Federal Waterways Engineering and Research Institute

Competence for Waterways

BAW Code of Practice

Rubber Gates (MSW)

Part B: Verification of the load-bearing capacity of membranes of water-filled rubber gates on inland waterways

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1 Preliminary remarks and scope

(1) Part B of the Code of Practice specifies the principles for the ultimate limit state design (STR) of membranes of rubber gates with a gate height of up to 3.5 m for weirs on inland waterways. Provided that there is prior consultation with the Federal Waterways Engineering and Research Institute (BAW), the Code of Practice can also be used for gate heights up to a maximum of 4.6 m in accordance with Table 1.

(2) Annex 1 contains informative explanations and remarks on individual sections which may be of assistance to users of this part of the Code of Practice.

(3) The verifications presented herein only apply in cases where an external clamping line (rubber membrane support) is used, see Figure 2. It needs to be checked whether they are also applicable to other support systems. The complete rubber membrane shall be designed to have a constant membrane cross-section. This excludes any changes in the type of fabric, number and position of the fabric layers used in the cross-section as well as any changes in the elastomer throughout the membrane as a whole.

(4) The choice of fabric is limited to polyester and polyamide.

(5) The Code of Practice covers only water as a filling medium.

(6) Rubber membranes have a design life span of 30 years.

(7) Deviations from this Code of Practice are permitted provided they can be sufficiently justified or are necessary owing to recent findings. In such cases, approval will be required in each individual case.

(8) Assessments of the load-bearing capacity of membranes for rubber gates performed in accordance with this Code of Practice shall be verified from a structural and design point of view, generally by a test engineer for civil engineering (double-checking principle).

2 General

2.1 Specific terminology

Fabric
The fabric acts as reinforcement and transmits loads.

Warp direction
Direction of the fibres in the production axis in fabric manufacturing.

Rubber membrane
The fabricated fabric-elastomer composite is referred to as a rubber membrane.

Weft direction
Direction of the fibres at right angles to the production axis in fabric manufacturing.

2.2 Designations and symbols

Latin letters

d_s	equivalent overall fabric thickness (derived from numerical calculations)
e	eccentricity of the fabric layer in the elastomer
E_d	design value of the effects of actions
$E_{d,cl}$	width-related test force for the pull-out test
f_1	reduction factor to take account of creep resistance
f_2	reduction factor to take account of ageing
g	gravitational acceleration
h_i	internal pressure of the rubber gate acting on the bottom of the weir
h_O	upstream water level above the weir sill
h_s	height of the rubber body at mid-span
R_d	design resistance
R_k	characteristic resistance
$R_{rel.}$	relative resistance
SCF	stress concentration factor
T_k	characteristic width-related membrane force in the continuous section (mid-span)
t	time

Greek letters

α	internal pressure coefficient with $\alpha = \frac{h_i}{h_O}$
γ_F	partial safety factor for actions
$\gamma_{M,warp}$	partial safety factor for the member resistance in the continuous section in the warp direction
$\gamma_{M,weft}$	partial safety factor for the member resistance in the continuous section in the weft direction
$\gamma_{M,joint}$	partial safety factor for the member resistance at the joints
$\gamma_{cl,test}$	partial safety factor for testing the resistance to being pulled out of the clamping system
ξ	overall reduction factor to take account of changes in material properties
ρ	density
σ_{Ek}	characteristic stress relevant for the design

3 Verification of rubber membranes

3.1 Basic principles

(1) For rubber gates within responsibility of the German Federal Waterways and Shipping Authority, a minimum of two fabric layers shall be embedded in an elastomer matrix for standard cross-sections. Fabric layers may be discontinuous in the weft direction.

(2) The structure of the fabric requires separate verifications of the load-bearing capacity of the rubber membrane to be performed in the warp and weft directions. It is not permitted to use comparative stresses, such as the equivalent von Mises stress.

(3) The warp fibres along the circumference direction shall be made without joints between the upstream and downstream clamping lines.

(4) The weft fibres of the rubber membrane are joined manually during the production process. A separate verification of the load-bearing capacity shall be performed for the joints. Joints in the transitional zone between weir sill and abutment (SCF_2) are not permitted. A SCF_4 value of 0.5 may be assumed for the purpose of verifying the joint in the weft direction provided the minimum distance of the joint (overall joined length) from the corner is 0.1 h_s.

(5) It is generally not possible to access the inside of the rubber body (for inspection purposes).

(6) Suitable countermeasures against vibrations shall be taken for overflow but also for deflated conditions. For further information see Gebhardt (2010) and Gebhardt and Kemnitz (2007).

