Precision measurement necessary: wall thicknesses differ

Slight disappointment on wall thickness

CIPP-liner samples from six countries tested. Test results still at high level. Only wall thicknesses are more frequently below target. Most non-German companies also score well.

by Roland W. Waniek, Dieter Homann and Barbara Grunewald

The IKT - Institute for Underground Infrastructure hereby presents its twelfth annual LinerReport. The report is based on just on 2,150 CIPP-liner samples taken for quality-control purposes on project sites and tested by the IKT CIPP Liner Test Centre in 2015.

The 2015 data-base

The 2015 IKT LinerReport comprises the results of those contractors from which the IKT has tested not less than twenty-five liner samples of one liner type obtained from five different sites. This requirement is met this year by twenty-four companies, six more than in the previous year. Five of these companies are represented by more than one liner type. Thirteen of them are active in Germany, five in the Netherlands and two in each of Austria and Switzerland. For the first time, one company from the United Kingdom and one from the Czech Republic are included in the test programme.

In 70% of all cases, the project clients (or their engineering consultancies) commissioned the IKT directly to perform laboratory testing of liner samples. Only 30% of the orders originated from the contractors themselves (see Table 1).

Target/Actual analysis

Four characteristics are analysed for each of the samples taken on site: modulus of elasticity, flexural strength, wall thickness and water-tightness. The Actual data is compared against the Target data from the DIBt (German Institute for Building Technology) approvals and against any divergent Target specifications by the client. The Target values for wall thickness are either defined on

Table 1: Contractors and liner systems, 2015

Contractors	Liner systems	Liner-type	Number of samples	IKT testing commissioned by	
				Contractor %	Client %
Aarsleff Rohrsanierung GmbH	iMPREG liner	GRP	178	0	100
Aarsleff Rohrsanierung GmbH	PAA SF-liner	NF	114	0	100
Arkil Inpipe GmbH	Berolina liner	GRP	155	0	100
Arkil Inpipe GmbH	SAERTEX liner	GRP	65	0	100
Arpe AG **(CH)**	Alphaliner	GRP	26	4	96
Erles Umweltservice GmbH	iMPREG liner	GRP	46	15	85
Geiger Kanaltechnik GmbH & Co.KG	Alphaliner	GRP	84	29	71
Geiger Kanaltechnik GmbH & Co.KG	Berolina liner	GRP	36	56	44
GMB Rioleringstechnieken B.V. **(NL)**	iMPREG liner	GRP	37	35	65
Hamers Leidingtechniek B.V. **(NL)**	Alphaliner	GRP	104	0	100
HF-Rohrtechnik GmbH **(A)**	Berolina liner	GRP	48	0	100
Insituform Rioolrenovatietechnieken B.V. **(NL)**	Insituform CIPP liner (NL)* Netherlands	NF	106	5	95
ISS Kanal Services AG **(CH)**	Alphaliner	GRP	41	83	17
Jeschke Umwelttechnik GmbH	Alphaliner	GRP	45	78	22
Jeschke Umwelttechnik GmbH	Brandenburger liner	GRP	114	42	58
Kanaltechnik Agricola GmbH	iMPREG liner	GRP	39	90	10
KATEC Kanaltechnik Müller und Wahl GmbH	Alphaliner	GRP	43	0	100
KTF GmbH	iMPREG liner	GRP	100	91	9
Pfaffinger Rohrnetz- & Sanierungstechnik GmbH	iMPREG liner	GRP	37	0	100
Sanierungstechnik Dommel GmbH	Alphaliner	GRP	43	79	21
SKS-Servicecenter für Kanalsanierung GmbH	Alphaliner	GRP	29	55	45
Swietelsky-Faber Kanalsanierung GmbH **(A)**	Brandenburger liner	GRP	25	0	100
Swietelsky-Faber Nederland Relining B.V. **(NL)**	Berolina liner	GRP	54	100	0
TKT GmbH &Co.KG	Alphaliner	GRP	249	18	82
Trasko a.s. **(CZ)**	Alphaliner	GRP	45	100	0
Umwelttechnik und Wasserbau GmbH	Alphaliner	GRP	161	38	62
Umwelttechnik und Wasserbau GmbH	Brandenburger liner	GRP	56	55	45
UKDN Waterflow Ltd. **(GB)**	iMPREG liner	GRP	27	100	0
Van der Velden Rioleringsbeheer B.V. **(NL)**	iMPREG liner	GRP	41	20	80
Total			2148	**30**	**70**

