

# NEW GERMAN RECOMMENDATIONS FOR GEOMEMBRANE SEALING SYSTEMS IN TUNNEL CONSTRUCTION

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**ABSTRACT:** The German recommendations “Empfehlungen Doppeldichtung Tunnel – EAG-EDT” are being completely revised. In future the recommendations deal with all geomembrane sealing systems in tunnels, not only special double layer geomembrane lining systems. Furthermore, in the revised recommendations new developments in the field of tunnel sealing technology due to findings gained in practice and due to research programmes as well as new binding European standards are taken into account. In this paper a general view on the structure and content of the revised recommendations is given. They consist of an introduction, basics, fundamentals of design, demands on the sealing elements and the system, the installation, the quality assurance and case studies. Additionally the main innovative aspects of the new recommendations are pointed out and explained.

## 1 INTRODUCTION

At present in Germany many road and railway tunnels are designed or already constructed (HAACK, 2003). Geomembrane sealing systems are installed in many of these tunnels, mainly in trenchless two-shell tunnels (Figure 1) and more seldom in tunnels via cut-and-cover construction method (Figure 2). Therefore, the recommendations “Empfehlungen Doppeldichtung Tunnel – EAG-EDT” of the German Geotechnical Society from 1997 are being completely revised.

The new edition of the recommendations

- is dealing with geomembrane sealing systems of tunnels in general, not only with special double-layer geomembrane sealing systems,
- considers new developments in sealing technology in practice as well as new research results and
- inserts the new pertinent and binding European standards for geosynthetics.

- high effort for tunnel design, construction and security,
- a long service life and
- low maintenance cost.



Figure 1 Trenchless two-shell tunnel with geomembrane sealing during construction

## 2 GENERAL VIEW ON THE RECOMMENDATIONS

The new recommendations are titled “Empfehlungen für Abdichtungen von Verkehrstunneln und anderen unterirdischen Bauwerken mit Kunststoffdichtungsbahnen EAG-EDT” and will be published in the near future. The recommendations are gained by a subgroup of the Working Group 5.1 “Geosynthetics in Geotechnique and Hydraulic Engineering” of the German Geotechnical Society. The content of the recommendations can be summarized as described below.

### 2.1 Introduction

A faultless waterproof sealing system is a very important component in a tunnel construction. Thus the new recommendations support



Figure 2 Vault tunnel with geomembrane sealing via cut-and-cover construction method during construction

## 2.2 Basics – Definitions and History

Differently specialised parties participate in tunnel design and construction. To avoid misunderstanding between the different parties consistent definitions of special words in the field of tunnel construction, sealing technology and geosynthetics are given.

Furthermore, essential steps of the historical development in tunnel sealing technique are explained without forgetting bad experiences, because one can learn from these and avoid the same mistakes in future.

## 2.3 Fundamentals of Design

At the beginning, the prevailing stresses and functions of the sealing systems and their requirements, e.g. service life, are given in general. Furthermore, all working steps of sealing system design are listed taking important interactions into account.

After this, the structure and elements of sealing systems with geomembranes in trenchless tunnels and tunnels via cut-and-cover-method are described (Figure 3 and 4). The systematology of sealing systems is given depending on the water aggressiveness and the amount of water pressure. In this context differences in the arrangement, the number of layers, the thickness of the geomembranes as well as the type and arrangement of joint strips and injection equipments are described. Furthermore, basic design demands concerning the drainage, if on hand, the protection layers, the connecting technology, sealings of the block joint, connections between geomembrane sealings and concrete linings as well as injection equipment are given.

## 2.4 Demands on the Sealing Elements and on the System

General demands and special demands on geomembranes, the sealing abutment, protection layers, drainage elements, thermoplastic joint strips, fixing agents as well as injection equipment and grout are given. Furthermore, demands on the sealing system are pointed out as the arrangement and connection of the sealing elements and the combination of different elements. The regulations of the new pertinent and binding European standards concerning geosynthetic products and testing are integrated.