3.2 Design values of loads on membranes

(1) The design values of the effects of actions on rubber membranes can be expressed in general terms as:

$$E_{d,i} = \gamma_F \cdot \frac{\sigma_{Ek,i}}{d_s} = \gamma_F \cdot SCF_i \cdot T_k \tag{3-1}$$

where

$E_{d,i}$ are the design values of the effects of actions,

γ_F is the partial safety factor of the effects of actions,

$\sigma_{Ek,i}$ is the characteristic stress relevant for design in the warp and weft directions,

d_s is the equivalent overall fabric thickness (derived from numerical calculations),

SCF_i are the stress concentration factors,

T_k is the characteristic width-related membrane force in the continuous section (mid-span).

The hydrostatic water pressure due to the downstream water level has a favourable effect on the design. For this reason it shall not be taken into account.

(2) Owing to the limitation of the internal pressure, the partial safety factor γ_F may be set at 1.35 for permanent actions, based on (DIN 19704-1) and (DIN EN 1990).

(3) The stresses relevant for the design, $\sigma_{Ek,i}$, can be determined on the basis of numerical models.

(4) In the absence of overall numerical models, the SCF values given in Table 1 may be used for multi-layer reinforced rubber membranes. Table 1 is based on an internal pressure coefficient α of 1.60.
The areas for application of the stress concentration factors are shown in Figure 1. SCF_1 describes the overall length of the clamping line up to the transition between weir sill and abutment. SCF_2 describes the corner sections between weir sill and abutment. Excess stresses at the folds along the abutment are covered by SCF_3. SCF_4 can be used for the continuous section (mid-span) and the abutment.

Table 1: Stress concentration factors for membranes for rubber gates [1]

	Clamping Section		Corner Section		Fold Section[2)] (informative)		Continuous Section[3)]	
h_s	SCF_1		SCF_2		SCF_3		SCF_4	
$[m]$	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
≤ 3.50	1.50	n.a	3.00	1.00	1.50	1.00	1.00[2)]	0.50
≤ 4.60	1.75	n.a.	3.00	1.00	1.50	1.00	1.00[2)]	0.50

1) The boundary conditions in Table 1 are given in „Re 3.2, re (4)".
2) Informative as not relevant for the design, by contrast to SCF_2.
3) Outside the non-continuous sections (supports, corners and folds)

