Stabilized Soil Foundations for Runways on Soils of low Bearing Capacity

Couches de fondation en sol stabilisé au ciment pour pistes d'envol sur sols de faible portance

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Summary

The construction of roads and runways on soils of low bearing capacity demand special methods and the use of cement-stabilized soil may provide a suitable solution to the problem.

The subgrade properties are considered by the authors as a criterion for the choice of the foundation material. To decide whether to use the stabilized layer in the base or in the sub base, the stresses in the different layers and the deflection characteristics of construction are discussed. These two criteria have led in the cases of two runways built on an organic and on a silty soil of high liquidity index to the following solution. A sub base of cement stabilized material lies directly on the subgrade and a base of granular aggregate is compacted on this layer. In both cases the solution adopted has been tried out before actual construction. The measurements of load distribution over the interface of the stabilized layer and the subgrade and the compaction values obtained on the base are given by the authors.

Sommaire

La construction des pistes et des routes sur un sol de faible portance exige des méthodes de construction particulières. L'emploi de la stabilisation au ciment est dans ce cas une aide précieuse.

Les propriétés du sol de fondation constituent le critère déterminant pour le choix du matériau à stabiliser. Pour savoir s'il était préférable de placer la couche stabilisée dans la fondation ou directement sous la couche portante, on a du étudier l'état de contrainte dans les diverses couches. Ces deux critères ont conduit dans le cas de deux pistes construites sur un sol organique et sur un sol silteux à la solution suivante ; une couche de matériau stabilisé au ciment est posée directement sur le sol comme couche de fondation. Sur cette dernière, une couche de base en matériau grenu peut être compactée. Dans les deux cas, la structure adoptée a été essayée avant la construction. La distribution de la pression verticale sur le sol de fondation est indiquée, ainsi que les valeurs de portance mesurées sur la couche compactée.

Introduction

In recent years an increasing number of aircraft runways and roads to take heavy traffic have been built on soils of low bearing capacity. As a result, new methods have been developed for undertaking such work rapidly and economically.

With this aim in view, the authors designed the runway of the municipal airport at Berne-Belpmoos and a section of the runway extension of the intercontinental airport at Geneva-Cointrin. In the first case the subgrade conditions were the same over the total length of the project, whereas in the second one only a section of low bearing capacity had to be crossed.

The types and thicknesses of the pavements had been previously determined by a third party.

Sub grade classification

In Berne the subgrade consisted of an organic soil of high plasticity. In Geneva a silty soil with low plasticity was cut during excavation work. Both soils were fine-grained and practically saturated with correspondingly low shear strength. No solid foundation could be found within economical depth. The mean values of the soil properties are shown in Table 1.

Table 1

			BERN	GENEVA
Type of soil			*silty clay of high plasticity with organic matter*	*clayey silt of low plasticity*
USCS soil class			*OH*	*CL - ML*
Dry density	γ_d	t/m^3	1,35	1,79
Moisture content	m	%	35,5	18,7
Density of solid particles	γ_s	t/m^3	2,68	2,69
Porosity	n	%	49,6	33,5
Degree of saturation	s	%	96,6	100,0
Liquid limit	L_L	%	57,0	19,5
Plasticity index	P_I	%	30,5	5,9
Liquidity index	L_I	%	29,5	86,5
Optimum dry density	$\gamma_{d,opt}$	t/m^3	1,49	1,86
Optimum moisture content	m_{opt}	%	25,5	12,6
Modulus of compressibility	M_E *)	kg/cm^2	86	20
California bearing ratio	CBR	%	—	3,1

*) $M_E = \frac{2a \cdot \Delta p}{\Delta W}$

$\Delta p = p_1 - p_0$: load interval, $p_1 = 1{,}5\ kg/cm^2$, $p_0 = 0{,}5\ kg/cm^2$

ΔW : settlement due to Δp

$2a = 30\ cm$: steelplate diameter

Proposed cross-sections

The low bearing capacity of the subgrade induced the authors to investigate a suitable application of cement-stabilization which has been used for a long time in various countries but which up to now has hardly been known in Switzerland.

