KBS TEKNISK RAPPORT

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Required physical and mechanical properties of buffer masses

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Högskolan i Luleå 1977-10-19

KÄRN-BRÄNSLE-SÄKERHET

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REQUIRED PHYSICAL AND MECHANICAL PROPERTIES OF BUFFER MASSES

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TEKNISK RAPPORT KBS 9

REPORT ON

REQUIRED PHYSICAL AND MECHANICAL PROPERTIES OF BUFFER MASSES

FOR ROCK DEPOSITION OF RADIOACTIVE WASTE PRODUCTS – A SUMMARY

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MASKINTEKNIK · GEOTEKNOLOGI · ARBETSVETENSKAP

REQUIRED PHYSICAL AND MECHANICAL PROPERTIES OF BUFFER MASSES FOR ROCK DEPOSITION OF RADIOACTIVE WASTE PRODUCTS - A SUMMARY

by
Roland Pusch

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Introduction

It was obvious already at an early stage of the author's investigation (cf. JACOBSSON & PUSCH, KBS 03) that safe deposition of radioactive canisters in bore-holes or tunnels requires an embedding substance (buffer mass) for which the following criteria are specified:

- Sufficient mechanical supporting power to prevent rock fragments from entering the mass. Also, a sufficient bearing capacity is required to carry the heavy canisters with only insignificant movement.

- Suitable mechanical properties to guarantee a homogeneous character of the buffer mass in case of small differential movements in the surrounding rock. This requires a plastic (non-brittle) behaviour and some swelling power of the buffer mass ("self sealing").

- Prevention of free circulation of ground water. This requires a homogeneous character and a very low permeability of the buffer mass.

- Ion-adsorption ability. This requires a sufficiently high base exchange capacity and a suitable originally adsorbed ion type of the buffer substance. (If the rate of diffusion for specific ions must not exceed a certain value, a sufficient amount of buffer substance has to be used. This is considered to be a matter of design).

- Sufficiently good heat conduction properties to keep the temperature in the mass within a suitable interval.

As mentioned in this early report by JACOBSSON & PUSCH the author considered Na-bentonite to be a very suitable buffer mass constituent since it would produce a low permeability, a swelling potential and a certain ion-adsorption capacity. Two major problems were obvious, however:

- A bentonite-rich buffer mass cannot be brought in a homogeneous condition unless it is either very wet (w>150%) or dry (w<20%). Since a wet mass would not have a sufficient bearing capacity the dry condition alternative has to be chosen. This yields two secondary problems:

  1. A dry buffer mass has a strong affinity to water. Even if the bentonite content is as low as 20% by weight a complete water uptake would largely decrease the bearing capacity and increase the permeability. To avoid this and to preserve the swelling potential of the mass the bore holes must be sealed effectively. In tunnels there would be no means of preventing the buffer mass from taking up water at free swelling until each tunnel is finally sealed with a concrete wall. The author's solution was to suggest a 10% (by weight) bentonite content for the bore-holes since this guarantees a sufficient bearing capacity whether complete water uptake occurs or not. For the tunnels from which the bore holes extend a higher bentonite content (20-50%) was suggested. Direct canister deposition in tunnels, on the other hand, would require a 10% bentonite content in the tunnels at least in part of the canister beds.

2. Medical inconvenience by handling dry silica powder masses is well-known. Discussions within the KBS Buffer mass group and with the AHLSELL & ÅGREN Co showed that a water content of about 8% should be required to give the mass a suitable condition for handling. This value has later been found to be of the order of 4% (statement by LUNDAHL, STABILATOR AB).

- The heat conduction capacity will be very low even if the bentonite is fully water saturated. Again, the author's solution was to suggest only a 10% (by weight) bentonite content. The other 90% should consist of quartz grains since this mineral conducts heat better than most other common rock constituents.

It should be added to these introductory remarks that the true difficulty in defining a suitable buffer mass is to prove that the required physical and mechanical properties are stable for thousands of years at the elevated temperature in the radiation field close to the canisters. As shown by the JACOBSSON & PUSCH report this problem, which is of a chemical and physico/chemical nature, is solved provided that temperature and water circulation are restricted. The matter is being further treated at the Div of Soil Mechanics, University of Luleå. Comments on this are given in the following.

Bearing capacity

A major part of the JACOBSSON & PUSCH report deals with the author's analysis of the strength properties of bentonite/quartz masses. The conclusive statement concerning bearing capacity is that the 10% (by weight) Na-bentonite and 90% quartz mass should contain fairly big quartz grains (silt and sand-sized) so that a moraine-like grain distribution is obtained. The reason for this is that compaction leading to high bulk densities is then easily obtained by applying well-known field compaction techniques. Laboratory investigations at the University of Luleå have shown that dry bulk densities of the order of 1.8 t/m^3 can be obtained without difficulty (cf. Fig 1).