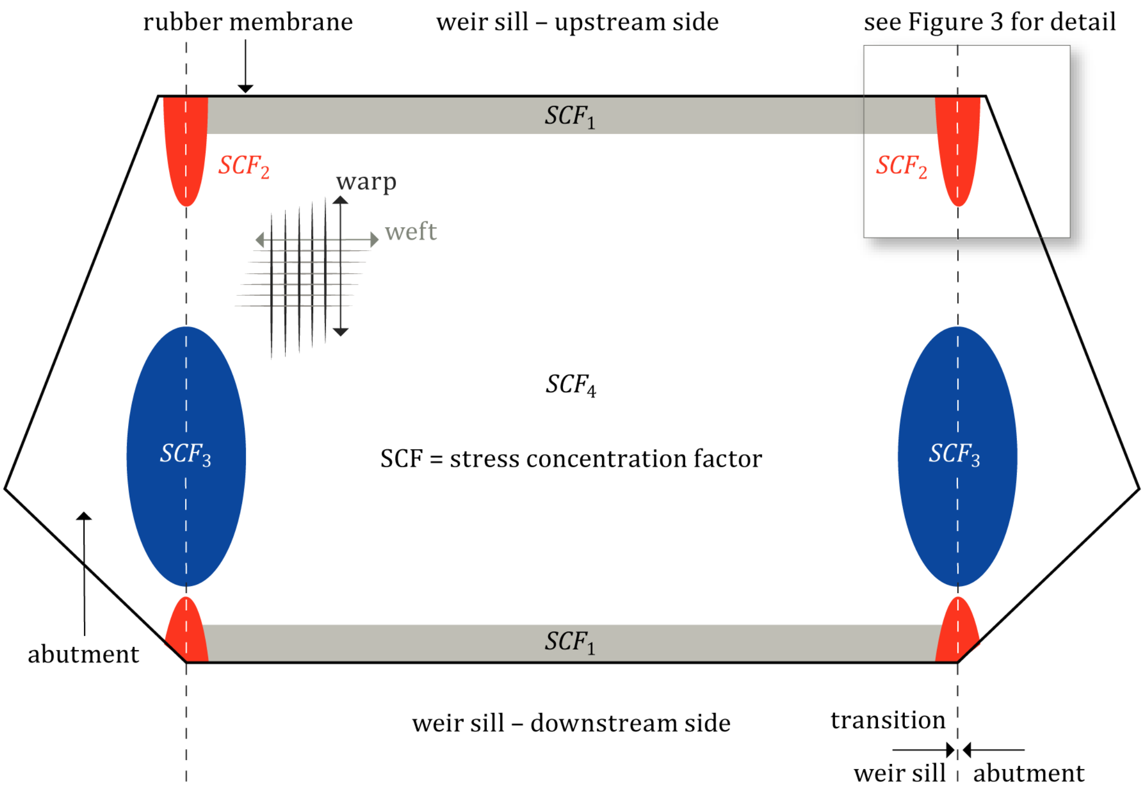

Figure 1: *Cutting plan for rubber membrane indicating the stress concentration factors – the size of the areas varies according to the geometry, the width for SCF_2 is 0.2 h_s, see also Figure 3*

(5) The characteristic width-related membrane force T_k can be determined analytically as a function of the height of the rubber gate in accordance with Gebhardt (2006). The following applies to water-filled membranes at the design upstream water level without tailwater where the rubber membrane runs horizontally behind the downstream clamping line, see Figure 2:

$$T_k = \frac{1}{4}\,(2\,\alpha - 1)\cdot\rho\cdot g\cdot h_s^2 \tag{3-2}$$

where

T_k is the characteristic width-related membrane force,

α is the internal pressure coefficient, with $\alpha = h_i/h_O$ (-),

h_i is the internal pressure in the rubber body acting on the bottom of the weir,

h_O is the upstream water level above the weir sill,

ρ is the density of water,

g is the gravitational acceleration,

h_s is the gate height at mid-span.

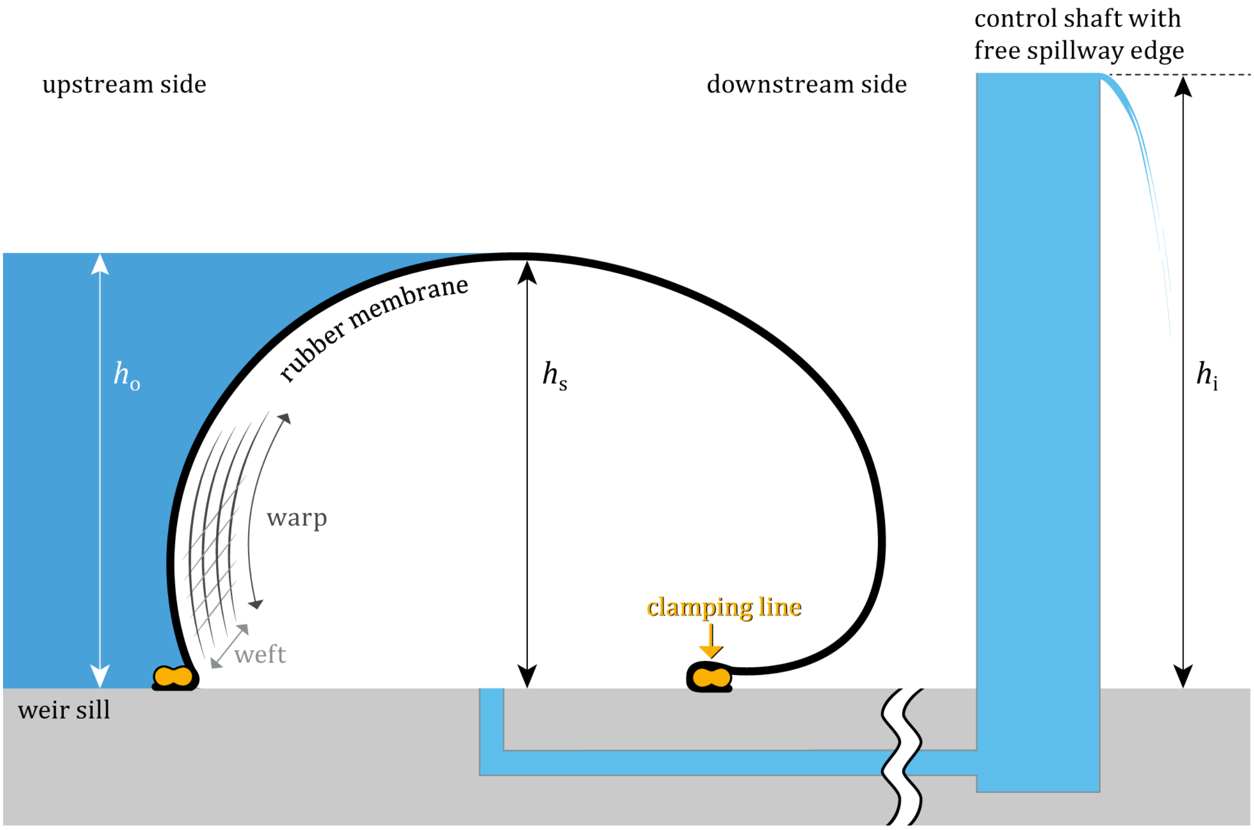

Figure 2: Sketch of cross-section of a rubber gate with hydraulic pressure head

3.3 Design load-bearing capacity of membranes

(1) The following design resistances apply to rubber membranes:

