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Jan-Gerd Krentler

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Environmental safe storage of animal waste in containers made of concrete and as plastic lined lagoons

Jan-Gerd Krentler[1]

Summary

The value of liquid animal waste as a fertiliser is well known. As the plants consume by far most of the fertiliser in springtime storage containers are needed. These containers must be large enough to contain the amount for six month (e. g. in Germany and Poland), but there are tendencies to demand even longer storage periods (Ackermann et al. 1999).

The methods of disposal and storage of liquid manure are very different world-wide. On the one hand different types and sizes of farms cause this; on the other hand it is also caused by various climatic conditions (Berge and Vernhardson 2000).

There are lots of regulations dealing with the building of slurry, dung and silage juice containers. It is the purpose of these regulations to avoid negative effects on the environment. From the authorities' point of view the problem focuses on the question, whether the containers are "tight" or not. Tests in this matter have not been carried out before (Hackeschmidt 2000).

To clarify this question, tests with slurry, water and concrete blocks of a defined quality (B 25 and B 35, water tight) were carried out at the Technical University of Braunschweig (Krentler 2001).

A first series of tests were run according to DIN 1048, a second one dealt with the long term dynamics of penetration, and the nitrogen content in the soil under a plasic-lined slurry lagoon was measured.

For the first time it could be proved that slurry is a material which can close tiny slits in concrete by its dry matter content. On the whole, the rations between the penetration depths measured with water and with slurry was 2.4 to 1 under regulations conditions. During the long term tests under natural conditions the penetration was much lower. The concrete test blocks (12 cm and 18 cm of thickness) did not allow passage of either water or slurry in any of the studies. Furthermore, tests on the dynamic of penetration were made (Krentler et al. 2001).

When measured under a plastic lined lagoon the nitrogen content in the soil is low and normally distributed. This proves that plastic lined lagoons are also "tight" and meet the legal standards.

Keywords: slurry storage, environmental protection, concrete, plastic lagoon

Zusammenfassung

Umweltsichere Lagerung von Wirtschaftsdünger in Betonbehältern sowie Kunststoff ausgekleideten Erdbecken

Der Wert flüssiger tierischer Exkremente als Dünger ist allgemein bekannt. Da die Pflanzen den bei weitem größten Teil des Düngers nur im Frühjahr verbrauchen, werden Lagerbehälter benötigt. Diese Behälter müssen groß genug sein um für sechs Monate Lagerzeit auszureichen (z. B. in Deutschland und Polen). Es bestehen sogar Bestrebungen, die Mindestlagerzeit zu verlängern (Ackermann et al. 1999)

Die Methoden der Gülleableitung und -lagerung sind weltweit sehr unterschiedlich. Dies wird einerseits durch die verschiedenen Arten und Größen, andererseits auch durch unterschiedliche klimatische Bedingungen verursacht (Berge und Vernhardson 2000).

Es gibt sehr viele Regelungen über den Bau von Güllelagern, Mistbehältern und Sickersaftsschächten. Zweck dieser Regelungen ist es, negative Einflüsse auf die Umwelt zu vermeiden. Aus Behördensicht spitzt sich das Problem auf die Frage zu, ob die Behälter "dicht" sind oder nicht. Bisher wurden keine Versuche hierzu durchgeführt (Hackeschmidt 2000).

Um diese Frage zu klären, wurden Versuche mit Gülle, Wasser und Betonprobekörpern definierter Qualität (B 25 und B 35, WU an der TU Braunschweig) gemacht (Krentler 2001).

Eine erste Versuchsserie wurde nach DIN 1048 durchgeführt, eine zweite Serie befaßte sich mit dem Langzeit-Eindringverhalten, und der Stickstoffgehalt im Boden unter einem Kunststoffausgekleideten Erdbecken wurde gemessen. Erstmalig konnte bewiesen werden, dass Gülle durch ihren Trockensubstanzgehalt eine selbst abdichtende Wirkung hat. Ingesamt verhielten sich die Eindringtiefen von Wasser zu denen von Gülle unter sonst gleichen Bedingungen im Mittel wie 2,4:1 unter DIN-Bedingungen. Während der Langzeitversuche unter natürlichen Bedingungen waren die Eindringtiefen wesentlich niedriger. Bei keinem der Versuche wurden die Betonprobekörper (12 cm und 18 cm stark) von Wasser oder Gülle durchdrungen Weiterhin wurden Langzeittests über das Eindringverhalten gemacht (Krentler et al. 2001).

