EXPERIENCES FROM A FIVE-YEAR FIELD STUDY OF GEOSYNTHETIC CLAY LINERS AND DIFFERENT RECULTIVATION MATERIALS

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Abstract: In 2002 an extensive field experiment for the research of different recultivation layers and the performance of needle-punched geosynthetic clay liners (GCL) was designed and built by the University of the Federal Armed Forces in Munich, Germany. Compost, silt and a gravel-sand-mixture were selected as recultivation material and placed over the sealing system consisting of geocomposite drainage products and needle punched GCLs. These alternative recultivation materials are typically excavated soil materials which according to German regulations are mostly treated as waste products. They have no specific function in the waste circle and can therefore be released as low-priced products to disposal sites.

The three different cover materials were analysed by measurements of leachate quantity, soil temperature, suction power and water content. Apart from soil mechanical investigations, the development of vegetation in general on top of the recultivation unit and possible variances in the seal effect of the mineral liner system were also observed at this point.

Another topic of the research was to investigate the drainage run-off over the GCLs as well as permeation rates through the GCL and compare these with existing comparable test plots in similar climate zones. Currently the GCL performance shows hardly any permeation rates and data will be presented in the paper.

Based on over five years of measurement data it is possible to highlight interesting differences between the three presented recultivation materials and to point out advantageous, cost-saving possibilities for economy and environment, including the GCL and drainage composite solution.

Keywords: In-situ test, field monitoring, GCL, leachate, suction, permeability

INTRODUCTION

The main task of recultivation (top soil) layers for sealing surfaces is the placement of an adequate top soil as a natural cover. Together with sealing layers the recultivation material has to minimise precipitation infiltration to reduce leaching of environmentally harmful substances in the base of the landfill. The appealing integration of landfills into the surrounding landscape is also a main focus.

Recultivation layers lead, due to their size and thickness of more than 1 m, to enormous production costs. In choosing cost-saving, locally available and appropriate recultivation materials, cost reductions and basic approaches for effective recycling of waste products can be gained. In any way, affectivity, reliability and the universal insertion based on the German legal landfill requirements of “Technische Anleitung zur Verwertung, Behandlung und sonstigen Entsorgung von Siedlungsabfällen” (TASi 2001) should be always followed. To examine alternatives for conventional recultivation materials, which are usually cost-intensive, a 600 m² sized measuring test plot was designed and constructed on the terrain of the University of the Federal Armed Forces in Munich during summer of 2002 (Figure 1). The size of the measuring field allowed a set-up of four lateral divided fields (Figure 2), each filled with different recultivation materials. This arrangement, put up on a natural slope, assured a direct comparison of behaviour and effectiveness of different materials under equal boundary conditions.

Figure 1. Measuring field in June 2004

MATERIALS AND METHODS

Three different soil materials were used as recultivation layers: compost, silt as a inert waste product of gravel production, and a gravel-sand-mixture in different degrees of compaction. The particle size distribution of gravel (field 2 and 3) and silt (field 4) is presented in figure 2.

The final decision on the material to be used was made on the basis of the transportation distance from extraction to the test plot point, to allow reduced transportation costs. To ensure further cost savings, the materials of field 1, 3, and 4 were placed with mean density. However, the anti-root-layer was compacted.

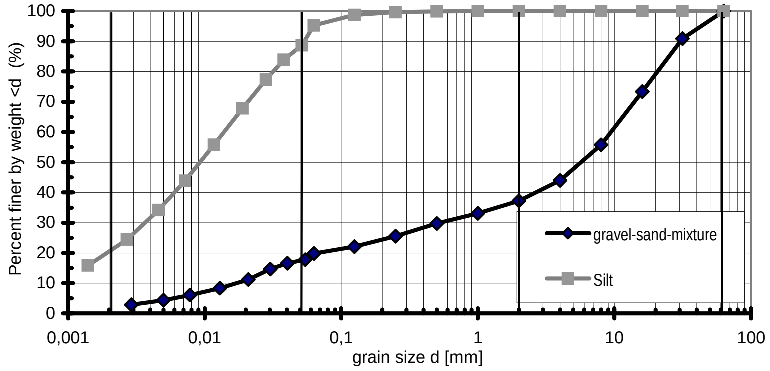

Figure 2. Particle size distribution of two materials used: gravel-sand-mixture and silt