Practical and theoretical considerations led to the two proposals shown in Fig. 1.

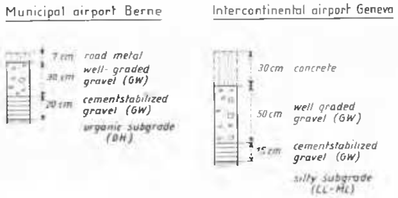


Fig. 1 Municipal airport Berne. Intercontinental airport Geneva. — Suggested cross-sections.
Coupes transversales proposées.

The authors regard the cement stabilized layer in the lowest part of the base as an essential feature of the two proposals. As this method differs from the frequently employed stabilization of the upper part of the base in one important point, the considerations which led them to adopt the present design are given.

Practical requirements : In the case of Berne as well as Geneva, the low shear strength of the subgrade made it impossible to bring in gravel by truck or to compact a normal base adequatlye. Both problems could be solved by the construction of a load distributing layer directly lying on the subgrade, e.g. by cement stabilization. This layer takes over the additional function of a sub base which — in any case — is necessary as a filter between the fine-grained subgrade and the coarse-grained base. Moreover a rigid layer equalizes local variations in the bearing capacity of the subgrade.

The following facts can furthermore be quoted in favour of the stabilization of the lowest layer of the base :

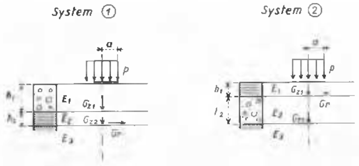
Relating to the stabilized layer—Lower influence of climatic conditions; the brought in gravel acts as a curing material.

Relating to the pavement—Cracks in the stabilized layer do not lead to cracks in the pavement.

The practical evaluation of the stabilization of the lower part of the base shows that this method has distinct advantages against the method of stabilizing its upper part.

Theoretical consideration : In order to balance the advantages and disadvantages of the stress- and deflection characteristics of the two arrangements against each other, the following calculations based upon the theory of equivalent thicknesses of N. Odemark were carried out for the two cross-sections shown in Fig. 2 : The vertical stresses σ_{z1} and σ_{z2}, the tensile stress σ_r occuring in the stabilized layer and the vertical deflection T of the surface of the upper layer.

A large circular load area was deliberately chosen to make a rough approximation of the load-spreading effect of a pavement. For the modulus of elasticity of the sub grade, which is assumed to have a low bearing capacity and the one of the stabilized layer the values of 200 kg per sq. cm and 100 000 kg per sq. cm respectively have been chosen in both cases. In conformity with the different possibilities for the compaction of the gravel base, the modulus of elasticity has been varied between 2 000 kg per sq. cm and 4 000 kg per sq. cm in the case of the stabilization of the lower layer, and in the case of the stabilization of the upper layer between the values 200 kg per sq. cm and 500 kg per sq. cm.



System	a [cm]	p [kg/cm²]	h_1 [cm]	h_2 [cm]	E_1 [kg/cm²]	E_2 [kg/cm²]	E_3 [kg/cm²]
①	36	1	30	15	2000 - 4000	100 000	200
②	36	1	15	30	100 000	200 - 500	200

Fig. 2 Stabilization of the bottom layer of the base. Stabilization of the top layer of the base. — Cross-sections assumed for the calculation.
Coupes transversales considérées dans les calculs.

The results of the calculations are shown in Table 2.