Die Messung des N-Gehaltes im Boden unter einem ausgebauten kunststoffausgekleideten Erdbecken zur Güllelagerung zeigte niedrige Werte bei gleichmäßiger Verteilung. Damit können auch kunststoffausgekleidete Erdbecken als "dicht" im Sinne des Gesetzes bezeichnet werden.

Schlüsselwörter: Güllelagerung, Umweltschutz, Beton, Kunststoff-Lagerbecken

[1] Institute for Production Engineering and Building Research, Federal Agricultural Research Centre, 38116 Braunschweig/Germany

1 Introduction

Any lifestock farming will cause animal waste. As can be seen by literature, there is a lot of concern world wide on the possibility of environmental pollution by nitrifikation.

- The value of slurry in agriculture is well known.
- Slurry storage containers must be large enough to contain the amount which is needed for six months at the minimum e. g. (Germany and Poland).
- From climatical reasons, Scandinavian countries store slurry for up to one year.
- Slurry should be applied when plant uptake is at its highest (Klikocka 1998).
- Slurry storage is necessary for the protection of the environment.

Of the competitive construction materials, reinforced concrete is used the most. Farmers and engineers have been complaining for years that the procedures for attaining building permits take too long, that they are difficult and involve too many authorities and constructional requirements.

From the authorities' point of view the problem focuses on the question of whether the slurry containers are "tight" or not, as this is the main demand of the German Water Household Law (WHG, see list), which serves as an example for similar regulations for environmental protection in other countries.

A similar law has been passed in Poland. Art. 18 of the law "O nawozach i nawozeniu" (Dz. U. Nr 89, poz. 991 from 26.07.2000) says that:

- agricultural buildings must stand on a ground plate,
- they must be "tight" against the soil,
- for slurry channels and slurry containers as well as for dung silos the same demands are in force (Hus et al. 1994).

To clarify the question whether concrete for agricultural buildings is "tight", tests with slurry, water and concrete blocks of a defined quality (B 25 WU and B 35 WU) were carried out at the Technical University of Braunschweig.

The literature review proved that world wide there is a lot of concern on the storage of animal waste and environmental protection, but there have not been tests in this field before.

2 Material and methods

2.1 Experiments on the "tightness" of concrete slurry containers

Cattle slurry from the FAL in Braunschweig (Germany) test station was used. Clear water in drinking water quality was used as a reference fluid under the same test conditions. The tests were run with a test machine according to DIN 1048. The concrete test blocks in the above mentioned qualities were set under pressure. The hardening process of the concrete blocks lasted for a minimum of 28 days, after which the test could start. This is also demanded by DIN 1048, which deals with the construction with concrete.

The test machine provided a pressure of 0.5 N mm^{-2} for a period of 72 hours, which equals 10 times the pressure which will occur naturally in a slurry container of 5.0 m of height. This shows the effect of a long term test. According to DIN 1048 Part 5 the average of the maximum penetration into three test blocks must be calculated.

The test blocks were ordered from two different concrete manufacturers in the Braunschweig area to make They were test blocks of two different concrete qualities with the receipt numbers 41430F in quality B25 and 61433 in quality B35. Both qualities were delivered from both of the manufacturers. The concrete blocks measured 20*20*12 cm.

2.2 On the dynamics of penetration

Different from the method described before, the dynamic process of penetration of slurry and liquid manure, and water as a reference fluid, was investigated also. In these tests the differences of penetration of the above mentioned effluents a very close relation to the natural conditions was of special interest. This is why a test pressure of 5.0 m of high was used, which equals the maximum height in very large slurry containers with capacities of 1,000 m^3 to 1,250 m^3. This pressure was kept up for periods of 14, 28 and 35 days. The concrete test blocks were made of quality B 25 WU B1, which is the lowest quality allowed for farm building, except fundamentations.

Cylindrical concrete test blocks with 100 mm diameter and 180 mm of height were made, which served as a part of an imaginative big concrete ground plate with the demanded minimum thickness of 18 cm. As during the tests the whole surface of the test block will be covered by different effluents, there will not be any transportation in horizontal direction, but in vertical direction only. To keep up these conditions, the side walls of the test block containers were cladded with PE-sheets (plastic linings).