The test plot design is similar for all four measuring plots. Drainage layers were placed under and above the primary and solely GCL sealing layer on the bottom of the plots (figure 3). Two different sodium bentonite GCLs were installed: NSP 4900-1 and NSP-4900-1S (the technical data are identical to the standard type NSP 4900). To control the effectiveness of the system and to determine the permeation through the GCL, a permeation collection system was installed under the GCL (Figure 3). Furthermore a compacted 250 mm thick anti-root-protection layer of a silty gravel-sand-mixture, already used in fields 2 and 3, was placed directly above the GCL and drainage material (Brauns *et al.*, 1996). To gain an optimal anti-root-protection, the gravel was brought in with an average density of 2.2 t/m³.

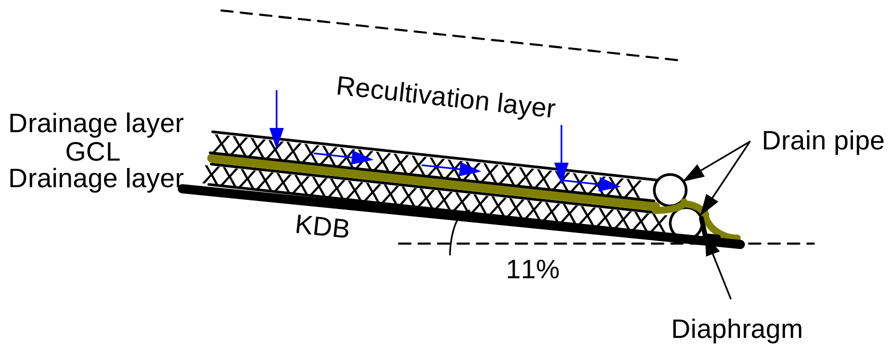

Figure 3. Cross-section of the measuring system to analyse the permeation rate

Above the sealing zone, the recultivation materials were filled into the four fields with a thickness of approximately 1m (Figure 4). Field 1 was filled with compost, field 2 and 3 with a gravel-sand-mixture and field 4 with silt. To investigate the influence of compaction, the gravel-sand-mixture of field 2 was brought in a consolidated manner (density ~ 2.1 t/m³).The recultivation layer was closed by 0.30 m thick topsoil and got replanted with bushes and shrubs.

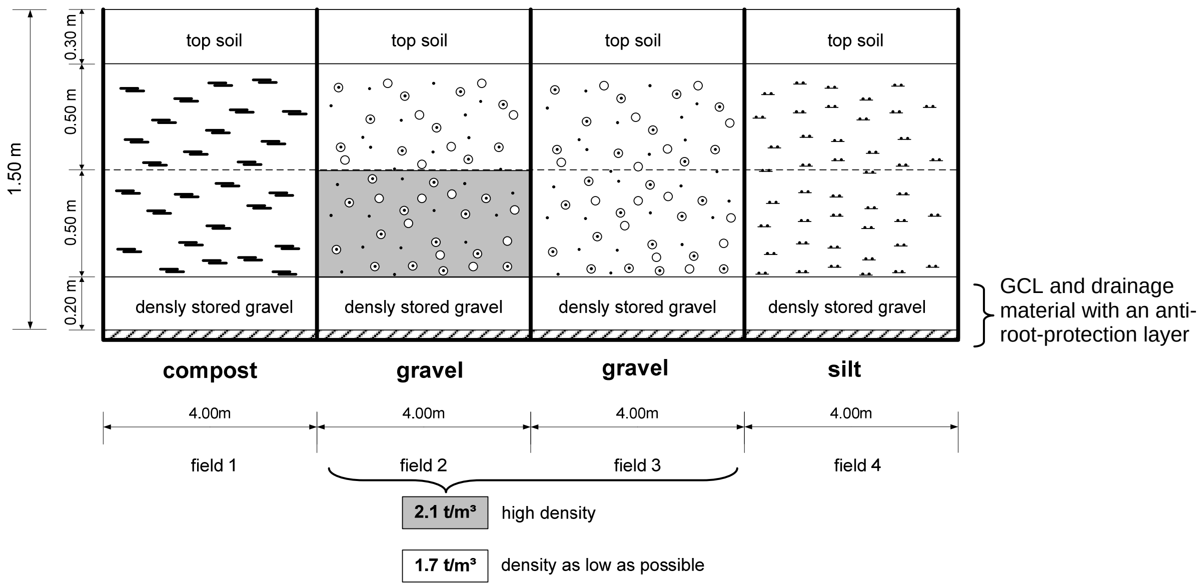

Figure 4. Cross section of the measuring field

To measure water content, suction power and the generation of permeation, measuring instruments were installed in three different depths underneath the top ground surface to assure an enclosing survey in the respective fields. All data gained together with climate data of the location were collected and stored in data loggers on site.