Table 2

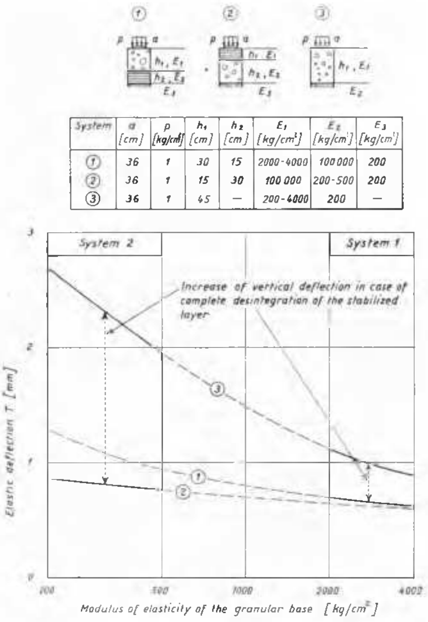
System	σ_{z1} kg/cm²	σ_{z2} kg/cm²	σ_r kg/cm²	T mm
1	0,46 - 0,57	0,07 - 0,08	8,0 - 9,2	0,62 - 0,70
2	0,14 - 0,15	0,09 - 0,10	11,4 - 12,0	0,76 - 0,86

It is evident that alternative *1* is superior to alternative *2* both as regards the vertical deformation as well as the stressing of the sub grade and the stabilized layer.

A further essential advantage of stabilizing the lower layer of the base is the considerably smaller effect which a decrease of the effect of the stabilized layer has upon the entire construction.

Fig. 3 shows besides the vertical deflections of systems *1* and *2* (curves 1 and 2) also their increase in case of a complete loss of the load spreading capacity of the stabilized layer (curve 3). The calculation of curve 3 is based upon the assumption that the compaction of the gravel base and therefore its modulus of elasticity will be preserved. Furthermore it is assumed that the modulus of elasticity of the disintegrated stabilized layer decreases to the value of the gravel base. These two conditions are satisfied only when the entire construction has been designed from the start without considering the reinforcing effect of the stabilized layer. Such proportioning is senseless for system *2* because it owes its quality exclusively to the load spreading capacity of the stabilized layer. In the case of system *1* the use of cement stabilization permits — on account of the high compaction of the granular base — smaller design thicknesses to be used than those normally employed, even if the slab effect of the stabilized layer is required during construction only.

The theoretical evaluation of the two arrangements of the stabilized layer shows that in those cases, where the durability of the stabilized aggregate can be guaranteed, the overall quality of the construction with the stabilized layer below is better on account of the higher compaction of the gravel base and of the lower stressing of the sub grade as well as the stabilized layer. This method makes it furthermore possible to build on soils of low bearing capacity more economically or better than with conventional methods even in those cases where the durability of the stabilized layer cannot be guaranteed.



System	a [cm]	p [kg/cm²]	h_1 [cm]	h_2 [cm]	E_1 [kg/cm²]	E_2 [kg/cm²]	E_3 [kg/cm²]
①	36	1	30	15	2000-4000	100 000	200
②	36	1	15	30	100 000	200-500	200
③	36	1	45	—	200-4000	200	—

Fig. 3 Deflection characteristics of the systems *1*, *2* and *3*.
Déflexions des systèmes *1*, *2* et *3*.

The cement-stabilized layer

After it had been decided to use cement-stabilization and the best arrangement of the stabilized layer had been determined, its realization was studied. As the quality and economy of a stabilized layer depend essentially upon its density and cement content, the decision was taken in accordance with the following criteria :

1. Bearing capacity of the subgrade : this determines if the soil-cement mixture can be adequately compacted or if it is necessary to use borrow material which — thanks to its grain-size distribution — reaches a sufficiently high strength with only light compaction.
2. Type of soil : The cement requirements depend upon the type of soil used. In each individual case it has therefore to be decided if it is more economical to stabilize either the existing subgrade with a high cement content, or to use borrow material with a lower cement consumption.

In the two cases under consideration these criteria led to the use of cement-stabilized borrow material. In Berne, a 20 cm thick layer of well graded gravel was stabilized with 4 per cent cement. The maximum grain size was 100 mm. In Geneva, a 15 cm thick layer of well graded gravel with a maximum grain size of 30 mm was stabilized with 6 per cent cement. The difference in the cement dosage has hereby been caused by the different grain-size distribution of the borrow materials used on the two sites.