Pressure: h = 5.0 m = 0.5 bar = 0.05 N mm^{-2}

The tests with slurry were carried out with a funnel, which was glued on top of the test blocks. On the funnel a plastic tube of 5.0 m of height, 40 mm in diameter, was erected.

As the test effluents liquid manure and water do not tend to stop up the test machine, the equivalent tests could be run with the machine, which of course is much easier. But for these tests it was necessary to put the tightened cylinder of 100 mm diameter into a form made of cement mortar of 150 mm of diameter, as an abutment for the rubber ring is needed.

Fig. 1:
Test machine for penetration tests in the TU Braunschweig

After periods of 14, 28 and 35 days in three replications the concrete test blocks were cut and the penetration was measured.

The concrete for the tests described before was produced as a B25, condition BI (recipe) according to DIN 1045, this is the lowest quality allowed for storage reservoirs. The demand of a minimum cement content of 350 kg m^{-3} with a maximum gravel diameter of 32 mm leads to a high water content, which may cause porosity in the concrete after hardening. This will not reduce the solidity of the concrete, but may lead to higher penetration. By this measure, the so-called “worst case possible”, which is demanded in engineering every where, was considered.

The following data characterize the quality of the concrete used for the tests:

Cement: CEM I 32, 5R, 350 kg m^{-3}
Gravel: Sive line A/B 32, 1,796 kg m^{-3}, dry
Water: W = 194 kg m^{-3}, W/Z = 0.56
Diameter of spread wet concrete: 43 cm
Specific weight of fresh concrete: 2.37 kg dm^{-3}
Solidity of concrete samples after 28 days: 42 N mm^{-2}
The investigations were made according to Darcy.

2.3 Measurement of nitrogen content in the soil under a plastic-lined slurry lagoon, replaced by concrete slurry container

In 1984 two plastic lined slurry reservoirs with a capacity of 750 m^3 each were built in the test station of the FAL, one of them being welded on the construction site, the second one was welded in a fabrication hall and then transportated to the construction site. The original plan was to use the slurry containers for a period of 15 years. At the time, there was no knowledge of the durability of plastic lined slurry containers. After they have been used for a period of 17 years both containers were taken out of ground in Nov./Dec. 2001 to be replaced by a concrete

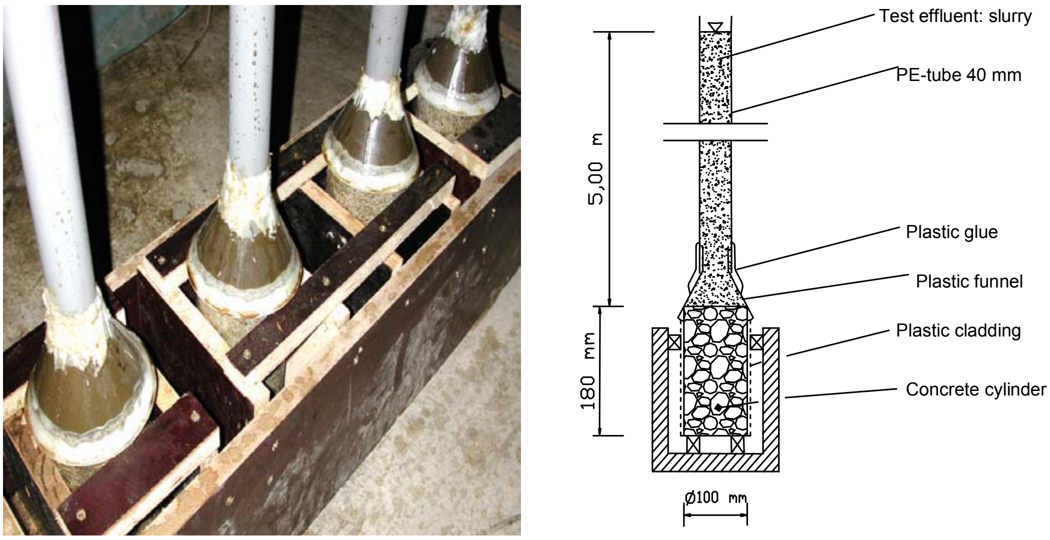

Fig. 2:
Test machine and scheme for long term penetration tests in the TU Braunschweig