Long term readings mark leading validations of the different materials used. Besides, the investigation of growth and overall development of vegetation on top of the recultivation layer was enabled by the construction of a Plexiglas cylinder along the whole depth of the recultivation layer to examine root depth and to analyze changes in the density of soil. Additionally, annual excavations were carried out to determine root development and to investigate the condition of GCL.

Additionally to the interpretation of soil properties with conventional methods and annual diggings a soil-water-balance-calculation according to BOWAHALD, a software for modelling disposal balances, was accomplished (Reisser 2004). This software enables to check measured data and to provide prognosis.

RESULTS AND DISCUSSION

Continuous measurements of leachate, suction power and water content summarize subsequently soil behaviour of the three materials used for recultivation layers.

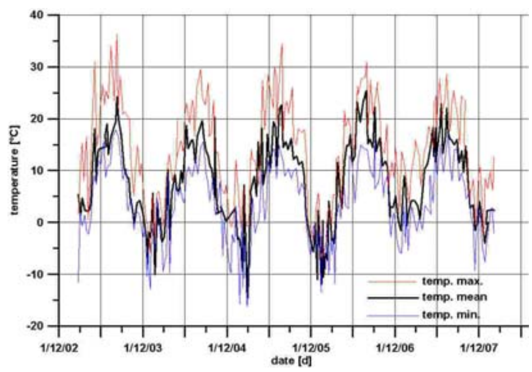

Figure 5. Average temperature sequence of Feb. 2003 to Feb. 2008

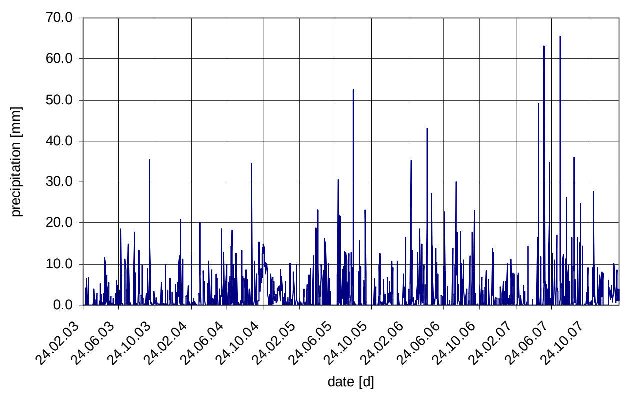

Figure 6. Precipitation sequence of Feb. 2003 to Feb. 2008

Apart from extensive measurements for usability evaluations of the recultivation materials, temperature and precipitation were recorded on site from February 2003 to January 2008. Southern Germany shows a humid climate with an average precipitation rate of about 950 mm/a. Just the exceptional summer of 2003 was dominated by an arid climate with hot and dry conditions. The succeeding summers of 2004 to 2007 were dominated by humid climate with moderate temperatures, just short droughts but therefore increasing rainfall.

Drainage run-off (above GCL) appears in all four measuring fields over the whole observation period, especially during rain-laden months between October and April. During summer most of precipitation evaporates, which leads to a noticeable reduction of drainage run-off, especially during the hottest summer of the century so far in 2003.

In the compost measuring field (Field 1, figure 4) constant but very low amounts of drainage run-off of just around 1% of total precipitation were recorded (Figure 7). The gravel-sand-mixture (field 2 & 3, Figure 4) show a notably higher sum of drainage run-off compared to compost of about one third of total precipitation. Its variation in degrees of compaction in field 2 and 3 lead to slightly higher leachate values for uncompacted material (Figure 8 & 9). In contrast, silt in field 4 shows only marginally higher leachate than compost with about 2.5% of total precipitation (Figure 10).