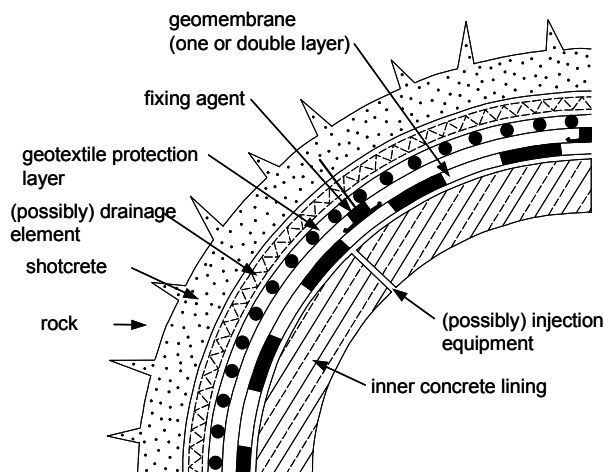


Figure 3 Structure of geomembrane sealing systems in the vault section of tunnels via mining construction method

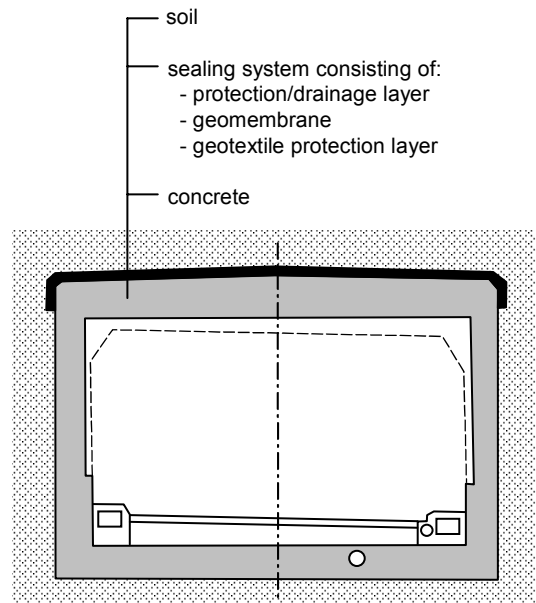


Figure 4 Structure of geomembrane sealing systems in tunnels via cut-and-cover construction method e.g. with rectangular cross-section and umbrella geomembrane lining

## 2.5 Installation

Important aspects of the sealing system installation are described. In addition to the pure installation of the sealing system elements, further points are treated if they mainly influence the function of the sealing system, e.g. the needs of the building site equipment, demands on transport, delivery and storage of the geosynthetic sealing system elements and the former or following works, such as the concreting of the permanent inner concrete lining.

## 2.6 Quality Assurance

A consistent system of quality management is introduced including:

- suitability test
- factory production control
- external monitoring of production
- self monitoring of execution of construction
- local construction supervision
- external monitoring of execution of construction

Demands on monitors of execution of construction are given. The monitors need practical experiences in design and installation of tunnel sealing systems with geomembranes, experiences in the field of geosynthetics as well as in quality management.

## 2.7 Case Studies

The recommendations are completed with some case studies. The case studies illustrate the content of the recommendations and give hints how to design and install secure and tight geomembrane lining systems.

### 3 IMPORTANT AND INNOVATIVE ASPECTS OF THE RECOMMENDATIONS

#### 3.1 General Aspects

In the past regulations for tunnel sealing systems with geomembranes were given by the way together with the regulations for the whole construction. The costs of the sealing system are low compared to the costs of the whole construction. Otherwise it has to be taken into account that faulty not waterproof sealing systems can subsequently lead to expansive redevelopment works, retardments, service obstacles and high maintaining costs. The main topics of the new recommendations are tunnel sealing systems with geomembranes and additionally aspects of the remaining construction if they mainly influence the sealing system. In that manner the recommendations are able to avoid faults and their negative consequences.

A general view on the sealing systems with geomembranes in relation to the remaining tunnel construction and the construction operations is given to the participated specialists. Thus the co-operation and consequently the result of work will be improved.

To translate and fulfill the aforesaid idea the working group has members from:

- consultant engineering offices,
- building companies,
- builders, that is to say the Deutsche Bahn AG and the German Federal Institute for Highways to represent the German Federal Ministry of Transport, Building and Housing,
- manufacturers of geosynthetics and applying companies and
- testing institutes.

The harmonisation of all manifold aspects, interrelations, experiences and developments including the European standards is laborious but advantageous for future tunnel projects.

The recommendations give a complete description of tunnel sealing systems with geomembranes including cut-and-cover and mining construction method, seepage and pressure water-tight tunnels, umbrella, continuous, one-layer and double layer geomembrane linings as well as undrained, partially drained and drained tunnels. In tunnels via cut-and-cover construction method the application of sealing systems with geomembranes is not the standard solution. Often these systems have been neglected in regulations up to now. Nevertheless it is important that faults are avoided and thus the working group has included these systems in the recommendations.