In both cases stationary mixing plants have been used for economical reasons.

In Berne the stabilized layer was compacted with a light caterpillar vehicle, while in Geneva a light steel wheel roller was used. Special curing was not necessary in Berne where, subsequent to the compaction of the stabilized layer, the gravel base was brought in. Due to the low bearing capacity of the subgrade in Geneva protection from drying was maintained with a wetted, 3 cm thick carpet of sand.

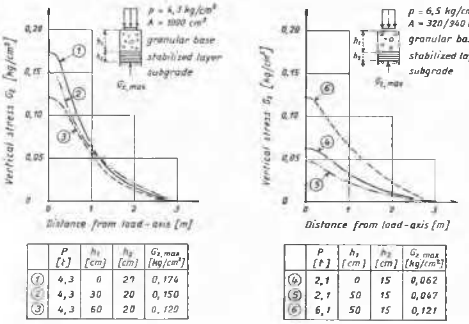
Verification of the proposed solutions

In Berne as well as in Geneva the proposed cross-sections of the runways were tried out by means of a test section. In both cases the following procedure was adhered to :

1. Classification of the subgrade by its dry density γ_d, moisture content m, plasticity, grain-size distribution and the modulus of compressibility M_E established with the 700 sq. cm plate in the load interval $0{\cdot}5 < p < 1{\cdot}5$ kg per sq. cm.
2. Determination of the crushing strength at 8 days of cubic samples of the stabilized layer.
3. Measurement of the distribution of vertical stress σ_z at the interface between the stabilized layer and the sub grade as a function of the thickness of the granular base. A truck with twin rear wheels was used as a roller.
4. Compaction of the granular base and selection of the suitable equipment. As a criterion use was made of the modulus of compressibility obtained with the first load application over a range of pressures from 2·0 to 4·0 kg per sq. cm.

Test results :

1. Subgrade : The subgrade conditions are represented by the soil properties shown in Table 1.
2. Stabilized layer : The crushing strength of test cube 8 days old with an edge length of 20 cm reached in the case of Berne 130 kg per sq. cm and in the case of Geneva 160 kg per sq. cm.
3. Vertical stress distribution :



	P [t]	h_1 [cm]	h_2 [cm]	$\sigma_{z,max}$ [kg/cm²]
①	4,3	0	20	0,174
②	4,3	30	20	0,150
③	4,3	60	20	0,120

	P [t]	h_1 [cm]	h_2 [cm]	$\sigma_{z,max}$ [kg/cm²]
④	2,1	0	15	0,062
⑤	2,1	50	15	0,047
⑥	6,1	50	15	0,121

Fig. 4 Municipal airport Berne. Intercontinental airport Geneva. — Distribution of the vertical stress σ_z at the interface of the stabilized layer and the subgrade.
Distribution de la pression verticale σ_z à l'interface de la couche stabilisée et le sol de fondation.

The curves 1 and 4 of Fig. 4 demonstrate the considerable load distributing effect of the stabilized layer alone. In Berne (curve 1) a maximum vertical stress $\sigma_{z,max}$ was measured under the stabilized layer which amounted to only 4 per cent of the contact pressure p, whereas in Geneva (curve 4) it hardly reached 1 per cent. The difference is due to the different proportions between the contact area and the thickness of the stabilized layer and to the different bearing capacities of the two subgrades.

A 50 cm thick well compacted granular base lying on the stabilized layer reduced the maximum vertical stress measured on the system "stabilized layer-subgrade" in both cases to 75 per cent.

4. Compaction tests : On both sites, well graded, gravel not susceptible to frost was used for the granular base.

The results of the compaction tests are recorded in Fig. 5.