GRP: Glass-fibre backing material
NF: Needle-felt backing material

* The Insituform CIPP liner (NL) has held the Dutch KOMO Foundation product certificate since 15 September 2014

Overview of test and inspection criteria

Modulus of elasticity (short-term flexural modulus)
- CIPP-liners must withstand loads such as those caused by groundwater, road traffic and soil pressure
- The modulus of elasticity is an indicator of load-bearing capability
- Stability may be endangered if modulus of elasticity is too low
- Test method: Three-point bending test in acc. with DIN EN ISO 178 and DIN EN ISO 11296, Part 4/DIN EN 13566, Part 4*

> Results: see Table 2

Wall thickness (average combined thickness)
- Minimum values are specified in the structural-analysis calculation
- Wall thickness and modulus of elasticity jointly determine the stiffness of the liner
- Excessively low wall thickness can endanger stability
- Test method: Average combined thickness is measured in acc. with DIN EN ISO 11296, Part 4** using a precision slide gauge

> Results: see Table 4

Flexural strength (flexural stress at rupture = short-term -σ_{fb})
- This denotes the point at which the liner fails as a result of excessively high stress
- The liner may rupture before the permissible deformation is reached if flexural strength is too low
- Test method: Increase of load up to failure in the three-point bending test in acc. with DIN EN ISO 178 and DIN EN ISO 11296, Part 4/DIN EN 13 566, Part 4* (short-term flexural strength)

> Results: see Table 3

Water tightness
- The inner film is cut if it is not an integral component of the liner; any outer film is removed
- Water containing a red dye is applied internally
- A 0.5 bar partial pressure is applied externally
- The liner is "Not tight" if water penetrates through
- Test period: 30 min.

> Results: see Table 5

A detailed description of these tests can be found on the IKT Homepage: **www.ikt-online.org/cipp-liner/**

* DIN EN ISO 11296, Part 4 superseded DIN EN 13566, Part 4 with effect from July 2011. The test results are nonetheless evaluated in acc. with DIN EN 13566, Part 4 for a number of liner systems, since the Target data for the mechanical properties (national technical approvals) were determined in accordance with this standard.

** Determination of combined thickness remains unchanged in DIN EN ISO 11296, Part 4 vis-à-vis DIN EN 13566, Part 4.

Three-point bending test on CIPP liners

Table 2: Test results for modulus of elasticity, 2015 (short-term flexural modulus)

Contractors	Liner systems	2015		2014	Trend
		No. of samples	Target* achieved in % of tests	Target* achieved in % of tests	
Aarsleff Rohrsanierung GmbH	iMPREG liner	178	100	100	↔
Arkil Inpipe GmbH	Berolina liner	155		100	↔
Arpe AG **(CH)**	Alphaliner	26		-	-
Erles Umweltservice GmbH	iMPREG liner	46		100	↔
Geiger Kanaltechnik GmbH & Co. KG	Berolina liner	36		100	↔
GMB Rioleringstechnieken B.V. **(NL)**	iMPREG liner	36		-	-
Hamers Leidingtechniek B.V.**(NL)**	Alphaliner	104		100	↔
HF-Rohrtechnik GmbH **(A)**	Berolina liner	48		-	-
ISS Kanal Services AG **(CH)**	Alphaliner	41		100	↔
Jeschke Umwelttechnik GmbH	Alphaliner	45		100	↔
Jeschke Umwelttechnik GmbH	Brandenburger liner	114		100	↔
Kanaltechnik Agricola GmbH	iMPREG liner	39		100	↔
KATEC Kanaltechnik Müller und Wahl GmbH	Alphaliner	43		-	-
KTF GmbH	iMPREG liner	100		100	↔
Pfaffinger Rohrnetz- & Sanierungstechnik GmbH	iMPREG liner	37		-	-
Swietelsky-Faber Kanalsanierung GmbH **(A)**	Brandenburger liner	24		-	-
Swietelsky-Faber Nederland Relining B.V. **(NL)**	Berolina liner	54		-	-
Trasko a.s. **(CZ)**	Alphaliner	45		-	-
Umwelttechnik und Wasserbau GmbH	Alphaliner	161		97,8	↑
UKDN Waterflow Ltd. **(GB)**	iMPREG liner	27		-	-
TKT GmbH & Co. KG	Alphaliner	249	99,6	99,3	↑
Aarsleff Rohrsanierung GmbH	PAA SF liner	114	99,1	96,9	↑
Average			**99,1**	**98,7**	↑
Van der Velden Rioleringsbeheer B.V. **(NL)**	iMPREG liner	41	97,6	93,5	↑
SKS-Servicecenter für Kanalsanierung GmbH	Alphaliner	29	96,6	-	-
Geiger Kanaltechnik GmbH & Co. KG	Alphaliner	84	96,4	-	-
Umwelttechnik und Wasserbau GmbH	Brandenburger liner	55	96,4	-	-
Arkil Inpipe GmbH	SAERTEX liner	64	95,3	-	-
Insituform Rioolrenovatietechnieken B.V. **(NL)**	Insituform CIPP liner	106	95,3	95,7	↓
Sanierungstechnik Dommel GmbH	Alphaliner	43	95,3	-	-

