

GERMAN RECOMMENDATIONS FOR SEALING SYSTEMS IN TUNNELS

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Abstract: In 2005 the German Geotechnical Society (DGGT) published the recommendations for sealing systems in tunnels "Empfehlungen zu Dichtungssystemen im Tunnelbau EAG-EDT" in German language. The recommendations have been compiled by Working Group AK 5.1 "Geosynthetics in geotechnics and hydraulic engineering". At the moment the English version "Recommendations for Sealing Systems in Tunnels" is being prepared and will be published soon.

The recommendations constitute a review of current practices in the design, selection, application and testing of geosynthetics for the tunnel construction industry. The work presents a comprehensive survey of the wide range of sealing systems currently available for tunnel construction operations. The recommendations serve as a reference manual for contractors, planners and operatives alike. They cover sealing systems based on synthetic geomembranes and associated protection and drainage layers as used in all types of tunnel construction projects, including both cut-and-cover and underground excavation systems as well as other types of underground engineering work. The publication also examines current developments in European standards, discusses the latest applied research findings and presents what has been learned from recent major tunnel construction projects. A series of case studies from the tunnelling industry round off the work.

Typically Working Group 5.1 is going on with public relations. With the help of courses, education and arrangements the adoption of the recommendations into practice is supported. Especially sample contract specifications for external monitoring of execution are being prepared.

This paper gives an overview on the recommendations. First experience in practice and ongoing work of AK 5.1 is described. Furthermore, an outlook on the future developments for sealing systems in tunnels is given.

Keywords: geomembrane, geosynthetic, geotextile, quality control, sealing.

INTRODUCTION

The recommendations EAG-EDT by the Working Group AK 5.1 "Geosynthetics in geotechnics and hydraulic engineering" of the DGGT are dealing with all types of geomembrane sealing systems at present in use in tunnel construction: umbrella and one or double layer continuous sealing systems, drained and undrained tunnels as well as trenchless tunnels and tunnels via cut-and-cover method. All elements of the sealing systems and their working together are considered. The recommendations also contain aspects of the remaining construction if they mainly influence the sealing system, e.g. hints on the inner concrete shell. A comprehensive quality management system including monitoring of the geosynthetic products and monitoring of execution of construction is recommended. The regulations of the pertinent and binding harmonized European standards for geosynthetics are inserted.

IDEA AND SIGNIFICANCE OF THE EAG-EDT

The recommendations EAG-EDT for geomembrane sealing systems in tunnel construction published in 2005 intend to supply the foundation for the owner specific far-reaching harmonized regulations for railway and road tunnels, namely:

- the revised Ril 853 by the "Deutsche Bahn AG" for German railway tunnels (in preparation) and
- the meanwhile published new Chapter 5 "Sealing" in Part 5 "Tunnelling Construction" of the technical and contractual regulations called ZTV-ING of the German Federal Ministry of Transport, Building and Housing including the affiliated Technical Delivery Conditions (TL) and Technical Testing Regulations (TP) (Bundesanstalt für Straßenwesen 2007a, b and c).

In respect of content the recommendations EAG-EDT intend to improve the mutual understanding of the participated experts and their interdisciplinary cooperation. The successful realisation of the recommendations EAG-EDT including the recommended quality assurance measures into practice shall help to avoid leakage, to optimize the costs of construction, service and maintaining and to build more sustainable tunnels.

The members of subgroup UG 6 of working group AK 5.1 are consultant engineers, civil engineers of building companies, of the builders of railway and road tunnels, of geosynthetic manufacturers, installation companies and testing institutes. So all kinds of aspects and relationships could be considered.

STRUCTURE OF THE EAG-EDT

The EAG-EDT consists of the following chapters:

- Introduction
- Basics and Definitions
- Fundamentals of Design

- Demands on the sealing elements and the system
- Installation
- Quality Assurance
- Summary and Outlook
- References
- Abbreviations
- Appendix with Case Studies

CONTENT OF THE RECOMMENDATIONS EAG-EDT

Introduction

The meaning, the application, all kind of aspects and critical points of geomembrane sealing systems in tunnel construction is given in general to the reader as well as the purpose and content of the recommendations.