The two companies VBB (consulting firm) and STABILATOR AB (contractor) have investigated in a joint field experiment buffer mass compaction in a 4 m diameter steel pipe "tunnel". Their work also comprised a series of laboratory compaction tests. The results show that field compaction of a 10-15% (by weight) Na-bentonite and 80-90% quartz mass (crushed quarzite (gravel-sized), quartz sand, quartz powder, cf. Fig 2) with water contents in the range of 5-15% produces a very firm, moraine clay-like substance as predicted by the author. The dry bulk density in the laboratory experiments was of the order of 1.8-2.0 t/m^3 while it was 1.4-1.7 t/m^3 in the field test.

As concluded from the author's analyses given in the JACOBSSON & PUSCH report the suggested mass composition will yield a sufficient bearing capacity, and a very high modulus of deformation. Creep will be insignificant only also if temperature effects are taken into consideration.

Permeability

The author's literature survey concerning the permeability of bentonite-containing soils gave evidence of very low k-values. Thus, the JACOBSSON & PUSCH report states that a 10% Na-bentonite/90% quartz powder mass should have a k-value of about $3 \cdot 10^{-11}$ m/s. Ion exchange to calcium is said to increase the permeability to about 10^{-9} m/s. It should be added here that an increase of the bentonite content to 33% should yield a k-value of about 10^{-11} m/s. A strongly compacted pure Na-montmorillonite can be regarded as impervious.

There is sufficient experience from laboratory and field investigations to believe that these values are reasonable. However, there are two differing statements concerning the k-value given in the present KBS investigation. Thus, AHLSELL & ÅGREN report a determination of k made by the Geological Department, University of Uppsala which gave surprisingly high k-values (10^{-6}-10^{-8} m/sec). However, these values are not relevant at all since the permeability tests were run as percolation tests on unconfined samples. This condition of free swelling enabled the samples to take up large amounts of water with a concomittant large increase in permeability. The other statement was given by the VBB company meaning that k is of the order of 10^{-9} m/s at 10% bentonite content and 10^{-10} m/s at 20% bentonite content. The discrepancy between the various values can be further investigated by making a series of relevant tests. In the author's opinion, however, this is not necessary since the moraine-like grain size distribution and the effective sealing properties of Na-bentonite would most certainly give the mass a maximum k-value of 10^{-10} m/sec provided that the bentonite content is at least 10% and that the bulk density is higher than 1.6 t/m³. Constant volume conditions during percolation are also required.

Swelling properties

As indicated by the introductory specification of the buffer mass functions, a certain swelling potential is required. The ability to swell and to exert a swelling pressure on bore hole or tunnel walls is dependent on the initial water content of any given bentonite/quartz ratio. The author's experiment on initially air-dry (w~5%) mixtures of bentonite and natural silt ("Pitesilt") gave a swelling of about 5-20% at swelling tests where the samples were laterally confined and axially loaded to 10 kPa. The lower value corresponded to 10% bentonite content and the higher to 20% bentonite content. The swelling pressure measured at constant volume under water uptake from an air-dry condition to equilibrium gave about 30 kPa at 10% bentonite content and about 110 kPa at 20% bentonite content.

The VBB company also reported values from preliminary tests. The investigated bentonite/quartz mixtures were compacted at 10-15% water content and were then allowed to swell freely under further water uptake. The swelling was found to be 15-30% which agrees reasonably well with the author's tests where the swelling took place under an external 10 kPa pressure. Also the VBB tests comprised measurements of the swelling pressure under constant volume conditions. The values range between 30 and 200 kPa which exceeds the author's values. The reason is probably that part of the water was taken up by organic constituents in the author's tests while it was all used for particle swelling in the other test.

It can be stated that the swelling behaviour of the buffer mass is sufficiently known and that no further separate test series have to be made.