The sealing system type has to be chosen considering the groundwater properties, namely aggressiveness and pressure. In the chapter dealing with the fundamentals of design pure water tight concrete structures are included. In that manner limits and overlappings of geomembrane and concrete sealing systems and selection criteria are pointed out. In the following chapters pure water tight concrete structures are not described in detail. In the recommendations demands on geosynthetic drainage elements for application in tunnels are given because they are neglected in other regulations.

#### 3.2 New findings gained in practice

The recommendations consider new findings gained in practice such as follow:

- During planning and execution of the new Cologne/Main rail route with 30 tunnels manifold findings were gained. Comparison between pure water tight concrete structures and tunnel sealing

systems with geomembranes and aspects of quality assurance are interesting in particular (e.g. BRUX, 2001, KOMMA, 2001, BREIDENSTEIN, 2002)

- A quality-approved inner concrete shell surface mainly influences the quality of the geomembrane sealing system. The concrete has to be placed with extreme care taking suitable action. Otherwise faults and leakage are inevitable (MAIER, 1996, PIERSON, 2001, DAUB, 2001). Non-destructive test methods e.g. impact echo method are used to recognize faults as cavities and leakage in tunnels (FRIEBEL, 2001 and 2003).
- Progress in installation technology took place e.g. mechanical welding of external joint strips and innovative fixing agents. The German Society for Welding is preparing new regulations for welding technology in tunnel sealing systems with geomembranes (DVS). Related research is still being continued.

#### 3.3 New Research Results

New research results are inserted:

- Research programmes were carried out at the Research Association for Underground Transportation Facilities Inc. (STUVA), Cologne, and the University of Hannover to improve geotextile protection layers in tunnels with geomembrane sealing (BRUMMERMANN, 2001, Universität Hannover, 1999, STUVA, 2001). Furthermore, in the STUVA double layer geomembrane sealing systems in tunnels were investigated (STUVA, 2000).
- An extensive investigation programme was performed to evaluate sealing systems for the Lötschberg and Gotthard base tunnels in Switzerland (RIETMANN, 2002). Although these tunnels have very extreme environmental conditions and high stresses, some of the results are interesting in general and are considered in the new recommendations.
- Research programmes were performed to investigate the efficacy of drains for transport tunnels taking sintering problems into account (NAUMANN, 2001, MAIDL, 1999, KIRSCHKE, 2001). Recognition of the research results are used to select suitable sealing and draining systems depending.

#### 3.4 European Harmonisation

Due to the European harmonisation it is necessary to insert the new pertinent and binding European standards for geosynthetics, as:

- DIN EN 13252 for geotextiles and geotextile-related products for use in drainage systems,
- DIN EN 13256 for geotextiles and geotextile-related products for use as protection layer in the construction of tunnels,
- DIN EN 13491 for geosynthetic fluid barriers in the construction of tunnels and
- related testing standards.

The recommendations have to bring together the regulations of the European standards and the intelligible additional demands of the builders on a high quality level, a long service life with continuous availability and altogether low construction, redevelopment and maintaining costs.

Up to now there are no European standards for joint strips. The German standards for joint strips do not consider all aspects of tunnel sealing systems with geomem-

branes. Therefore, special additional recommendations for joint strips are given.

### 3.5 Quality Assurance

A consistent quality management system is described. The self and external monitoring of the execution of the construction are very important components of this system in order to reach a high quality level. Up to now we have no consistent quality management system for geomembrane sealing systems in tunnels. Often the local construction supervisors do not have the necessary specialized experience in the field of geomembrane sealing systems and the sealing system aspects are neglected during execution.

## 4 CONCLUSION

The new recommendations for sealing systems of tunnels with geomembranes shall present the state of the art of the sealing technology considering the findings gained up to now.

Reading and application of the recommendations will contribute to economic and waterproof tunnels. Faults and connected cost-intensive redevelopment or maintenance works and costs can be avoided.

The recommendations supply the foundation for far-reaching identical demands on rail and road tunnels in Germany. Currently the Ril 853 for German railway tunnels (DEUTSCHE BAHN AG) is being revised as well. As part of the technical and contractual regulations of the Federal Ministry of Transport, Building and Housing concerning bridge and engineering construction ZTV-ING the Part 5 Chapter 5 "Geomembrane Sealing of Road tunnels" is in preparation (BMVBW or RODER, 2003). It is assumed that the co-operation between the working groups will lead to far-reaching harmonised regulations.

Further development of the sealing technology e.g. investigation of the geosynthetic long-term behaviour, material modification and installation improvement may be initiated by the new recommendations.

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