* Target values as per client's data (structural-analysis/sample data record)
– Not evaluated, too few liner samples

Table 3: Test results for flexural strength, 2015
(short-term -σ_{fb})

Contractors	Liner systems	2015		2014	Trend
		No. of samples	Target* achieved in % of tests	Target* achieved in % of tests	
Aarsleff Rohrsanierung GmbH	iMPREG liner	178	100	100	↔
Arkil Inpipe GmbH	Berolina liner	155		100	↔
Arpe AG **(CH)**	Alphaliner	26		-	-
Erles Umweltservice GmbH	iMPREG liner	46		100	↔
Geiger Kanaltechnik GmbH & Co.KG	Alphaliner	84		-	-
Geiger Kanaltechnik GmbH & Co.KG	Berolina liner	36		100	↔
Hamers Leidingtechniek B.V.**(NL)**	Alphaliner	104		100	↔
HF-Rohrtechnik GmbH **(A)**	Berolina liner	48		-	-
ISS Kanal Services AG **(CH)**	Alphaliner	41		100	↔
Jeschke Umwelttechnik GmbH	Alphaliner	45		100	↔
Jeschke Umwelttechnik GmbH	Brandenburger liner	114		100	↔
Kanaltechnik Agricola GmbH	iMPREG liner	39		100	↔
KATEC Kanaltechnik Müller und Wahl GmbH	Alphaliner	43		-	-
KTF GmbH	iMPREG liner	100		100	↔
Pfaffinger Rohrnetz- & Sanierungstechnik GmbH	iMPREG liner	37		-	-
SKS-Servicecenter für Kanalsanierung GmbH	Alphaliner	29		-	-
Swietelsky-Faber Kanalsanierung GmbH **(A)**	Brandenburger liner	24		-	-
Swietelsky-Faber Nederland Relining B.V. **(NL)**	Berolina liner	54		-	-
TKT GmbH & Co. KG	Alphaliner	249		100	↔
Trasko a.s. **(CZ)**	Alphaliner	45		-	-
Average			**99,3**	**98,7**	↑
Umwelttechnik und Wasserbau GmbH	Alphaliner	161	98,8	97,8	↑
Arkil Inpipe GmbH	SAERTEX liner	64	98,4	-	-
Umwelttechnik und Wasserbau GmbH	Brandenburger liner	55	98,2	-	-
Sanierungstechnik Dommel GmbH	Alphaliner	43	97,7	-	-
Aarsleff Rohrsanierung GmbH	PAA SF-liner	114	97,4	99,2	↓
GMB Rioleringstechnieken B.V. **(NL)**	iMPREG liner	36	97,2	-	-
Insituform Rioolrenovatietechnieken B.V. **(NL)**	Insituform CIPP liner	106	97,2	92,8	↑
UKDN Waterflow Ltd. **(GB)**	iMPREG liner	27	96,3	-	-
Van der Velden Rioleringsbeheer B.V. **(NL)**	iMPREG liner	41	95,1	93,5	↑

* Target values in acc. with client's data (structural-analysis/sample data record)
– Not evaluated, too few liner samples

Table 4: Test results for wall thickness, 2015
(average combined thickness in acc. with DIN EN ISO 11296, Part 4)

