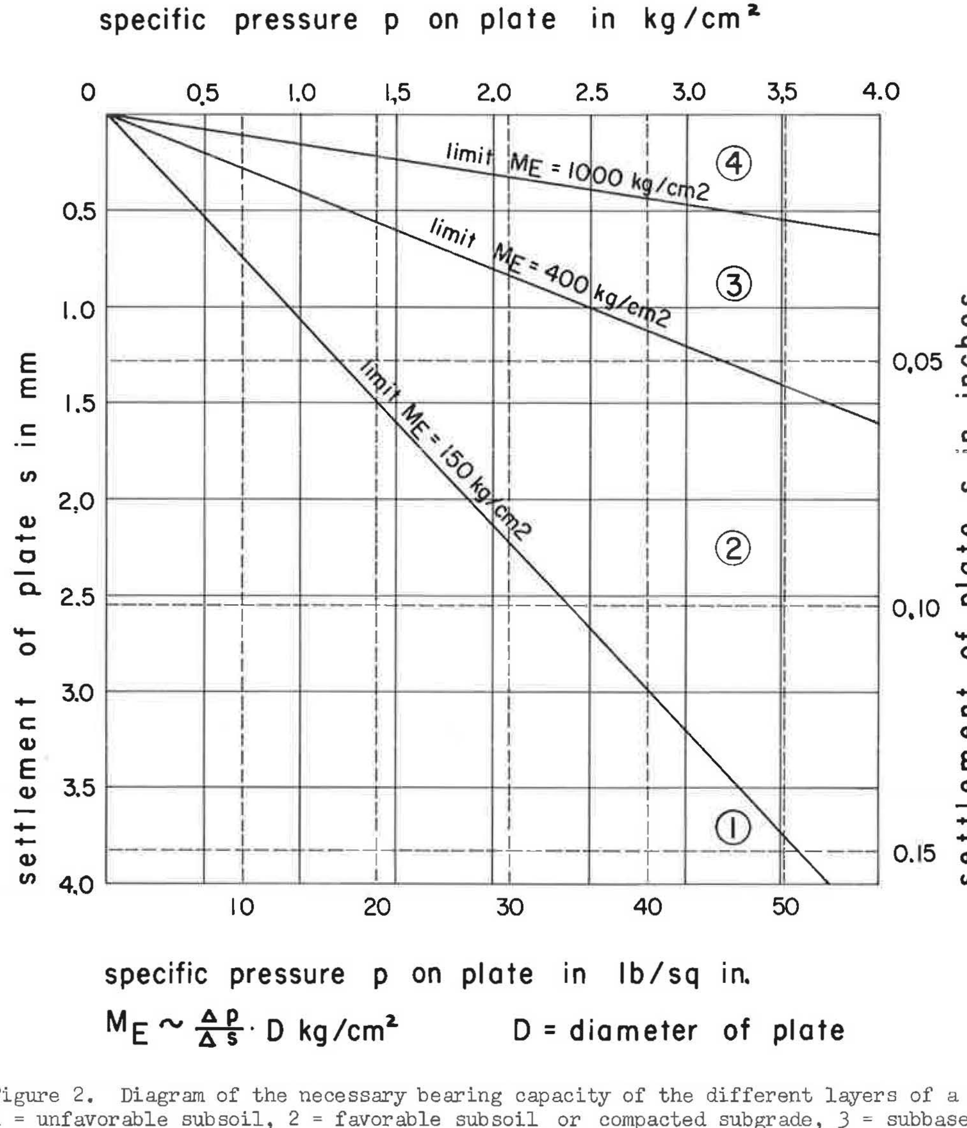

Figure 2. Diagram of the necessary bearing capacity of the different layers of a road. 1 = unfavorable subsoil, 2 = favorable subsoil or compacted subgrade, 3 = subbase, and 4 = base, after Norm SNV 40 317/1953 of the Swiss Association of Road Engineers.