Basics and Definitions

The fundamental experiences and developments of tunnelling and sealing technology of the last decades are explained. On this way the selection of suitable sealing and drainage systems is supported. Mainly the sintering problem of drainage systems and the relationship between groundwater and sealing system are mentioned.

From experience values of sealing system costs in trenchless tunnels are given. The costs reach from 2.5 up to 3.5 % of the whole rough work costs of seepage water-tight sealing systems without special drainage and up to 10 % of the whole rough work costs of double layer geomembrane sealing systems in the case of large water pressure. In the case of sealing damages considerable additional costs of repair are usual. It is seriously recommended, already during design to look at all costs together that is to say the construction costs including quality assurance and repair as well as service and maintaining costs.

The technical terms of tunnelling and sealing used in the EAG-EDT are defined to avoid misunderstandings of the participated specialists and to ease their communication.

Fundamentals of Design

The geomembranes are applied loosely to the sealing abutment and joined together by welding. The geomembrane sealing is not allowed to bear tensile forces and has to be installed between the connecting layers as free from tensile stress as possible, the pressure contact between rock and inner concrete shell or between soil and concrete may not be interrupted. The tunnel constructions and sealing systems usually have to be designed for a working life of a hundred years.

The general structure of the sealing system in trenchless tunnels and tunnels with cut-and-cover method is shown in Figures 1 and 2. Joint strips (external joint strips and terminal strips) and fittings as clamping appliances, you can not see in the figures, are further components of the sealing system.