Contractors	Liner systems	2015		2014	Trend
		No. of samples	Target* achieved in % of tests	Target* achieved in % of tests	
Arkil Inpipe GmbH	Berolina liner	56		97,6	↑
Arkil Inpipe GmbH	SAERTEX liner	56		-	-
Arpe AG **(CH)**	Alphaliner	11		-	-
Erles Umweltservice GmbH	iMPREG liner	35		100	↔
Geiger Kanaltechnik GmbH & Co.KG	Berolina liner	16		91,7	↑
Hamers Leidingtechniek B.V.**(NL)**	Alphaliner	104		100	↔
Jeschke Umwelttechnik GmbH	Alphaliner	45	100	98,7	↑
Jeschke Umwelttechnik GmbH	Brandenburger liner	114		100	↔
Kanaltechnik Agricola GmbH	iMPREG liner	39		100	↔
KATEC Kanaltechnik Müller und Wahl GmbH	Alphaliner	13		-	-
Pfaffinger Rohrnetz- & Sanierungstechnik GmbH	iMPREG liner	36		-	-
Sanierungstechnik Dommel GmbH	Alphaliner	42		-	-
Swietelsky-Faber Nederland Relining B.V. **(NL)**	Berolina liner	54		-	-
KTF GmbH	iMPREG liner	100	99,0	100	↓
ISS Kanal Services AG **(CH)**	Alphaliner	40	97,5	96,3	↑
Umwelttechnik und Wasserbau GmbH	Alphaliner	65	96,9	97,9	↓
Average			**95,4**	**96,8**	↓
Geiger Kanaltechnik GmbH & Co.KG	Alphaliner	64	95,3	-	-
Van der Velden Rioleringsbeheer B.V. **(NL)**	iMPREG liner	41	95,1	89,3	↑
Aarsleff Rohrsanierung GmbH	PAA SF-liner	64	93,8	100	↓
GMB Rioleringstechnieken B.V. **(NL)**	iMPREG liner	27	92,6	-	-
TKT GmbH & Co. KG	Alphaliner	31	90,3	91,8	↓
Trasko a.s. **(CZ)**	Alphaliner	45	88,9	-	-
Insituform Rioolrenovatietechnieken B.V. **(NL)**	Insituform CIPP liner	102	87,3	92,9	↓
Aarsleff Rohrsanierung GmbH	iMPREG liner	96	75,0	94,1	↓
HF-Rohrtechnik GmbH **(A)**	Berolina liner	0	**	-	-
SKS-Servicecenter für Kanalsanierung GmbH	Alphaliner	5	**	-	-
Swietelsky-Faber Kanalsanierung GmbH **(A)**	Brandenburger liner	0	**	-	-
UKDN Waterflow Ltd. **(GB)**	iMPREG liner	0	**	-	-
Umwelttechnik und Wasserbau GmbH	Brandenburger liner	5	**	-	-

* Target values in acc. with client's data (structural-analysis/sample data record)
** Too few/no samples with statement of the target data for combined thickness
– Not evaluated, too few liner samples

the basis of structural-analysis calculations or are specified by the client.

Two procedures are used for the testing of the water-tightness of needle-felt liners: with and without cutting of the inner film. The latter method is selected for liners, the DIBt approval - or, in the Netherlands, the KOMO Foundation certificate - for which confirms the inner film as an integral element with an influence on tightness. The inner film of all other needle-felt liners is cut. GRP liners which do not have an inner film which remains in the sewer are tested without cutting.

Modulus of elasticity very good

The majority of contractors achieved very good results for the test criterion "modulus of elasticity", an indicator of the liners' load-bearing capacity. This test was passed by 99.1% of the site samples, slightly above (by +0.4 percentage points) the already excellent level achieved in the previous year. With the exception of just one contractor, all managed to at least maintain or even improve their 2014 performance. Particularly worthy of note is the fact that 100% of the samples fulfilled this criterion in twenty of twenty-nine cases.

Flexural strength also very good

An even better result than in the case of modulus of elasticity is actually apparent for the criterion of flexural strength, which denotes the point at which the liner fails as a result of excessively high stress: 99.3% of the site samples achieve the specified Target values, also an improvement (+0.6%P) over the already extremely good results for last year. As in the case of modulus of elasticity, this test criterion is 100% achieved in twenty of twenty-nine instances. With one exception, all the contractors also maintained or im- proved on their results for the previous year.