Plastic behaviour

One of the most important required properties of the buffer mass is to stay plastic for very long periods of time (10 000 years or more). Plasticity is interpreted here as a condition of single particle or aggregate behaviour without any formation of cracks or fissures which is typical of brittle substances. Brittle behaviour can be caused by mechanical as well as by chemical processes. The first-mentioned deal with "pressure solution" which is known to produce cementation between quartz grains at high contact pressures and the second process is a complicated phenomenon which involves dissolution, transport, and precipitation of

SiO_2 as a function of pH, temperature, and amount of percolated water. The author has shown in a report "Influence of cementation..", which is going to be printed in the KBS-series, that neither of the mechanismswill produce cementation bonds. Thus, mechanical stress ("effective" stress) will be very much lower than required to cause "pressure solution". Nor will quartz dissolution and precipitation produce cementation to a degree which affects the mechanical properties. The main reason for this is that pH will not be critical and that the amount of percolated water will be moderate even if extremely long periods of time are considered (>>10 000 years).

An investigation of the pattern of internal buffer mass movement caused by rock displacement (KBS report no 22) gives some interesting informations. In this report the author showed that a sudden displacement of less than 20 cm does not produce any cracks or other types of open space anywhere in a buffer mass which fills a 5 m tunnel with a 7 m long canister (1 m diameter). Since the distribution of possible future rock movements is well known (old shear zones, zones of crushed rock, plane graphite-, clay- or chlorite-containing joints) the position of the canisters can be chosen so that only insignificant movement, certainly less than 20 cm, will occur. Therefore, the suggested buffer mass will have the necessary plastic and self-sealing properties to fulfil the requirements.

Heat conductivity (λ)

The main requirement to preserve the chemical stability of the bentonite for long periods of time is to keep its temperature below about $100^{\circ}C$ when the water uptake has proceeded to the state of complete or almost complete water saturation. Calculation of the temperature field in the surrounding of the canisters has shown that the heat conductivity of the buffer mass is a very important parameter in this context. This was realized early and was one of the main reasons for suggesting a high quartz and a low bentonite content of the buffer mass (KBS reports no 2, 3 and 23). The general relationship is that λ increases with increasing degree of water saturation. A 10% (by weight) bentonite and 90% quartz silt/sand mass will take up water to equilibrium corresponding to a water content of about 20-30% at water saturation provided that no swelling takes place. If the mass is applied in a dry condition (w=4% is minimum for safe handling) λ has been found to be at least 0.5 W/m, ^{o}C at a density which is equal to or lower than the density in the bore holes or tunnels. When the mass is fully saturated, on the other hand, λ will be at least 2.0 W/m, ^{o}C. It would be logical therefore to apply the mass as wet as possible but field experience (VBB and STABILATOR companies) shows that the water content must be less than 20% to avoid heterogeneities and cluster formation at the compaction. A safe value in this respect would be about 15% but this has been found to yield another problem. Thus, a series of λ tests with a sealed buffer volume showed that water is transported as vapour from the warm side (vicinity of canister) and is enriched at the cold side (rock wall) when the degree of water saturation is between 25 and 75%, that is at water contents of the order of 10-20% (extreme values of the porosity about 25-65%). This means that the mass will dry out at the warm side which reduces the λ-value asymptotically to about 0.5 W/m, ^{o}C. One way of solving the problem would be to give access to free water and to create a considerable hydraulic gradient by placing perforated water pipes in the buffer mass at the outer periphery (rock wall) in which water is kept under pressure (300-500 kPa would be sufficient). The applied dry mass - w=8% would probably be very suitable - will then take up water in a process which, according to the author's tests, would probably lead to a continuously increasing water content. It will ultimately correspond to complete water saturation. This will definitely be the case when the tunnel system is finally closed and the original ground water table restored.

Organic activities

Microbial activity may contribute to metal canister corrosion. It is therefore important to consider whether it is possible for bacteria to live and to be active in the buffer mass. All the buffer mass components contain bacteria or fungi but this content will probably be insiginificant in the quartz fraction. The natural Na-bentonite, on the other hand, is said to have an organic content lower than 1 percent by weight of the solid substance.

Previous investigations by the author (cf. Document D11:1973, Nat. Swedish Building Res. Council) have shown that in natural Quaternary clays with an organic content of less than 2% the organic bodies are very widely spaced. This indicates that the original microbe, normally a bacterium, was not able to move or create pores once it was buried during the sedimentation. Since the buffer mass will be denser than these Quaternary clay sediments the locking of the bacteria will be even stronger. This means that the life-time will probably be very short and that the possible attack will be confined to the extremely small canister surface area where a certain number of bacteria happen to be located at the deposition.

Conclusions

So far all evidence given in the current investigation by the KBS buffer group shows that a combination of Na-bentonite and silt/sand-sized quartz components gives a buffer mass with optimum properties. The physical, physico/chemical, and mechanical properties of such masses are sufficiently well-known to allow us to use them in this very serious context. Furthermore, the handling of the masses at the deposition involves no new or unknown technique, only moderate changes or improvements have to be made. Thus, the practical deposition work will very probably be successful as far as the buffer mass concerns.