Table 1:
Matrix of tests “technical safety of concrete slurry containers”

Concrete Manufac-turer	Sample No.	Kind of concrete/ classification	Penetration depth			
			with water		with slurry	
			values x mm	average $\bar{x}$	values x mm	average $\bar{x}$
L	1-3	41430.F	33; 19; 15	22	-	-
	4-6	B25	-	-	0; 18; 16	11
	7-9	61433.F	17; 20; 22	20	-	-
	10-12	B35	-	-	10; 5; 10	8
	13-15	41430.F	17; 27; 16	20	-	-
W	16-18	B25			11; 15; 7	11
	19-21	61433.F	15; 18; 13	15	-	-
	22-24	B35	-	-	12; 11; 20	14

slurry container. This gave the chance for measurements in the soil to see whether there was a contamination from ammonium.

After the whole containers including the control system were taken out of the ground, three control drillings were made in the left upper edge of the former western container. (Fig. 3). The plan was to bring the control drills down to a depth of 1.0 m each, but the compressed ground layer of gravel proved to be too hard. This was why the maximum depth of the control drillings was reduced to 0.80 m each. Samples of the soil were taken every 20 cm using a probe drill.

These parameters were measured: depth in cm, dry matter content in %, NO_3-N in kg ha^{-1}, NH_4-N in kg ha^{-1}, S N_{min} in kg ha^{-1} and the total amount of N in 80 cm depth. The analyses were carried out in the laboratory of the Institute of Crop and Grassland Science of the Agricultural Centre in Braunschweig, Germany, in December 2001.

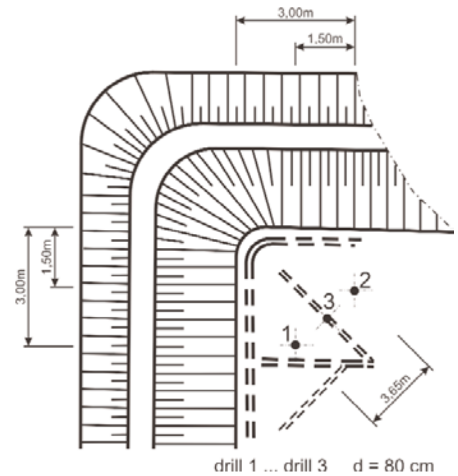

Fig. 3:
Position of the control drills

3 Results

3.1 Experiments with periods of 72 hours and 0.5 N mm^{-2} pressure

A general overview of the results of the experiments dealing with the “tightness” of concrete under pressure with slurry and water is given in Table 1. The minimum penetration depth was measured with slurry at a pressure of 0.5 N mm^{-2} after a period of 72 hours, in concrete of quality B25. The results ranged from 0 (zero) to 18 mm. According to the demand of DIN 1045 (“Building with concrete”) the average of three samples was calculated. The penetration with the same material of a better quality (B 35) showed an average of 8 mm, which is 3 mm less. These results refer to the test blocks made by factory L. The penetration depth after the pressure with water under the same conditions was higher, but also different as far as the concrete quality was.

The range of penetration depths in B 25 was from 15 to 33 mm, which results in an average of 22 mm, concerning factory L. The results of the test blocks from factory W were rather similar: the average was 20 mm, which is just 2 mm less; at a range of 16 to 27 mm. The comparison of the two concrete qualities showed very similar penetration depths. To make comparisons easier, on each page the results of the test with water will be shown at the top of the page and the test with slurry at the bottom of the page (Fig. 4).