$$R_{\mathrm{d,warp}} = \xi \cdot \frac{R_{\mathrm{k,warp}}}{\gamma_{\mathrm{M,warp}}} \tag{3-3}$$

$$R_{\mathrm{d,weft}} = \xi \cdot \frac{R_{\mathrm{k,weft}}}{\gamma_{\mathrm{M,weft}}} \tag{3-4}$$

$$R_{\mathrm{d,joint}} = \xi \cdot \frac{R_{\mathrm{k,joint}}}{\gamma_{\mathrm{M,joint}}} \tag{3-5}$$

where

ξ is the overall reduction factor to take account of the change in the material properties between installation and the end of the design life span,

$R_{\mathrm{k,warp}}$ is the characteristic value of the resistances (tensile strength) in the warp direction,

$R_{\mathrm{k,weft}}$ is the characteristic value of the resistances (tensile strength) in the weft direction,

$R_{\mathrm{k,joint}}$ is the characteristic value of the resistances (tensile strength) at the joints.

$\gamma_{M,warp}$ is the partial safety factor for the member resistance in the continuous section in the warp direction,

$\gamma_{M,weft}$ is the partial safety factor for the member resistance in the continuous section in the weft direction,

$\gamma_{M,joint}$ is the partial safety factor for the member resistance at the joints.

(2) Reduction factors are combined to form an overall reduction factor ξ and are introduced to take account of the change in the properties of synthetic materials over time. The reduction factors are based on empirical values for numerous rubber gates constructed in Japan (see (Ministry of Land, Infrastructure and Transport, River Bureau, 2000)). The overall reduction factor ξ is obtained as follows:

$$\xi = \frac{1}{f_1} \cdot \frac{1}{f_2} \tag{3-6}$$

where

f_1 is the reduction factor to take account of the creep resistance,

f_2 is the reduction factor to take account of ageing.

(3) The reduction factor f_1 shall be determined by testing samples of the rubber membranes used in practice for creep resistance, see Annex 1. For preliminary design purposes, a reduction factor f_1 of 1.95 may be used for a life span of 30 years for both polyester and polyamide fabrics in accordance with Annex 1.

(4) To determine the reduction factor f_2, rubber membrane samples have to be mounted on site at the same time as the rubber membrane is installed. Tensile tests must be conducted on the exposed samples after 5, 10, 15, 20 and 25 years. The results are used to determine the reduction factor f_2, see Annex 1. For design purposes, a reduction factor f_2 of 1.55 may be assumed for a life span of 30 years for both polyester and polyamide fabrics in accordance with Annex 1. The final life span is obtained using the values determined for f_2.

(5) Upon conclusion of the tests, the BAW shall be notified of the reduction factors that have been determined.

(6) The partial safety factor $\gamma_{M,warp}$ shall be derived from the tensile tests conducted to determine the reduction factor f_1 (100 % value, see Annex 1 – re 3.2(3)). The partial safety factors in weft direction and at the joints are determined in a similar manner. The lower limiting values $\gamma_{M,warp} = \gamma_{M,weft} = 1.1$ and $\gamma_{M,joint} = 1.25$ shall apply. Lower partial safety factors are not permitted. The values $\gamma_{M,warp} = \gamma_{M,joint} = 1.1$ and $\gamma_{M,joint} = 2.0$ may be assumed for preliminary design purposes, see Annex 1.

3.4 Verification of rubber membranes in the ultimate limit state

(1) In the ultimate limit state it shall be verified that:

$$E_{\mathrm{d},i} \leq R_{\mathrm{d},i} \tag{3-7}$$

where

$E_{\mathrm{d},i}$ are the design values of the effects of the actions, in accordance with section 3.2,

$R_{\mathrm{d},i}$ are the design resistances (tensile strength), in accordance with section 3.3.

4 Verification of the clamping system

(1) The clamping system shall be verified in consultation with the BAW.