Plate Bearing Method. – Norm SNV 40 317/1953 describes a design method based on the measurement of the bearing capacity by a plate bearing test (plates of 200 cm^2 and 700 cm^2). To control construction, the results of measurements on different parts of the road structure with the 200-cm^2 plate are plotted in Figure 2. If a measured M_E falls outside the required zone, the compaction should be continued or the method of compaction changed. If M_E falls within the zone, then the job is ready for the next layer.

Before the surfacing is started, the compaction should be checked on top of the base with a 700-cm^2 plate and the result compared with Figure 3. If the point falls into zone B, the work is in order. If it falls into zone A, the compaction should be continued or the method changed. The zones of Figures 2 or 3 are empirical and were established after much discussion of experiences.

CBR Method. – The second recommended design for a road, based on the well-known amd still discussed field CBR test, is treated in Norm SNV 70 315/1959 (first edition SNV 40310) and (SNV 40315/1953).

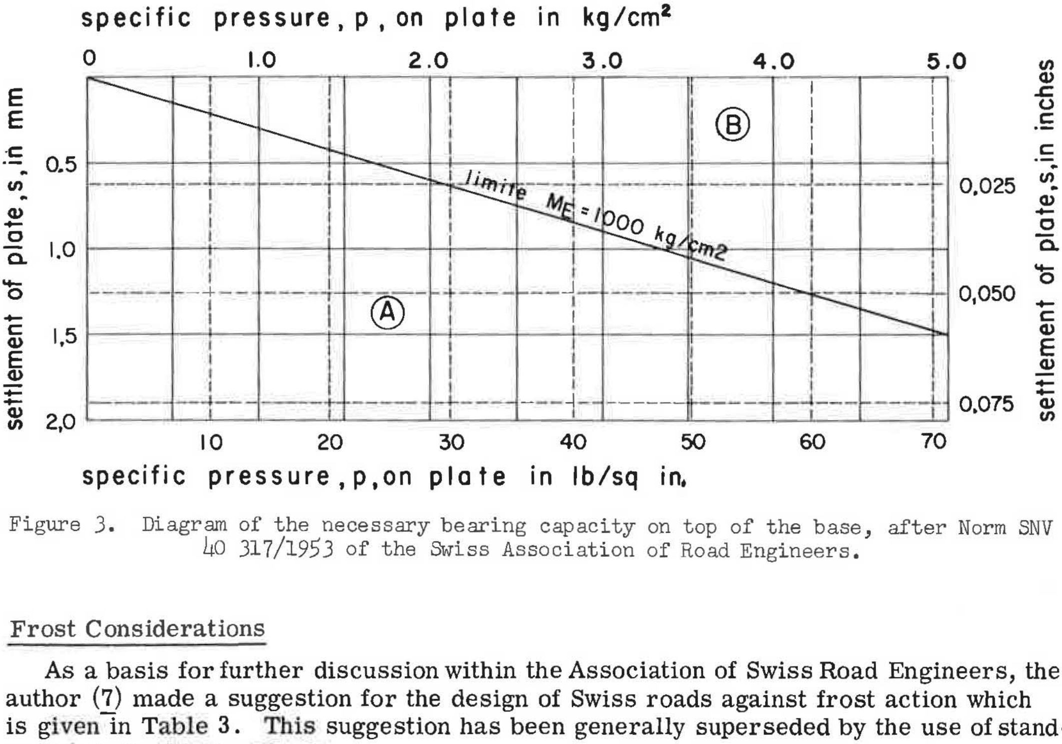

Figure 3. Diagram of the necessary bearing capacity on top of the base, after Norm SNV 40 317/1953 of the Swiss Association of Road Engineers.

Frost Considerations

As a basis for further discussion within the Association of Swiss Road Engineers, the author (7) made a suggestion for the design of Swiss roads against frost action which is given in Table 3. This suggestion has been generally superseded by the use of standard classification systems.

Use of Classification Systems

In order to unify the nomenclature of soils, the Association of Swiss Road Engineers and some other Swiss organizations agreed after long discussion to accept the Unified Soil Classification System (USCS) (see Norm SNV 70 005/1959). This was a great help in further work.