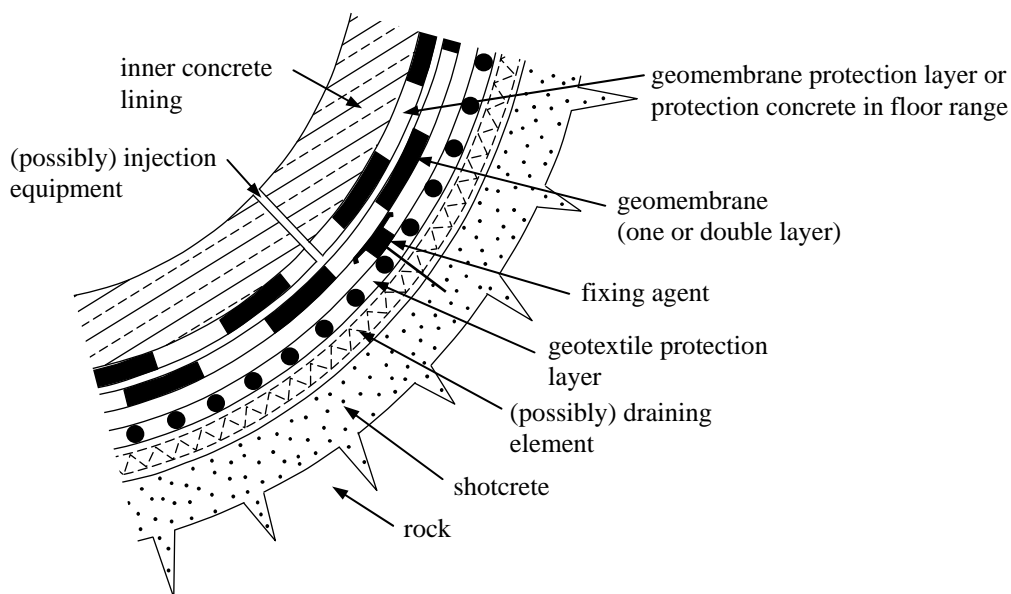


Figure 1. Sealing system structure in a trenchless tunnel

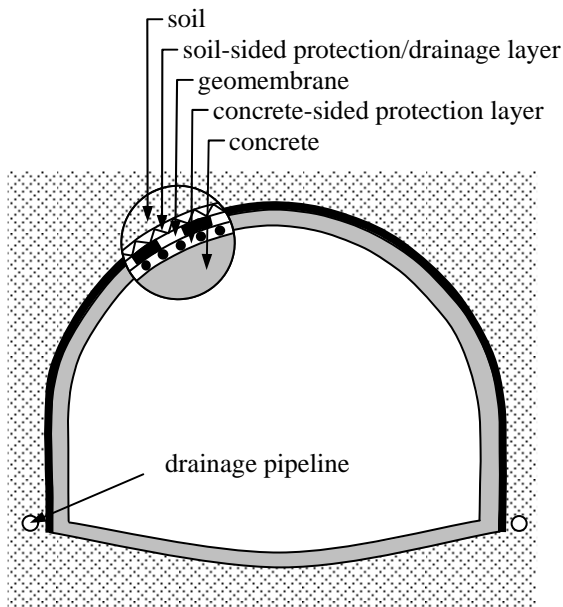


Figure 2. Sealing system structure in a tunnel via cut-and-cover-method

Tables 1 and 2 give an overview of the sealing classification in trenchless tunnels and in tunnels via cut-and-cover method depending on the surrounding water conditions, namely the hydrostatic pressure and possibly the kind of chemical attack against concrete. The classification includes pure waterproof concrete structures (WP-CS), although the recommendations EAG-EDT does not treat with such structures in detail.

The geomembrane stresses have to be reduced by one-sided or double-sided protection layers, which have to prevent leaks or adverse effects on the long term stability. In the case of drained tunnels the water flowing must have durably sufficient hydraulic discharge possibilities. Regarding sintering and/or adding danger low-maintenance systems are to be preferred.

Then the constructional design of joint sealings, watertight bulkheads and connections, predominantly made off joint strips as external joint strips or connecting strips is described. Also the fixing of the sealing, the injection equipment and special fittings are treated.

To avoid or to recognize sealing system damage in good time quality assurance measures are necessary including the monitoring of the products and in particular the monitoring of the construction works.

Table 1. Sealing system classification of trenchless tunnels depending on the groundwater conditions

No.	geomem-brane (GM)-sealing geometry	hydrostatic pressure over floor in m water column	chemical concrete attack (exposure class) according to EN 206-1		necessary additional measures		
			slightly, moderately (XA1, XA2)	highly (XA3)	joint strips		integrated injection system *
					internal	external	
1	umbrella	without (no back-water allowed)	GM 2 mm †	-	no	no	no
2			WP-CS 4)	-	system-related existing	no	no
3			-	GM 2 mm †	no	no	no
4	continuous	up to about 30	GM 3 mm †		no	yes	yes
5			WP-CS †	-	system-related existing	no	no
6			WP-CS _{mod} †, § + GM 3 mm		no	yes	yes
7			double layer GM † (mountainside 3 mm + innerside 2 mm)		no	yes	yes

* usually from water pressure of approximately 10 m water column on

† concrete-technical requirements for the inner concrete lining according to Ril 853 or ZTV-ING, WP-CS means waterproof concrete structure

‡ In the case of bigger water pressures special project-related measures are needed.

§ WP-CS_{mod} means modified waterproof concrete structure, because without internal joint strips in the block joints

Table 2. Sealing system classification of tunnels via cut-and-cover-method depending on the groundwater conditions

No	geo-membrane (GM)-sealing geometry	hydrostatic pressure over floor in m water column	chemical concrete attack (exposure class) according to EN 206-1		cross-sectional area with GM-sealing			necessity of internal joint strips
			slightly, moderately (XA1, XA2)	highly (XA3)	ceiling / vault	wall	floor	
1	umbrella	without (no backwater allowed)	WP-CS *	-	-	-	-	system-related existing
2			GM 3 mm †	-	necessary	necessary	-	no
3			-	GM 3 mm†.4)	necessary	necessary	necessary	no
4	continuous	up to about 30	WP-CS ‡	-	-	-	-	system-related existing
5			-	WP-CS * + GM 3 mm ‡	necessary	necessary	necessary	system-related existing

* waterproof concrete structure WP-CS according to ZTV-ING or Ril 853

† concrete-technical requirements for the concrete structure according to Ril 853 or ZTV-ING; construction from waterproof in-situ concrete not necessary

‡ In this case the geomembrane primarily has to protect the concrete structure against corrosion.

Product and System Requirements

Sealing system elements having contact to each other must be durably compatible. The harmonized European standards DIN EN 13491 for geomembranes, DIN EN 13252 for geotextile drainage elements and DIN EN 13256 for geotextile protection layers are to be considered. Additionally in the EAG-EDT further demands on the sealing system elements are included. For protection geomembranes, joint strips and drainage elements, which do not belong to the group of geotextiles or geotextile-related products, at present no harmonized European standards are available.