As to the bentonite/quartz ratio it can be stated that the bentonite should form at least 10 weight percent of the solid mass. This is where the bearing capacity or canister- or rock-supporting power is important. In other parts of the bore holes, tunnels and shafts the bentonite content can be increased to 20 or even higher percentages. The final choice of this ratio is considered to be a matter of design with special reference to required temperatur limitations and aspects which deal with the properties of the mass when transported, compacted etc.

Luleå 1977-10-19

Roland Pusch

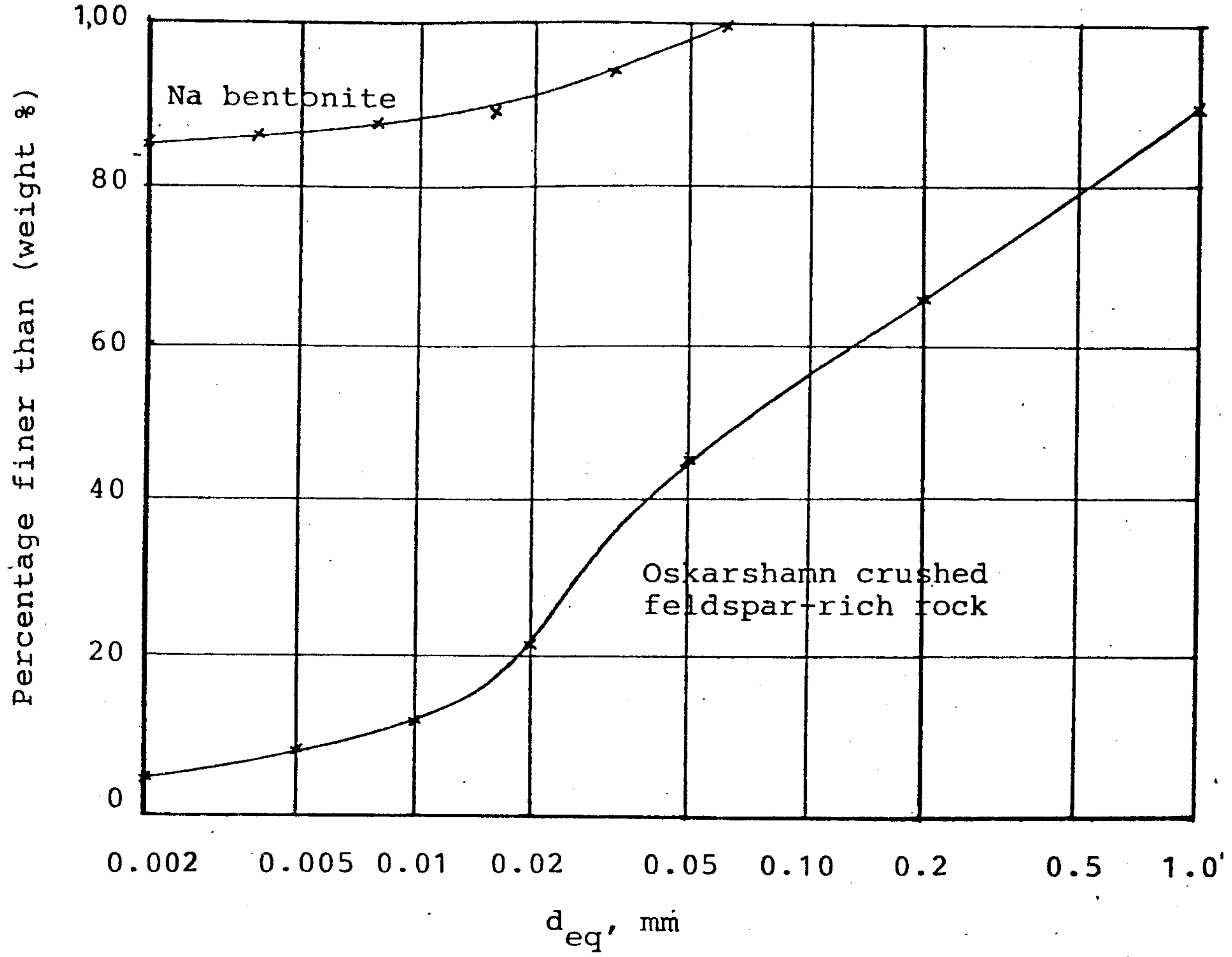


Fig 1. Grain-size distribution curves for the buffer substance used in Test II. (From KBS report no 23)