To accommodate differences in opinion and get, as quickly as possible, a generally acceptable method of design against damage due to freezing and thawing, the Association of Swiss Road Engineers issued 1957 Norm SNV 40 325 based on the classification of soils by both the USCS and the U.S. Public Roads Administration Classification.

The road design is based on Table 4 and Figure 4. The designer may classify the soil in accordance with either the USCS or the U.S. Bureau of Public Roads Classifi-

TABLE 3

PROPOSAL FOR THE DESIGN OF SWISS ROADS AGAINST DAMAGE DUE TO FROST ACTION DIMENSION OF SURFACING, BASE AND SUBBASE AFTER VON MOOS 1956

Soil Groups	Depth of the Groundwater Table	Flexible Pavements		Concrete Pavements	
		Normal Road Frequency[a]	Expressway Frequency[b]	Normal Road Frequency[a]	Expressway Frequency[b]
Coarse stone, gravel-sand, sand, material smaller than 0.02 m/m less than 3% of the total sample	No influence	Design after bearing capacity only, see Norm SNV 40' 317/1953 and SNV 70' 315/1959			
Coarse stone, gravel-sand, sand, material smaller than 0.02 m/m between 3 and 15% of the total sample	More than 200 cm under the surface of the road				
	Between 0 cm and 200 cm under the surface of the road	50 cm[c]	60 cm[c]	35 cm[c]	45 cm[c]
Silt, clay, gravel and coarse stone, material smaller than 0.02 m/m over 15% of the total sample	More than 200 cm under the surface	60 cm[c]	70 cm[c]	50 cm[c]	60 cm[c]
	Between 0 and 200 cm under the surface of the road	70 cm[c]	80 cm[c]	60 cm[c]	70 cm[c]
Peat, lake marl, clays		Design should be based on special studies			

[a] Less than 6,000 vehicles per day.

[b] More than 6,000 vehicles per day.

[c] Addition for elevation above sea level in meters: from 600 to 1,000, 10%; 1,000 to 1,500, 20%; over 1,500, 30%. Reduction on embankments: 10 cm, addition in cuts: 10 cm.

TABLE 4

DESIGN OF THE ROAD CONSTRUCTION ACCORDING TO NORM SNV 40'325 OF THE SWISS ASSOCIATION OF ROAD ENGINEERS 1957

Class	Soil Group	Soil Classification System		Design	
		USCS[a]	BPR[b]	Good Groundwater Conditions	Bad Groundwater Conditions
a (no frost sensitivity)	Well and poorly graded gravel-sands or sands with little or no fines	GW, GP SW, SP	A-1, A-2 A-3	Only if bearing capacity according SNV 70'315/ 40'317	
b (little frost sensitivity)	Well and poorly graded silty or clayey gravel-sands or sands	GM GC	A-1b	Zone 1 (Fig. 4)	Zone 2 (Fig. 4)
c (medium frost sensitivity)	Silty or clayey sands, inorganic clays of high plasticity, organic clays of medium to high plasticity	SM, SC CH OH	A-2, A-4 A-6, A-7 A-7	Zone 2 (Fig. 4)	Zone 3 (Fig. 4)
d (heavy reaction to frost)	Inorganic silts and very fine sands with slight plasticity; inorganic clay of low to medium plasticity	ML, MH CL	A-4 A-5	Curve 4 (Fig. 4)	Curve 4 (Fig. 4)
	Organic silts and organic silty clays of low plasticity	OL	A-7-5		

[a] USCS: Unified Soil Classification System, U.S. Dept. of the Interior, Bureau of Reclamation 1953

[b] BPR: U.S. Bureau of Public Roads Classification, HRB Proc., 25:375 (1945).