(2) Pull-out tests shall be performed to verify that it is not possible to pull the rubber membrane out of the clamping system. The width-related test force is as follows:

$$E_{\mathrm{d,cl}} = \gamma_{\mathrm{cl,test}} \cdot \gamma_{\mathrm{F}} \cdot T_{\mathrm{k}} \tag{4-1}$$

where

$E_{\mathrm{d,cl}}$ is the width-related test force for the pull-out test

$\gamma_{\mathrm{cl,test}}$ is the partial safety factor for testing the resistance to being pulled out of the clamping system, with $\gamma_{\mathrm{cl,test}} = 1.25$,

γ_{F} is the partial safety factor for actions, see 3.2(2),

T_{k} is the characteristic width-related membrane force in the continuous section (mid-span).

(3) The design shall ensure that the required contact pressure is maintained in the long-term.

(4) The clamping lines and bolts shall be designed to (DIN EN 1993-1-1). Information on modelling can be found in Gabrys (2007).

(5) The anchorage of the bolts in the solid structure shall be verified in accordance with (DIN EN 1992-1-1) and (DIN 19702).

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Annexes

Annex 1: Explanatory remarks on the specifications and provisions given in the Code of Practice

Re 1 Preliminary remarks and scope

Re (1):
Verifications are performed on the basis of current standards and codes, taking into consideration the provisions and information given in this Code of Practice. The design principles are based on the application rules given in (DIN EN 1990).

Re (6):
The life span is in accordance with design working life category no. 3 in (DIN EN 1990) Table 2.1 and was derived from the Japanese guidelines (Ministry of Land, Infrastructure and Transport, River Bureau 2000).

Re 3 Verification of rubber membranes

Re 3.1 Basic principles

Re (1):
It is not possible to form joints without overlapping in the weft direction if only one fabric layer is used. Joints must be stepped, without intermediate fabric (reinforcement). For further information see (DIN 22102-3) Figures 5, 7 and ff.

Re (2):
Rubber membranes are composite materials comprising several reinforcement layers of synthetic fabric with elastomer coatings on the outside.

Re (4):
Rubber membranes are composed of vulcanised or non-vulcanised sheets that are produced in a continuous process and subsequently assembled. The production width of the sheets is limited by the fabric or by the presses. The reinforcement (fabric layers) is partially interrupted at the joints and the loads are transmitted in the weft direction by overlapping the fabric. The joints have a lower tensile strength.

Ideally, the corner at SCF_2 should be located in the centre of a sheet of fabric manufactured in the continuous production process, see Figure 3.