Wall thickness slightly poorer

Wall thickness which, together with the modulus of elasticity, determines the stiffness of a liner, results in a less positive picture than for the first two test criteria: the average for all samples passing the test has fallen by 1.4 percentage points (%P) compared to the previous year, to 95.4%. In thirteen of

Table 5: Test results for water-tightness, 2015

Contractors	Liner systems	2015		2014	Trend
		No. of samples	Target* achieved in % of tests	Target* achieved in % of tests	
Arpe AG **(CH)**	Alphaliner	26		-	-
Arkil Inpipe GmbH	Berolina liner	155		98,8	↑
Geiger Kanaltechnik GmbH & Co.KG	Alphaliner	83		-	-
Geiger Kanaltechnik GmbH & Co.KG	Berolina liner	35		100	↔
Hamers Leidingtechniek B.V.**(NL)**	Alphaliner	104		100	↔
HF-Rohrtechnik GmbH **(A)**	Berolina liner	48		-	-
Insituform Rioolrenovatietechnieken B.V. **(NL)**	Insituform Schlauchliner*	93		79,8**	↑
ISS Kanal Services AG **(CH)**	Alphaliner	41		100	↔
Jeschke Umwelttechnik GmbH	Alphaliner	45		100	↔
Jeschke Umwelttechnik GmbH	Brandenburger liner	114	100	100	↔
KTF GmbH	iMPREG liner	90		100	↔
Pfaffinger Rohrnetz- & Sanierungstechnik GmbH	iMPREG liner	37		-	-
Kanaltechnik Agricola GmbH	iMPREG liner	39		100	↔
Sanierungstechnik Dommel GmbH	Alphaliner	43		-	-
SKS-Servicecenter für Kanalsanierung GmbH	Alphaliner	29		-	-
Swietelsky-Faber Kanalsanierung GmbH **(A)**	Brandenburger liner	25		-	-
Swietelsky-Faber Nederland Relining B.V. **(NL)**	Berolina liner	54		-	-
Trasko a.s. **(CZ)**	Alphaliner	45		-	-
Umwelttechnik und Wasserbau GmbH	Brandenburger liner	56		-	-
Umwelttechnik und Wasserbau GmbH	Alphaliner	161	99,4	97,8	↑
Aarsleff Rohrsanierung GmbH	PAA SF liner*	114	99,1	100	↓
Average			**98,6**	**96,6**	↑
Erles Umweltservice GmbH	iMPREG liner	46	97,8	89,3	↑
Van der Velden Rioleringsbeheer B.V. **(NL)**	iMPREG liner	41	97,6	96,8	↑
Arkil Inpipe GmbH	SAERTEX liner	65	96,9	-	-
TKT GmbH & Co. KG	Alphaliner	249	96,8	98,5	↓
Aarsleff Rohrsanierung GmbH	iMPREG liner	178	96,6	97,2	↓
KATEC Kanaltechnik Müller und Wahl GmbH	Alphaliner	43	95,3	-	-
GMB Rioleringstechnieken B.V. **(NL)**	iMPREG liner	36	91,7	-	-
UKDN Waterflow Ltd. **(GB)**	iMPREG liner	27	85,2	-	-

* No cutting of integrated inner film
** No cutting of integrated inner film since 15 September 2014, due to KOMO Foundation certificate in NL
– Not evaluated, too few liner samples

Table 6: Test results by liner types, 2015

Liner system	Liner type	Water-tightness		Modulus of elasticity		Flexural strength		Wall thickness	
		No. of samples	Watertight in % of tests	No. of samples	Target* achieved in % of tests	No. of samples	Target* achieved in % of tests	No. of samples	Target* achieved in % of tests
Berolina liner	GRP	292	100	293	100	293	100	126	100
Alphaliner	GRP	869	98,7	870	99,2	870	99,7	460	97,0
Brandenburger liner	GRP	195	100	193	99,0	193	99,5	114	100
PAA SF liner	NF	114	99,1**	114	99,1	114	97,4	64	93,8
Insituform CIPP liner	NF	93	100**	106	95,3	106	97,2	102	87,3
iMPREG liner	GRP	494	97,0	504	99,8	504	99,2	374	92,2
SAERTEX liner	GRP	65	96,9	64	95,3	64	98,4	56	100
Average			**98,6**		**99,1**		**99,3**		**95,4**

indicates average or above average
indicates below average
* Target values in acc. with client's data (structural analysis/sample data record)
** Without cutting of integrated inner film
GRP: Glass-fibre-reinforced plastic backing material
NF: Needle-felt backing material

Tightness testing of CIPP liners

twenty-four cases, 100% of the samples fulfil this criterion.