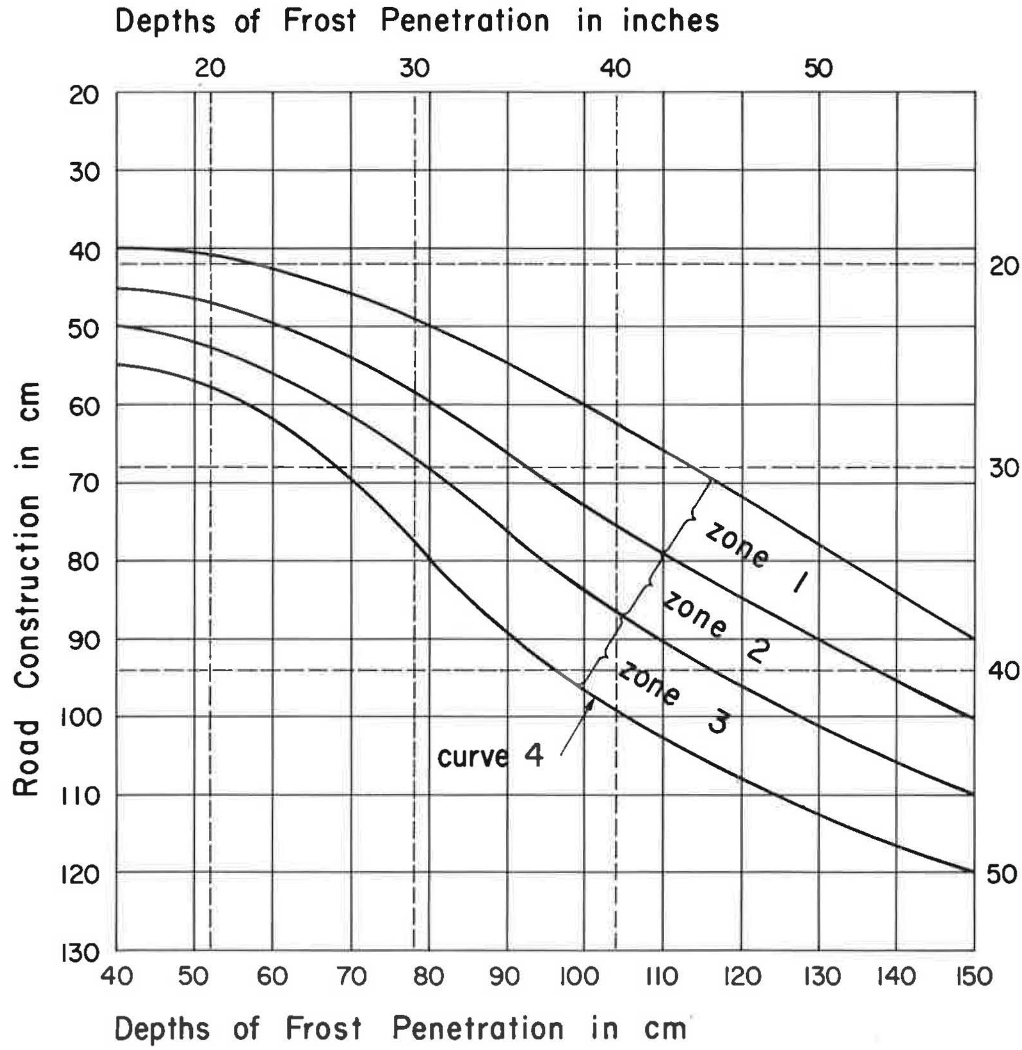

Figure 4. Thickness of the road construction in frost areas in case of thin surfacing, after Norm SNV 40 325 of the Swiss Association of Road Engineers.

cation. Soils are termed frost resistant if parts smaller than 0.02 mm constitute less than 3 percent by weight, and frost susceptible if this content is more than 3 percent. Ground water conditions are considered good if the ground water level is deeper than three times the maximum frost penetration. In the absence of more detailed information, the maximum frost penetration may be estimated from Table 5, but a more reliable estimate can usually be made from Table 2.

This method of design has been widely applied but must be revised in the near future. Experience has indicated that some reductions in design thickness may be possible.