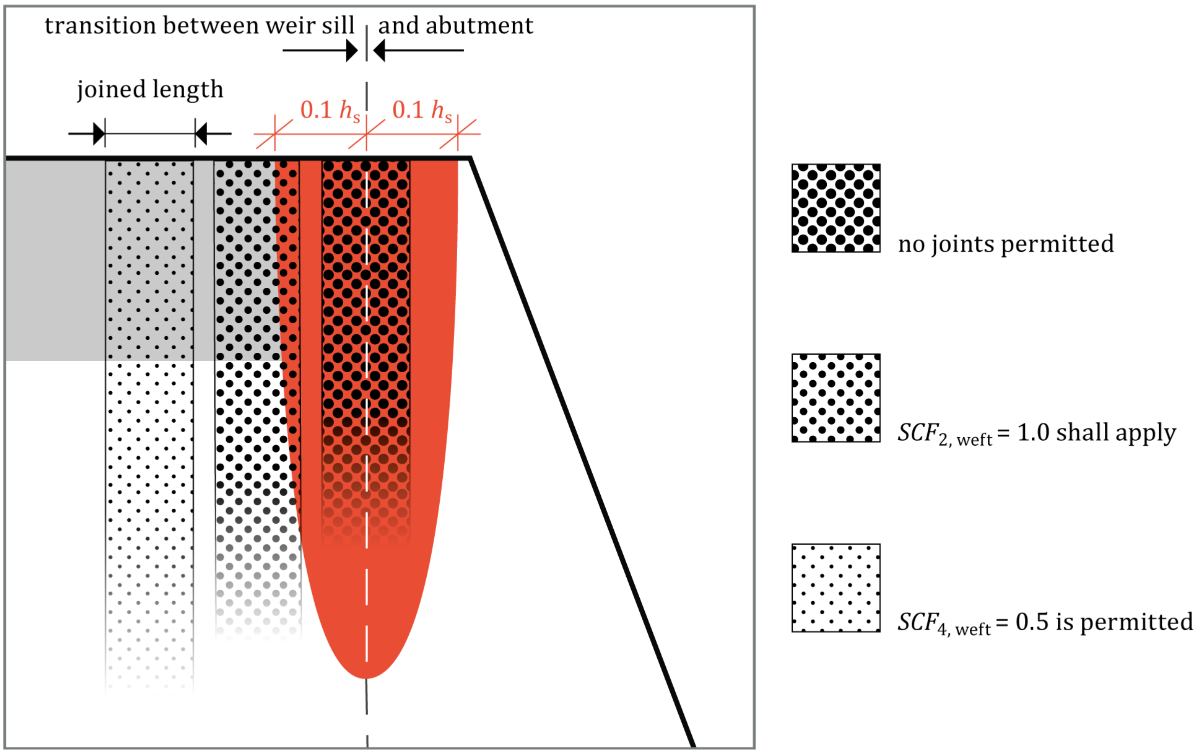

Figure 3: Sketch of section of the cutting plan (Figure 1) with information on SCF in the weft direction for the joint

Re (5):
The inner surface of the membrane and the weir sill can only be inspected after the membrane has been dismantled. In this connection, the appropriate production quality must be ensured.

Re (6):
Vibrations of the membrane in a deflated condition can be prevented by emptying the rubber gates completely and allowing the rubber membrane to lie flat on the weir sill (e. g. stepped weir sill). Jambor sills have been shown to be beneficial as the rubber membrane is held in place by the hydrodynamic pressure. Discontinuities in the direction of flow cause flow separation and increase the risk of vibrations. Lowering the clamping lines and small bending radii achieved by using flexible rubber membranes are therefore beneficial. Vibrations during overtopping can be avoided by installing breakers on the rubber membrane, see (Bundesanstalt für Wasserbau, 2007). These also form a discontinuity but are unavoidable.

Re 3.2 Design values of loads on membranes

Re (1):

Partial safety factors for the actions

Owing to the nonlinear behaviour of the rubber membrane, the effects are generally not proportional to the actions. The simplified rules specified in (DIN EN 1990) 6.3.2(4) may therefore be applied. Accordingly, it may be assumed that the relationship is disproportionately low so that the partial safety factor γ_F can be applied to the effects due to the representative action.

The partial safety factor is not reduced owing to the relatively short life span of the rubber membranes.

Stress concentration factor

The stress concentration factors SCF_i are obtained by dividing the maximum width-related forces relevant for the design at the points i by the membrane force T_k at mid-span.

The stress concentration factor depends on:

a) the materials used (combination of materials, type of weave of the fabric),

b) the direction (warp and weft),

c) the geometry of the clamping system,

d) and which section of the rubber membrane is being investigated (clamping section, corner section, fold section, …).

A stress concentration factor does not need to be determined if the characteristic stresses $\sigma_{Ek,i}$ relevant for design are derived from numerical models.

Design situations

The design situations to be taken into consideration include the design upstream water level (persistent) and the pressure test (transient). The pressure test may be relevant for design owing to the 5% increase in the internal pressure in the ultimate limit state ($\alpha = 1.65$ based on the design upstream water level) during revision. However, based on (DIN 19704-1), a lower partial factor γ_F of 1.25 may be taken for the internal pressure in transient design situations.

Re (2):
Examples of internal pressure limits are a spillway wall in the control shaft or a control system open at the top in open systems.

Re (3):
The stresses relevant for design purposes can be determined from numerics by using numerical models and programs which take account of non-linearities in the materials and geometry and the application of a specific water pressure, including in the final position of the rubber membrane.

Re (4):

The information given in Table 1 applies under the following material-related and geometrical boundary conditions:

a) width-related membrane stiffness: ≤ 6000 N/mm
(determined in tensile tests in accordance with (DIN EN ISO 283)

b) compressive stiffness of the elastomer: ≤ 12 N/mm^2 at -20°C

c) thickness of cover layer: ≤ 7 mm

d) inclination of abutment ≤ 75°

e) The stress concentration factors SCF_2 of 3.0 in the warp direction and 1.0 in the weft direction were determined for a stiffness ratio between the warp and weft directions of 20:1. These values are based on experience at the BAW. The stress concentration factors SCF_2 have to be increased if the stiffness ratios are lower.

f) The stress concentration factor SCF_1 was derived from a bending radius on the lower side of the clamping line of 5 mm for h_s ≤ 3.5 mm and 8 mm for h_s ≤ 4.6 m.

g) An eccentricity e of the fabric layer within the membrane cross-section of 0.18 d_s for gate heights h_s ≤ 3.5 mm and 0.10 d_s for gate heights h_s ≤ 4.6 mm was taken into consideration when determining the values of SCF_i.