3.2 Experiments with 14, 28 and 35 days periods and 0.05 N mm^{-2} pressure

As shown in Table 2, the long term penetration of water was the deepest e_t with 4.5 mm on an average after 14 days, the average after 28 days was 5.0 mm and after 35 days it was 6.0 mm. The penetration of liquid manure was

Table 2:
Maximum penetration depth et_{max} of water, liquid manure and slurry into concrete B25 WU (pressure 0.05 N mm^{-2}) after different periods

Specifications	Maximum penetration depth in mm					
	14 days		28 days		35 days	
	values	average	values	average	values	average
	x	$\bar{x}$	x	$\bar{x}$	x	$\bar{x}$
with water	3; 5; 5	4.5	4; 5; 6	5.0	4; 6; 8	6.0
with liquid manure	4; 4; 4	4.0	4; 4; 5	4.3	4; 5; 6	5.0
with slurry	3; 3; 4	3.3	3; 3; 4	3.3	3; 4; 4	3.7

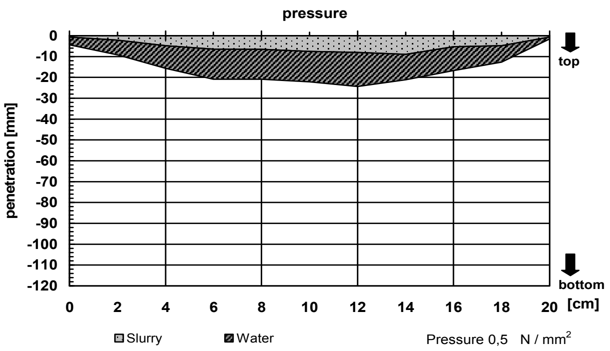

Fig. 4:
Test on the penetration slurry and water into concrete

less, with an average of 4.0 mm after 14 days, 4.3 mm after 28 days and 5.0 mm after 35 days, although the consistency of the liquid manure after the centrifugation was rather similar to that of water. The lowest penetration was measured with slurry; it was 3.3 mm on an average after 14 days, still 3.3 mm after 28 days and 3.7 mm after 35 days.

All these results are much lower than those shown by the tests according to the regulation DIN 1048 for water, and they are very much lower than the 50 mm allotted there.

Another result of the long term observation is that by far most of the penetration is reached after 14 days only, the improvement during the next weeks is visible with clear water, but it is little with agricultural effluents. Also can be seen, that penetration is lower, the higher the dry matter content of the effluent is. Fig. 5 shows the long term penetration of water, liquid manure and slurry on an average after 35 days.

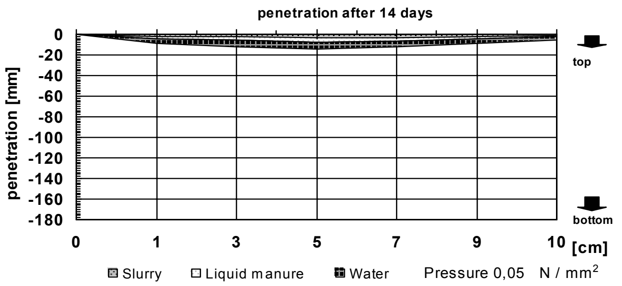

Fig. 5:
Test on the penetration of slurry, liquid manure and water into concrete after 35 days

Table 3:
N_{min} (kg ha^{-1}) in a dry soil layer beyond a plastic lined slurry lagoon

Sample	depth cm	dry matter %	NO_3-N kg ha^{-1}	NH_4-N kg ha^{-1}	Σ N_{min} kg ha^{-1}	Σ 0-80 kg ha^{-1}
1.1	60-80	95.6	7.9	5.4	13.3	69.5
1.2	40-60	94.0	10.0	7.5	17.5	
1.3	20-40	93.5	12.0	8.9	20.9	
1.4	0-20	93.1	7.5	10.3	17.8	
2.1	60-80	96.5	10.2	6.6	16.8	107.0
2.2	40-60	94.9	17.7	4.4	22.1	
2.3	20-40	95.6	25.9	3.6	29.5	
2.4	0-20	95.9	34.7	3.9	38.6	
3.1	60-80	93.1	26.6	5.8	32.4	84.1
3.2	40-60	96.3	18.6	2.8	21.4	
3.3	20-40	96.2	10.2	2.1	12.3	
3.4	0-20	94.1	12.9	5.1	18.0	

3.3 Measurement of nitrogen content in the soil under a plastic-lined lagoon

The results of the 12 soil samples, which were taken under the plastic lined slurry lagoon after removal, are shown in Table 3. The control drillings no. 1 and no. 2 were made in the free space between the outer control tube and the central control tube system (herringbone shape). Drilling no. 3 was made precisely under one of the control tubes. The chemical analysis was carried out at the Institute of Crop and Grassland Science.