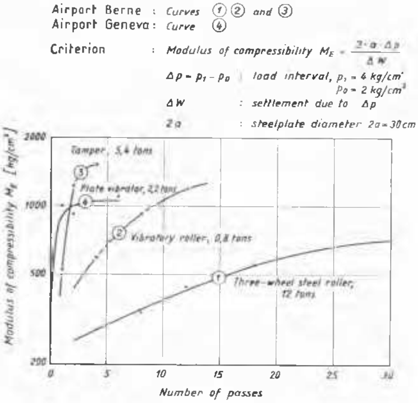


Fig. 5 Compaction values obtained on the base with different equipment.

Valeurs de compactage obtenues sur la couche de fondation avec différents engins de compactage.

The comparison of the curves 1, 2 and 3 determined on the test section in Berne shows that the multi plate vibrator gave maximum compaction values with the minimum number of passes. On account of the small thickness of the granular base, however the use of such a compacter would have been risky as it might have resulted in a dynamic overstressing of the stabilized layer. The combined use of the 12 tons three-wheel steel roller with the 0·8 tons vibratory roller was therefore preferred.

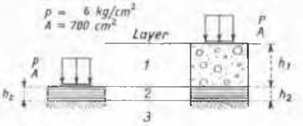
In Berne as well as in Geneva, the required modulus of compressibility had been fixed at 1 000 kg per sq. cm. The field density controls carried out in Berne showed, that this value is equivalent to 100 per cent Proctor standard.

Elastic properties of the different layers

The additional measurement of the total and the elastic deformations W and T with the 700 sq. cm steel plate on the two-layer and three-layer system of Geneva rendered it possible to calculate the moduli E_1 and E_3 of the gravel base and the sub grade. For the modulus of elasticity E_2 of the stabilized layer, the average value established from the stress-strain diagrams of the compression tests was used. The results obtained with the method of equivalent thicknesses are shown in Table 3. The denominations E and E^* indicate, that the respective moduli of elasticity have been computed from the total, respectively from the elastic deformation.

Table 3

Layer	h cm	E kg/cm²	E* kg/cm²
1	50	900	1 830
2	15	225 000	225 000
3	∞	225	980



Based upon the calculated moduli of elasticity E and E^* the vertical stresses induced at the interface of the subgrade and the stabilized layer were computed according to N. Odemark. The result is shown in Fig. 6 together with the measured values.

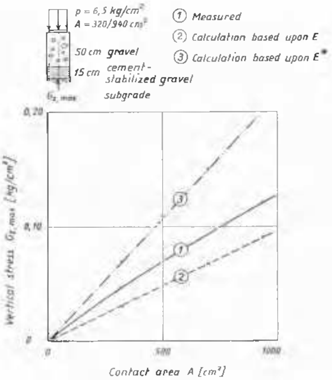


Fig. 6 Comparison between the measured and calculated maximum vertical stress $\sigma_{z, max}$ in the load axis at the interface of the stabilized layer and the subgrade.

Comparaison entre la pression verticale maximum $\sigma_{z, max}$ mesurée et calculée dans l'axe de charge à l'interface de la couche stabilisée et du sol de fondation.

The comparison of curves 1, 2 and 3 demonstrates that the theory of equivalent thicknesses is a useful method for evaluating complicated layered systems.

Conclusions

The cement-stabilization of the lowest part of a base is considered to be a valuable expedient for construction of aircraft runways and roads on sub grades of low bearing capacity. If the stabilized layer is durable, this method guarantees — due to the high compaction of the gravel base and the lower stressing of the subgrade as well as the stabilized layer — a higher overall quality of the three-layer system than in the case of the stabilization of the topmost layer. Even in those cases, where the durability of the stabilized layer cannot be guaranteed, the method enables a more economical and better construction to be achieved than by using conventional methods.

The results obtained on the two test sections at Berne and Geneva as well as the deflection measurements carried out on the runway of Berne after the beginning of operations, have confirmed the quality of the proposed design suggested by the authors.

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