Institute of Technology Method

In 1959, the Soil Mechanics Laboratory at the Swiss Federal Institute of Technology suggested their own rule for the design of roads using the following three groups based on the USCS. Grouping a material must be based on the field classification during the

TABLE 5

AVERAGE FROST PENETRATION

Location	Frost Penetration (cm)
Southern Switzerland, Central plain and Alpine valleys up to 600 m above sea level	50-100
Jura and Alps 800 to 1,400 m above sea level	80-140
Exposed parts of Jura Mountains, Alps over 1,400 m above sea level	120-200

investigation of the subsoil of the road. In critical cases, a sample should be studied in the laboratory.

Group 1

GW, GP, SW, SP--soils which, under the influence of the penetration of the 0 C isotherm, experience neither a heave nor a loss of bearing capacity during thawing. These roads can be designed for bearing capacity only.

Group 2

ML, MH, partly SM and GH—soils which, under the influence of the penetration of the 0 C isotherm, show a considerable heave. During the thawing process a sudden total loss of bearing capacity will follow. These soils should be removed and replaced by GW or SW material. The depth to which the material is to be replaced should equal the frost penetration in the GW and SM material. Frost penetration for some 35 places in Switzerland in different parts and elevations are given in Table 2.

Group 3

CH, OH, OL, CL, partly SC and GC—soils which, during the penetration of the 0 C isotherm, show a small heave due to a small heaving pressure. During the thawing of these soils, the bearing capacity is only reduced a little. These roads should not be designed for full frost penetration, but for only a reduced bearing capacity during thawing.

As a rule, roads which have to be built on soils of the latter group should be constructed of material of high resistance so that the pressure of the rolling vehicle is spread out over a wide area. In these cases, it is often very effective to stabilize the subsoil or the base by treatment with cement. This treatment of the base provides a good working surface for the mechanical compaction of the succeeding layers of the road. This treatment might also be used to change the upper part of a subsoil consisting of a silty or a clayey gravel or sand into a less frost-and thaw-susceptible material. As a rule, good drainage of these soils is very effective.

CONCLUSION

In Switzerland there is still no universally agreed method to design roads against frost action.

The working committee of the Association of Swiss Road Engineers has suggested a revision of their Norm SNV 40 325 regarding design of roads against damage due to freezing and thawing. This will be done in co-operation with the Soil Mechanics Laboratory at the Swiss Federal Institute of Technology, especially with Dr. F. Balduzzi, taking into account the new experiences in laboratory, field, and especially the results of the AASHO Test. The trend is towards a design based on the principle of maintaining a sufficient bearing capacity during thawing; by soil stabilization with cement for example. In all cases, a reduction in the total thickness of the road is possible, and this results in a more effective and economic way of building new roads.

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Discussion

W. H. PERLOFF, JR., Assistant Professor of Civil Engineering, Ohio State University, Columbus— The author presented a most interesting and informative description of frost action in Switzerland and Swiss practices of design against detrimental effects. Consideration of frost effects clearly plays an important role in pavement design throughout Switzerland. The problems which the Swiss face are similar to those encountered in the United States, because the maximum frost penetrations observed in Switzerland are of the same order of magnitude as those observed in the New England and northern midwest States.

It is of particular interest to compare Swiss design practices with those in use in this country. Dr. von Moos indicates that pavement components for Swiss roads are designed on the basis of bearing capacity, independent of frost effect. Field check of construction methods is performed with a plate bearing test or the field CBR method.

These methods seem to offer distinct advantages over the compaction criteria often applied in this country. Because the primary function of the soil components of a pavement system is to bear the loads imposed on them, a load-test technique of construction control seems reasonable.

The Swiss approaches to design, on the basis of frost considerations, are similar in many ways to methods used in the United States. The method suggested by the Association of Swiss Road Engineers appears to be similar in concept to that recommended by the U. S. Army Corps of Engineers (17). The Swiss method appears to yield somewhat more conservative values for total thickness of the paving system than the U.S. Corps of Engineers' approach. This can be illustrated by an example: For a frost penetration of 40 in. in soils which have little to medium frost sensitivity, von Moos' Table 4 indicates a total road thickness of approximately 35-40 in. For the same frost penetration and soil (groups F-3, F-4, Corps of Engineers' designation), a combined thickness of approximately 25-35 in. is indicated. This applies to the limited subgrade frost penetration method of design. The Corps of Engineers reduced subgrade strength design would generally give an even smaller thickness of road construction.