Eight contractors nonetheless managed to maintain or improve their previous year's score, while five, on the other hand, performed less well - one of them very significantly, with a minus of 19 %P compared to last year. Three other contractors managed to achieve 100% success rates for wall thickness, using the same type of liner. The bandwidth between the best result and the poorest is 25 %P for the test criterion of wall thickness and is thus conspicuous (see Table 4).

An examination of the various liner types shows that the test results for wall thickness fall into two groups: one group with a pass rate of 97% to 100%, and another group exhibiting poorer results, of 87% to 94% tests passed (see Table 6).

Water-tightness better

The test for water-tightness is passed on average in a pleasing 98.6% of all cases, an increase of 2.0%P compared to the previous year. Here, too, the overwhelming majority of the contractors have managed to maintain or improve their 2014 results. Poorer

Table 7: Test results compared to previous year

Liner type	Watertight in % of tests			Modulus of elasticity Target* achieved in % of tests			Flexural strength Target* achieved in % of tests			Wall thickness Target* achieved in % of tests		
Averages	2015	2014	+/–	2015	2014	+/–	2015	2014	+/–	2015	2014	+/–
– All samples	98,6	96,6	+ 2,0 ↑	99,1	98,7	+ 0,4 ↑	99,3	98,7	+ 0,6 ↑	95,4	96,8	- 1,4 ↓
– GRP	98,5	98,7	- 0,2 ↓	99,3	99,2	+ 0,1 ↑	99,5	99,5	0,0 ↔	96,2	97,3	- 1,1 ↓
– NF	99,5	87,4	+ 12,1 ↑	97,3	96,2	+ 1,1 ↑	97,3	95,3	+ 2,0 ↑	89,8	95,0	- 5,2 ↓

GRP: Glass-fibre-reinforced plastic backing material
NF: Needle-felt backing material
* Target values in acc. with client's data (structural analysis/sample data record)

scores than last year are achieved only in three cases.

The great improvement achieved by a Dutch contractor - by a good 20%P - is striking. This is attributable to an amendment to the approval (the so-called KOMO Foundation certificate) in September 2014, under which the inner film is to be considered an integral component of the liner. This film has since then not been cut prior to the water-tightness test.

Refurbishing quality at high level in 2015

The quality of installed CIPP liners has nothing to be ashamed of: Anyone who awarded a CIPP-liner refurbishing project in 2015 could rightly expect that the specified targets for three of the four test criteria, i.e., modulus of elasticity, flexural strength and water-tightness, would be met with a probability of 98% to 99%. This is without doubt an impressive statistic, one which is of comfort for project clients, and one which shows that the refurbishing contractors and liner producers have significantly improved the quality of their services and products over recent years.

Quality also good outside Germany

For some good time now, more and more results obtained from foreign site samples have been incorporated into the IKT LinerReport. Conspicuous here is the fact that, with a few exceptions, liner types supplied by German producers are mainly used abroad, too, and that the installation quality closely approaches that of the German refurbishing contractors. With only a few exceptions, foreign contractors were well able to hold their own against their German counterparts in the 2015 LinerReport.

Still keeping an eye on wall thickness

Only one small tinge of disappointment clouds the overall positive picture: the targets were achieved for the stability criterion of wall thickness in around 95% of all cases - but in 5% they were not. This means that the required wall thickness was not met in around every twentieth CIPP-liner installation in 2015.

The picture is much better for the other three test criteria, on the other hand. The test for water-tightness was not passed only in every seventieth installation, for example, that for modulus of elasticity only in every 110th and that of flexural strength only in every 140th.

Testing recommendable at end-of-warranty inspection

Clients should therefore emphatically insist on adherence to the contractual obligations, particularly in the case of the criterion most frequently not fulfilled, wall thickness. Even if the test results after installation fall only slightly below the specified targets, renewed testing at the end-of-warranty inspection - i.e., after several years of exposure to operating loads - is nonetheless recommendable in every case.

Dipl.-Ök. Roland W. Waniek
Dipl.-Ing. Dieter Homann
Barbara Grunewald, M.Sc.
IKT - Institute for Underground Infrastructure
Exterbruch 1
45886 Gelsenkirchen
Germany
T. +49 (0) 209 17806-0
info@ikt.de
www.ikt-online.org