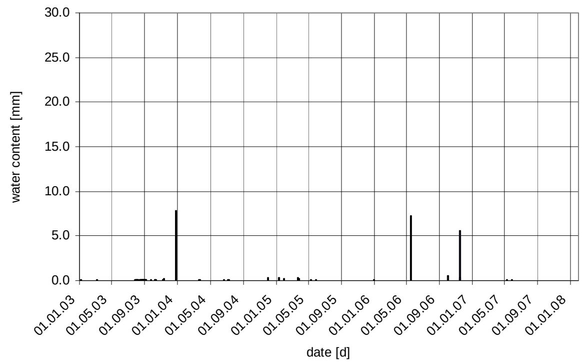

Figure 7. Leachate in field 1

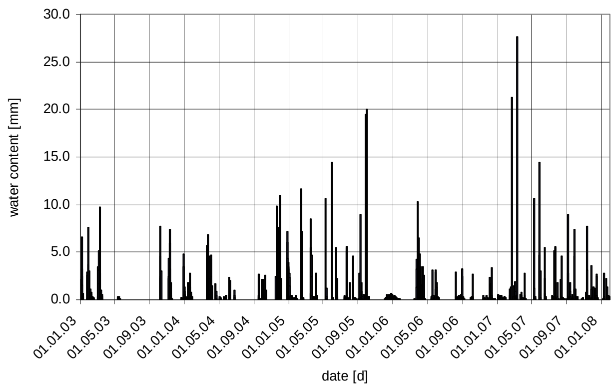

Figure 8. Leachate in field 2

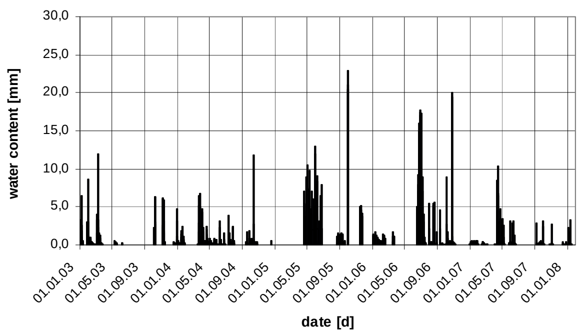

Figure 9. Leachate in field 3

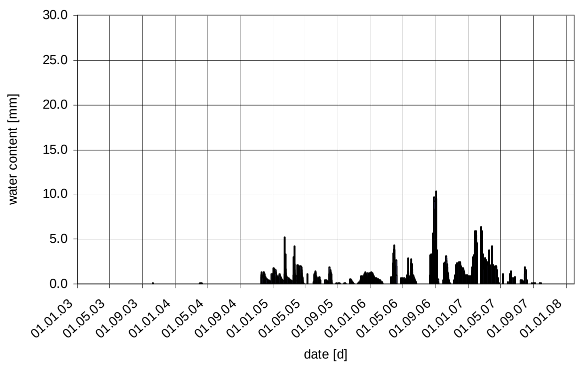

Figure 10. Leachate in field 4

Table 1 gives a good overview of the system effectiveness of the GCLs by comparing drainage run-off to the total precipitation for fields 1 and 2. The values show the sealing capability of the GCL. In general the effectiveness of the GCLs is reduced through dehydration during summer. This behaviour is compensated by evapotranspiration of recultivation material as well as vegetation. After a five-year-observation-period the inserted GCL layers are still in good condition and have an effective sealing behaviour. Permeation through the GCL has always been < 1 % of total precipitation (table 1). Therefore the sealing effectiveness reaches more than 98 % in all test plots.

Table 1. Drainage run-off and permeation in the GCL test plots in 2003 to 2007

Year	2003		2004		2005		2006		2007	
Precipitation [mm]	461		1034.5		855.17		918.5		1118.7	
Test plot No.	1	2	1	2	1	2	1	2	1	2
Drainage run-off [mm]	8.82	142.82	3.88	194.90	0.00	355.00	13.70	131.3	0.2	210.3
underneath GCL	0	0.21	0	0	0	0.70	0.10	1.8	0	2.4
Effectiviness to precipitation [%]	100	99.95	100	100	100	99.9	99.99	99.8	100	99.8
Effectiviness to drainage run-off [%]	100	99.85	100	100	100	99.8	99.3	98.6	100	98.9