VATTENBYGGNADSBYRÅN

(VBB)

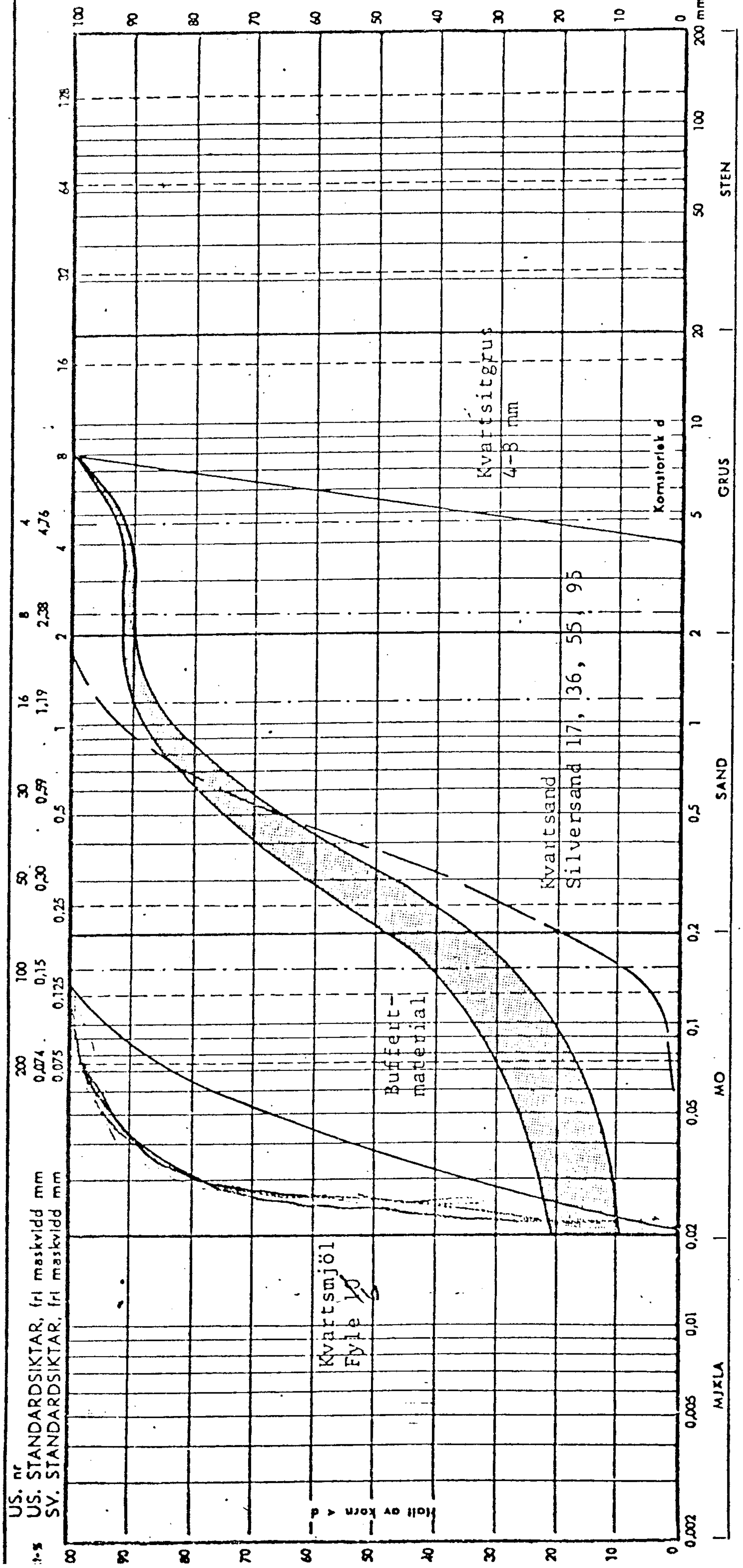
58115-000

Sprutat buffertmaterial

JORDPROVNINGSBLAD 1

KORNFÖRDELNING, PERMEABILITET m.m.

2



Provnr	Provtagningsplats och märkning	Geoteknisk benämning	Permeabilitetsbestämning: Försöksmetod	Torr volymvikt, t/m³	Permeabilitet k, m/s	Tävärde (-10log k)
3174-3180	Sprutat buffertmaterial av					
	10-20 kg bentonit,					
	10 kg kvartsmjöl,					
	80 kg kvartssand,					
	10 kg kvartsitgrus					

Anm.

Stockholm den 13/7 1977 Sign.

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