The following applies to boundary conditions a) to d):
Values lower than those given above would result in lower values of SCF_i. To err on the safe side, the values given in Table 1 shall be used. Values higher than those given above will result in higher values of SCF_i so that a numerical calculation will be required. Interpolation and extrapolation are not permitted.

Re (5):
A derivation of the width-related membrane force and related information are given in (Gebhardt 2006). The definitions of h_i, h_o and h_s are given in Figure 2.

Re 3.3 Design load-bearing capacity of membranes

Re (1):
Overall reduction factor

The overall reduction factor ξ does not take any safety factors into account but is a product of individual reduction factors. According to (Stommel et al. 2011), reduction factors take account of the influence of certain technological boundary conditions that result in a reduction in strength, such as temperature, creep resistance, etc. By contrast, (partial) safety factors are used to evaluate the risk of failure.

In brief: The overall reduction factor ensures that the material properties at the end of the design life continue to fulfil the requirements of the ultimate limit state design.

Resistance

The resistance R_k is a nominal value expressing a minimum tensile strength that is guaranteed by the manufacturer. This minimum tensile strength must be confirmed by test certificates. The tensile strength of the rubber membrane, given either as a lower value X_k (5 % - quantile) or as a nominal value, is introduced as the characteristic member resistance R_k.

The approach by which the loss of tensile force at the joints is considered can be used for joints without intermediate fabric reinforcement in accordance with (DIN 22102-3) if the appropriate requirements are fulfilled. The reduction in tensile strength depends on the separated fabric layers at the joints.

Re (2):
The reduction factors are derived, for a preliminary design, from (Ministry of Land, Infrastructure and Transport, River Bureau 2000) and apply to a design life of 30 years. Modification of the two factors is obligatory if the design life is longer and optional if the design life is shorter. It must be taken into consideration that the relationship between them is non-linear. Linear interpolation is therefore not permitted, see Re 3.2(3) and (4).

The reduction factors are combined as follows to form the overall reduction factor:

$$\xi = \frac{1}{f_1} \cdot \frac{1}{f_2} = \frac{1}{1.95} \cdot \frac{1}{1.55} = 0.51 \cdot 0.65 = 0.33 \tag{A-1}$$

Re (3):
f_1: Creep resistance

Definition of creep resistance: When exposed to long-term loads, plastics exhibit permanent deformations and damage and subsequently fail before the strengths determined in the accelerated test are reached (Ehrenstein 2002, p. 20).

In accordance with (Erhard 2008), the test can be performed as described in (DIN EN ISO 899-1).

A load/time-failure diagram is drawn up here instead of the creep diagram typical of classic creep tests. In this case, the relative resistance to long-term actions $R_{\mathrm{rel.t},i}$ is plotted over time. It is determined for various load levels using the following equation:

$$R_{\mathrm{rel.t},i} = \frac{R_{\mathrm{k},t_i}}{R_{\mathrm{k,t_0}}} \tag{A-2}$$

where

$R_{\mathrm{rel.t},i}$	is the relative resistance to long-term actions in terms of fatigue strength,
$R_{\mathrm{k,t}_i}$	is the tensile strength at time t_i,
$R_{\mathrm{k,t_0}}$	is the tensile strength during the accelerated test with $t = 0$.

At first, a statistically validated number of accelerated tensile tests are performed (at least 10 samples in the warp direction in accordance with Annex D of (DIN EN 1990)) to obtain the tensile strength $R_{\mathrm{k,t_0}}$ (100 %-value) at time $t = 0$. Specimens are subsequently subjected to different load levels $R_{\mathrm{k,t}_i}$ (between around 70 % and 95 % of the tensile strength during the accelerated test) and the time t_i to failure is measured. All results are plotted on a double-log diagram and connected by drawing a line of best fit. To err on the safe side, a lower limit obtained by parallel and downward displacement of the line (envelope) is used. The test results must all be above the resulting line. The value f_1 of the creep resistance can be determined by extrapolation of the lower limit in relation to the design life span of the rubber membrane, see Figure 4.