Apart from some rises in suction power during summer and short-term dehydration of the tensiometers, all materials in the measuring fields oscillate just slightly between 0 to 100 hPA (pF-value < 2) during the whole observation period. The heavy increases during warm and dry seasons result in the decrease of soil water content through transpiration and evaporation. This behaviour gets underlined by the extraordinary hot and dry summer of 2003. For example, suction power of materials in field 2, 3, and 4 increases up to 800 hPa during warm and dry weather periods, which corresponds to a pF-value of 2.9 (Figure 12, 13 & 14). In field 1 suction power oscillates around 0 hPa during the whole observation period. Even during summer, measured data increases infrequently up to around 100 hPa (Figure 11). The definite increase and decreases of data at the end of the measuring period of field 1 result in a dehydrated tensiometer. Due to the excellent ability of the compost material to store water, its water content is just near saturation. Again the difference between compacted and uncompacted gravel in field 2 and 3 is marginal (figure 12 & 13).

Furthermore, the measurements show a more definite reaction of suction power to precipitation and aridity respectively in the two upper horizons underneath top ground surface than in the lowest (Figures 11–14). The bottom layer reacts only slightly and is delayed to weather changes. For illustration reasons just the top and bottom layers are marked in the four figures below.

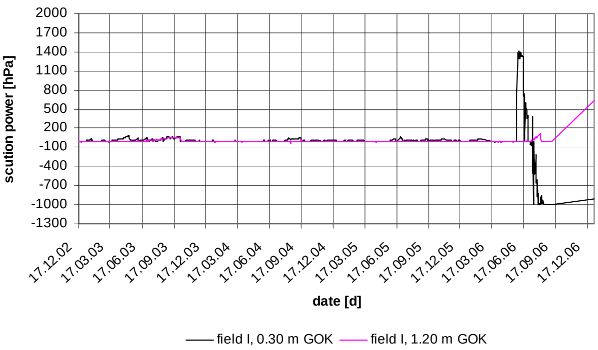

Figure 11. Suction power in field 1

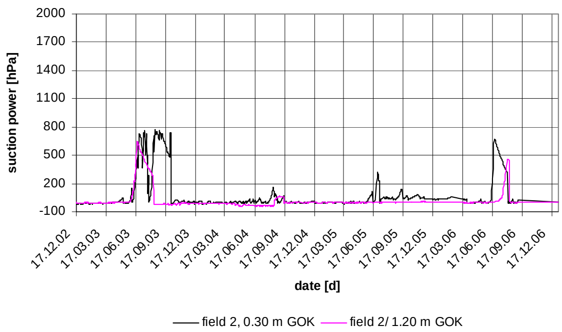

Figure 12. Suction power in field 2

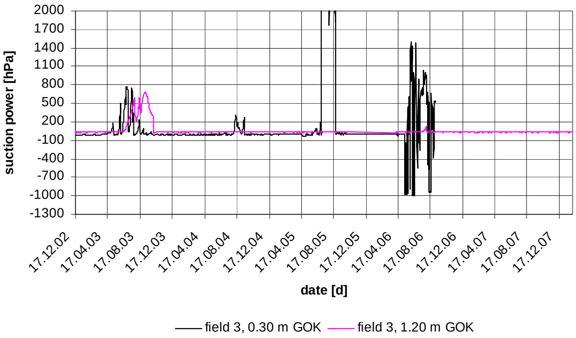

Figure 13. Suction power in field 3

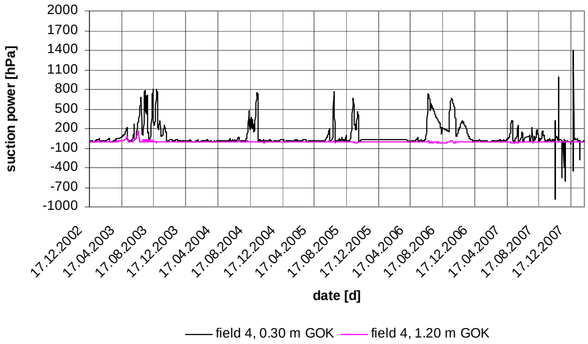

Figure 14. Suction power in field 4

From 2003 till 2005 several excavations were carried out for sampling and controlling material of the applied GCLs in all four testing fields. The samples were cut and removed carefully with rigid PE plates (Figure 15 - 17). This procedure was carried out to minimise structural changes while sampling.