The method suggested by the Swiss Federal Institute of Technology is also similar in concept to the Corps of Engineers approach. However, no specific values are given to permit comparison. On the basis of this discussion, this writer agrees with Dr. von Moos that the present Swiss design practices are quite conservative and that a reduction of the total thickness of roads is possible and desirable. The indicated trend is toward the use of a "reduced bearing capacity during thaw" method. Perhaps the United States practice in this regard may be of assistance to the Swiss as they formulate their own criteria for design of roads against frost action by this method.

WM. P. HOFMANN, Director, Bureau of Soil Mechanics, New York State Department of Public Works. — This discussion and comparison of methods is based on the practices of the New York State Department of Public Works.

From the author's statistics, it appears that the climates of Switzerland and New York are somewhat similar, except that the freezing indexes of the northern third of the State are considerably greater than those calculated for the higher measuring stations in Switzerland.

All of New York State, except a small area south of the Allegheny River, was covered by the last continental glacier. In general, the topography is either rolling or mountainous, but the subsurface conditions are quite complex, exhibiting extreme variations in small horizontal and vertical distances.

Dr. von Moos indicates that, although Swiss highway engineers have not as yet agreed on a method of pavement design, the methods presently in use are based on a classification of the subgrade soil in accordance with either the Unified or AASHO System, a consideration of the depth to the water table, and the depth of frost penetration.

It is extremely difficult and impractical to accurately predict future subgrade behavior under frost action in areas of complex glaciation with any reasonable amount of subsurface exploration and laboratory testing. It is equally impractical to design satisfactory and yet economical pavements in glaciated areas by inserting laboratory test results into formulas for pavement thickness. Replacement of frost-susceptible soils with clean, granular materials to the full depth of anticipated frost penetration is generally extremely uneconomical, particularly in areas where these materials are scarce or not available.

In areas of complex glaciation, terrain and environment become the most important factors; not the texture of the major component of any deposit. For example, in New York the most critical differential pavement heave problems occur in cuts through kame, outwash and esker terrains generally composed of clean, granular materials. The stratification, permeability, topography and the presence of silt layers and lenses in such deposits produce great problems in differential heave. Cuts through folded rock formations produce differential heave problems of similar magnitude.

For many years, the New York State Department of Public Works has used a method of pavement design that is based on an evaluation of the performance of existing pavements serving under similar terrain and environmental conditions. This method is not as primitive or archaic as it seems at first glance. The State has many thousands of miles of highways on all types of terrain under wide ranges of environment. They constitute full-scale models readily available for observation. However, the essential requirement of this method is the judgment of an engineer thoroughly experienced in the design, construction and performance of pavements on any terrain under any environment.

The following points are valid assumptions when designing highway pavements to serve in areas of complex glaciation and significant seasonal frost action:

(1) All surface and shallow subsurface drainage facilities are generally inoperative during freezing and thawing, shallow culverts and underdrains are frozen, and the ditches blocked with snow.

(2) Consequently, most subgrades and subbases are saturated during freezing and thawing, regardless of the position of the water table.

(3) Generally, all pavements heave measurable amounts, regardless of any reasonable or economical preventive measures. Every effort should be made to obtain uniformity of subgrade and pavement conditions so that the heave is sufficiently uniform to minimize adverse riding qualities of and damage to the pavement surface.

(4) The thickness of the pavement section should be governed by the reduced bearing capacity of the subgrade during the spring thaw, and not necessarily the depth of frost penetration. Because bearing capacity during the thaw is known to vary considerably from year to year, the effect over a span of several years can only be estimated by observations of the performance of existing pavements serving under similar terrain and environment.