Precise requirements are given for all sealing elements: the sealing abutment, geomembranes, protection layers, geotextile drainage elements, joint strips, fixing elements, injection mechanisms and means, special fittings and the sealing-sided surface of the inner concrete shell in the case of trenchless tunnels. The requirements pay regard to mechanical and hydraulic characteristics, the behaviour in case of fire, the environmental compatibility and specifically for geomembranes the weldability. Furthermore special attention is directed to the identification of the raw materials and the long-term stability if necessary.

In the case of water pressure holding geomembrane sealing systems polyolefin geomembranes are demanded generally. The manufacturers confidentially have to depose a product description including the kind and quantity of the polymers, the stabilizers, the fillers and the flame protection means as well as the differential scanning calorimetry (DSC) fingerprints.

The mountain-sided geotextile protection layers of trenchless tunnels must have an average mass per unit area of 1.000 g/m². Only in the case of special boundary conditions (particularly favourable surface texture of the sealing abutment) the recommended mass of the geotextile protection layer may be reduced, however not at all under 500 g/m². In such a case further requirements for the geotextile protection layer have to be modified.

Behind the requirements for individual sealing elements recommendations for their spatial arrangement are given including the design layout of impacts, connections and penetrations.

For trenchless tunnels next to the arrangement of the drainage elements, protection layers and their fixing elements are described. One has to pay attention that the mountain-sided protection layer has to be applied in the complete face, even if the tunnel is equipped with drainage elements. The drainage elements are applied in strips only.

Thereafter the arrangement of the geomembranes, external joint strips and associated fixing elements is treated. Umbrella sealings are led down to the longitudinal drainage equipment. For continuous sealings the geomembranes are impacted above the connection armouring between floor and coming up vault. In the case of double layer geomembrane sealing systems closed elements with an area between 40 and 70 m² are to be installed. If technically possible impacts between geomembranes and between geomembranes and joint strips have to be connected by overlapping seams which can be tested.

Furthermore in the EAG-EDT the arrangement of injection mechanisms, that is to say injection hoses for making joint strips fit, after-concreting pipes in the roof, mechanisms for roof gap grouting, injection hoses for making working joints fit and injection connecting pieces in integrated injection systems for grouting of bulkhead fields or closed elements in the case of double layer sealing systems, is described in detail.

After some demands on tunnels via cut-and-cover method the requirements for kind and geometry of welding seams are given. Overlapping seams with testing channel are demands as standard. Overlapping seams without testing channel may be used in special cases only.

Finally explanations about all testing methods having to be applied are given. If necessary testing conditions are determined and not standardized test methods are described.

Installation

The installation recommendations serve on the one hand the production of a functional sealing system and on the other hand the occupational safety during execution. Because the sealing system is no longer accessible for direct repairs after completion of the construction measure, large care is necessary with the installation.

First recommendations regarding the building site facilities, the supply of electric current, the equipment of the applying company as well as the occupational and fire protection measures during installation are given.

Then arranged according to the installation sequence recommendations regarding the installation of the sealing system elements or trenchless tunnels are given, i.e. among other things:

- closely fitting installation of the drainage elements, of the mountain-sided protection layers and of the geomembranes and prevention of material surplus and connecting development of wrinkles during concreting
- prevention of out-standing connecting nails in the case of classical connecting technology using disc-headed bolts and zipper-like separations of adhesive bonding attachment
- careful installation of the external joint strips centrally in the block joint on a sealing abutment of acceptable quality and with carefully implemented waterproof welding seams and waterproof integration of the joint strips into the inner concrete lining
- no direct driving on the geomembrane sealing within the floor range, if possible installation of the inner floor protection layer immediately after geomembrane installation

A very important part of this chapter are the measures to accomplish an acceptable quality of the inner concrete lining, because in the past inner concrete linings of poor quality (e.g. with uncovered reinforcement) often caused sealing system damage and expensive remedial costs. Therefore sealing-relevant recommendations are given for the reinforcement and formwork works, for the concrete composition, for concreting, for in any case after concreting in the block joint and roof range, for in any case the examination of the outside contour surface of the inner concrete lining using non destructive testing methods e.g. the impact echo procedure, and for roof gap grouting. Also injection works to repair sealing system leakages are treated.