Figure 15. Excavation of GCL (9/2005)

Figure 16. Cutting out sample (9/2005)

Figure 17. Sampling by underlying PE plate (9/2005)

After their removal (Figure 16), the plate samples were taken to the lab to be stored in conditioning cabinets. On the same day of sampling the water content of the respective probes was determined. The data is illustrated in table 2: In comparison the data of 2003 to 2005 shows only marginal differences concerning its water content with variances of 12 % at its maximum.

Table 2. Comparison of water content of applied Bentonite mats in the testing fields during 2003 till 2005 (1): NSP 4900-1, (2): NSP 4900-1S

	compost		**consolidated gravel**		**gravel**		**silt**	
Field I-IV	I.1	I.2	II.1	II.2	III.1	III.2	IV.1	IV.2
Water-content (%) 2003	78,50	92,50	84,78	94,81	91,67	82,86	104,17	86,11
Water-content (%) 2004	84,55	87,60	87,60	84,48	84,97	87,57	107,81	90,94
Water-content (%) 2005	90,61	89,30	81,79	95,17	92,50	87,14	97,30	94,97

In 2004 the water content of the bentonite mats reached for fields 1 to 3 an average amount of 86 % (Tab. 2). Field 4 (top soil silt) showed higher water contents and differences in comparison to test plots 1 and 2 (NSP 4900-1 and NSP 4900-1S). An explanatory statement for these values could refer to a very high calcium content of the applied silt of above 65 %, which could lead to bentonite reactions (ion exchange and therefore slight increase in permeability). However, this statement needs further investigation. Furthermore a relative low transmissibility of silt compared to the values of gravel and compost prevents/reduces water to evaporate in between the GCLs, which explains higher water contents in the GCLs in field 4 compared to field 1 and 3.

Besides taking GCL samples, excavations in 2005 showed maximal root depths of less than 0.6 m (field 1), although compost generally tends to allow deeper root growth due to its high amount of humus (Figure 18). An overall thickness of the recultivation layer of the present test series of 1.30 m and the placement of an anti-root-protection layer proof to achieve an adequate protection effect against deep rooting and damaging spot in the surface sealing. Reuter (2005) confirms these results.

Figure 18. Excavation to confirm root depths and development of vegetation in field 2

In summer 2008 new excavations are planned to receive comparative values concerning water contents and root depths and to underline the results from the previous excavations.

CONCLUSIONS

After a five year investigation period the GCL efficiency test series under in-situ conditions confirmed to be effective and economical and demonstrated the long-term behaviour of cap sealing systems with different types of recultivation (top soil) layers.

Compost materials prove to be the material with the lowest amount of drainage run-off and permeation of approx. 1% of total precipitation. This top soil material has an excellent ability to store release enough water for plants.

The gravel-sand-mixtures of field 2 and 3 are only just suitable as recultivation material due to their low utilizable field capacity and the high amount of water permeating through the layer appearing throughout the entire investigation period. The applied consolidation of soil in field 2 slightly reduces water permeation as well as the suction power, but a general improvement or deterioration through consolidation could not be observed.

Silt is similarly suitable for recultivation as compost. It reduces permeation and holds a high utilizable field capacity, which favours the growth of plants. Again a deep rooting does not occur, which may be linked to high lime content in the soil.

The results of existing research allow the conclusion that compost material as well as silt are promising alternatives to conventional recultivation layers; both being economical and an environmental friendly solution. Both materials show positive soil properties and offer conditions for ideal growth of plants. Due to a lack of internal stability in both materials an admixture with gravel might be recommended.

Concerning the condition of GCLs, differences in the sealing effect due to the application of various recultivation materials did not occur during the entire investigation. The sealing effect of the tested needle-punched GCLs allow the conclusion that they are safe alternatives to conventional clay liners, indicated by measurements of drainage run-off and permeation as well as by data of water content determined after the excavations and testing of the GCLs .

The length of the investigation period of about five years allows the assumption, that ion exchange of the sodium bentonite has been completed by now and that the sealing performance is still effective. In foreseeable time additional excavations will be conducted. Further testing on samples will include about the chemical composition of the bentonite, water content and permeability of the GCLs.

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