The total amount of nitrogen in drilling 1 and 2 was 69.5 kg ha^{-1} and 107.0 kg ha^{-1}, the centre drilling no. 3 was 84.1 kg ha^{-1}. The dry matter content in all samples from 0 (zero) to 80 cm of depth ranged from 93.1 to 96.6 %, indicating that growing depth shows higher dry matter content. The NO_3-content ranged from 7.5 kg ha^{-1} to 34.7 kg ha^{-1}, which is a rather wide span, the NH_4-content was between 2.1 and 10.3 kg ha^{-1}. These contents sum up to between 13.3 kg ha^{-1} N_{min} and 38.6 kg ha^{-1} $N_{min.}$

4 Discussion

A theoretical consideration on the penetration of water “into bodies with capillary tubes” was made according to ***Darcy*** (by Beddoe and Springenschmidt, 1999). He postulated that water will finally go through totally after a certain time, which is influenced by pressure and quality of material.

According to ***Darcy*** the penetration of clear water can be predicted by the equation:

$$e_t = \sqrt{\frac{2kh_D t}{P}}$$

with:
- e_t = penetration in mm,
- k = constant related to quality of material
- h_D = hight of water column
- t = time
- P = porosity

This equation was used for the test relations as described before, provided that the value after 35 days would be according to the test result, at pressure of 5.0 bar after 3 days, theoretically. Of course, in this case the effluents slurry and liquid manure must be handled like water.

The values taken for the following comparisons were taken from the test results, considering 3 options:

- the penetration may act according a $\sqrt{t \cdot h_D}$ -relation,
- the penetration may act according a $\sqrt{t}$ -relation,
- the penetration may act according to a $\sqrt{h_D}$ -relation, with time being without influence. This leads to the results in Table 4.

As can be seen, even in the worst theoretical case the demand of the safety regulation is absolutely fulfilled with water; conditions with liquid manure and slurry are even better.

Furthermore, it is obvious that the “self-tightening quality” of effluents in concrete containers will be improved by higher amounts of solids.

For the practical building of slurry containers made of concrete this means, that even the lowest quality allowed by the regulations, the maximum height being used with building parts of a minimum thickness of 180 mm (e. g. Germany and Poland) is safe in the sense of law.

5 Conclusions and recommendations

- The concrete test blocks did not allow passage of either water or slurry in any of the studies.
- Thus the requirements of the Water Household Law or similar state laws on slurry containers made of concrete to be impermeable are met.
- The tests showed that slurry penetrates less deeply into concrete than water under similar conditions.
- If water impermeable concrete (WU Concrete) is used for the manufacturing of slurry containers from an accepted technological perspective, impenetrable slurry containers can be manufactured.
- Constructive secondary conditions for the manufacturing of water impermeable constructions according to DIN 1045 must be considered.
- During the hardening process, concrete for slurry containers must be kept absolutely wet to prevent slits.
- The quality of the manufacture of slurry containers should be monitored and documented during the construction process.

Table 4:
Theoretical penetration depths in comparison to the measured penetration depths accordding to Darcy

Test effluent	Measured at 0.5 bar after 35 days	Theoretical penetration after 3 days and 5 bar $\sqrt{t \cdot h_D}$	$\sqrt{t}$ no h_D influence	$\sqrt{h_D}$ no time influence	Penetration allotted according to the regulation DIN 1048 (t = 3 days, h_D = 5 bar)
Water	8 mm	7.4 mm	2.34 mm	25.3 mm	50 mm
Liquid manure	6 mm	5.6 mm	1.75 mm	19.0 mm	50 mm
Slurry	4 mm	3.7 mm	1.17 mm	12.7 mm	50 mm

- More regulations or demands for environmentally safe slurry storage do not promise to improve the environmental safety of the containers, but would result in higher building costs.
- The classification of slurry as a "dangerous substance" cannot be supported from the perspective of storage.
- Finally, it would be desirable in the future that concrete manufacturers guarantee the impermeability of these containers. This would certainly be a weighty argument, which could speed up government approval processes.
- Measurement of the nitrogen content in the soil under a former plastic lined slurry lagoon showed low contents of nitrogen. This means that soil, which has not been used as arable land is not "clean", but there is no overload of nitrogen from a leakage of the plastic lined slurry lagoon.

Acknowledgements

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