At the end of the chapter hints at the sealing system installation in tunnel construction via cut-and-cover method are given.

Quality Assurance

A consistent system of quality management is introduced including:

- suitability test,
- factory production control,
- third party monitoring of production,
- self monitoring of execution of construction including geosynthetic product receiving inspection,
- local construction supervision and
- third party monitoring of execution of construction.

All parts of the quality management system are described. High value is set on geosynthetic receiving inspection and third party monitoring of execution. Demands on third party monitors of execution of construction are given. The monitors need practical experience in design and installation of tunnel sealing systems with geomembranes including aspects of the remaining construction if they mainly influence the sealing system, experience in the field of geosynthetics as well as in quality management. The importance of the interrelations to the former or following works has to be considered. It is strongly recommended to involve the third party monitor of execution during design already. The duties of third party monitoring of execution are mentioned.

For geomembranes, geotextile protection and drainage layers as well as for joint strips detailed recommendations are given tabularly regarding kind and frequency of product testing beginning with the suitability test and ending with the external monitoring of the execution.

Summary and Outlook

A short summary of the recommendation is given and important parts are brought into sharper focus. Further need of action and development in the future are shown, e.g. by improvement of the product parameters, by system simplification and mechanization of installation.

Case Studies

The recommendations are supplemented by the following case studies:

- tunnels “Doelzchen” and “Coschuetz” of the German motorway BAB 17 with a one-layer geomembrane sealing system
- tunnel “Eichheide” of the Deutsche Bahn AG’s new Cologne-Rhine/Main rail line with a double layer geomembrane sealing system
- sealing and drainage of the tunnel “Euerwang” of the Deutsche Bahn AG’s Nürnberg-Ingolstadt rail line

- tunnel “Himmelberg” of the Deutsche Bahn AG’s new Cologne-Rhine/Main rail line with a geomembrane sealing system and integrated injection equipment

STAGE OF REALISATION AND ONGOING WORK OF AK 5.1

Actually the idea of the recommendations EAG-EDT finds its way into the owner regulations. Far-reaching harmonized German regulations for road and railway tunnels are in sight, although the completion is unexpectedly time-consuming. The fine-tuning of the regulations and the notification of the ZTV-ING Part 5 Chapter 5 by the EU was finished at the end of 2007. Thus only a short time ago the new Chapter 5 “Sealing” in Part 5 “Tunnelling Construction” of the technical and contractual regulations ZTV-ING of the German Federal Ministry of Transport, Building and Housing including the affiliated Technical Delivery Conditions (TL) and Technical Testing Regulations (TP) has come into force (Bundesanstalt für Straßenwesen 2007a, b and c). The revision of the Ril 853 for railway tunnels is still not finished. Therefore first tenders according to the new Chapter 5 in Part 5 of ZTV-ING are starting only now.

Surely the users need further education to become familiar with all innovations. Especially the new requirements on geosynthetic sealing products, the receiving inspection of geosynthetic products and the extended external monitoring of execution of construction in particular for the geomembrane sealing systems still have to be established. The new revised owner regulations do not redundantise the recommendations EAG-EDT. The EAG-EDT include explanatory notes to reveal the background story and the history. They pull all relevant aspects together. Special experts or trainees can learn the superior interrelations about geomembrane sealing systems in tunnels by reading the recommendations EAG-EDT.

The work of subgroup UG 6 of working group AK 5.1 is going on. The working group seeks to support the users to become familiar with the new regulations. Courses have been offered. At present further documents are worked out to relieve the practical application of the new regulations, to avoid mistakes and to save time and costs. For example sample contract specifications and tender documents and examples of job costing are being prepared.

OUTLOOK ON FUTURE DEVELOPMENTS FOR GEOMEMBRANE SEALING SYSTEMS IN TUNNELS

Further development of geomembrane sealing systems in tunnels is possible and desired to improve the sustainability and economic efficiency. Geosynthetic products and testing methods can be optimized. At present for example the long term behaviour of geomembranes and the innovative autoclave testing method are investigated. Installation can be automatised to save time and costs, to avoid imperfections and to improve the quality of sealing systems. Further on the interdisciplinary discussion in the working group of the AK 5.1 will continue to help the further development of geomembrane sealing systems in tunnels.

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