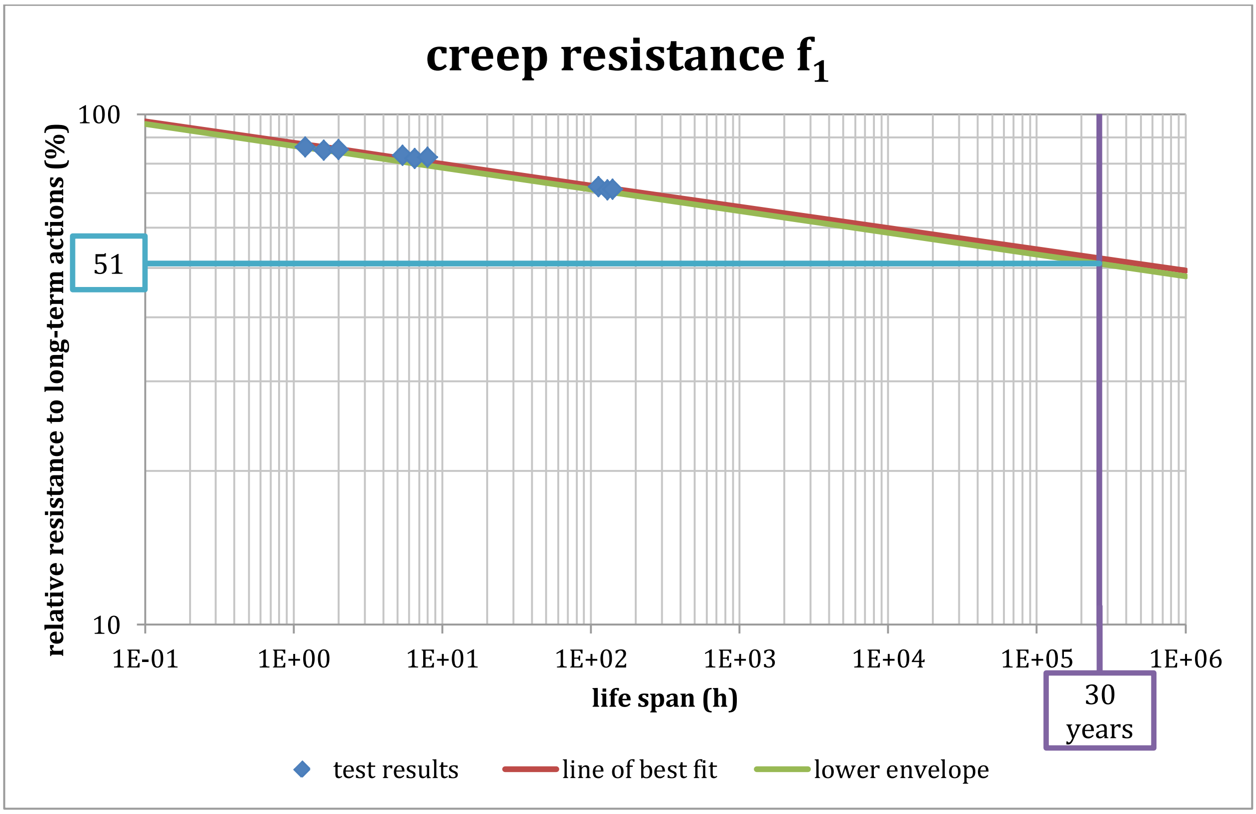

Figure 4: Example of determining the reduction factor f_1 of the creep resistance over a 30-year period

Example: $f_1 = \frac{1}{0.51} = 1.95$

Re (4):
f_2: Consideration of ageing

Definition of ageing: The term 'ageing' is taken to mean all irreversible intra- and intermolecular changes to high-polymer materials owing to environmental influences. Ageing can be caused by thermal, mechanical, dynamic and chemical energy as well as by light and radiation, see (Erhard 2008, p. 139).

Reserve samples of materials are set aside for the test during installation of the rubber membrane and stored in situ under the same environmental conditions. A rubber membrane sample is exposed to the sun (UV radiation) while another sample is stored in water. Test specimens are cut out of the reserve samples at regular intervals (~5 years) and subjected to tensile testing. This enables the tensile strengths $R_{\mathrm{k,A}_i}$ after A years to be determined. These strengths are compared with the tensile strength $R_{\mathrm{k,t_0}}$ (100 % value) at the time of installation ($t = 0$). The relative resistance to long-term actions $R_{\mathrm{rel.A},i}$ is therefore obtained as follows:

$$R_{\mathrm{rel.A},i} = \frac{R_{\mathrm{k,A}_i}}{R_{\mathrm{k,t_0}}} \tag{A-3}$$

where

$R_{\mathrm{rel.A},i}$ is the age-related relative resistance to long-term actions,

$R_{\mathrm{k,A}_i}$ is the tensile strength at time A_i,

$R_{\mathrm{k,t}_0}$ is the tensile strength in the accelerated test, $t = 0$.

The assumption for the reduction factor for ageing with time (in years) can be checked by extrapolating below the test results. It may be necessary to replace the rubber membrane prematurely or it may be possible to use it for a longer period of time. An example of plotting is shown in the graph in Figure 5.

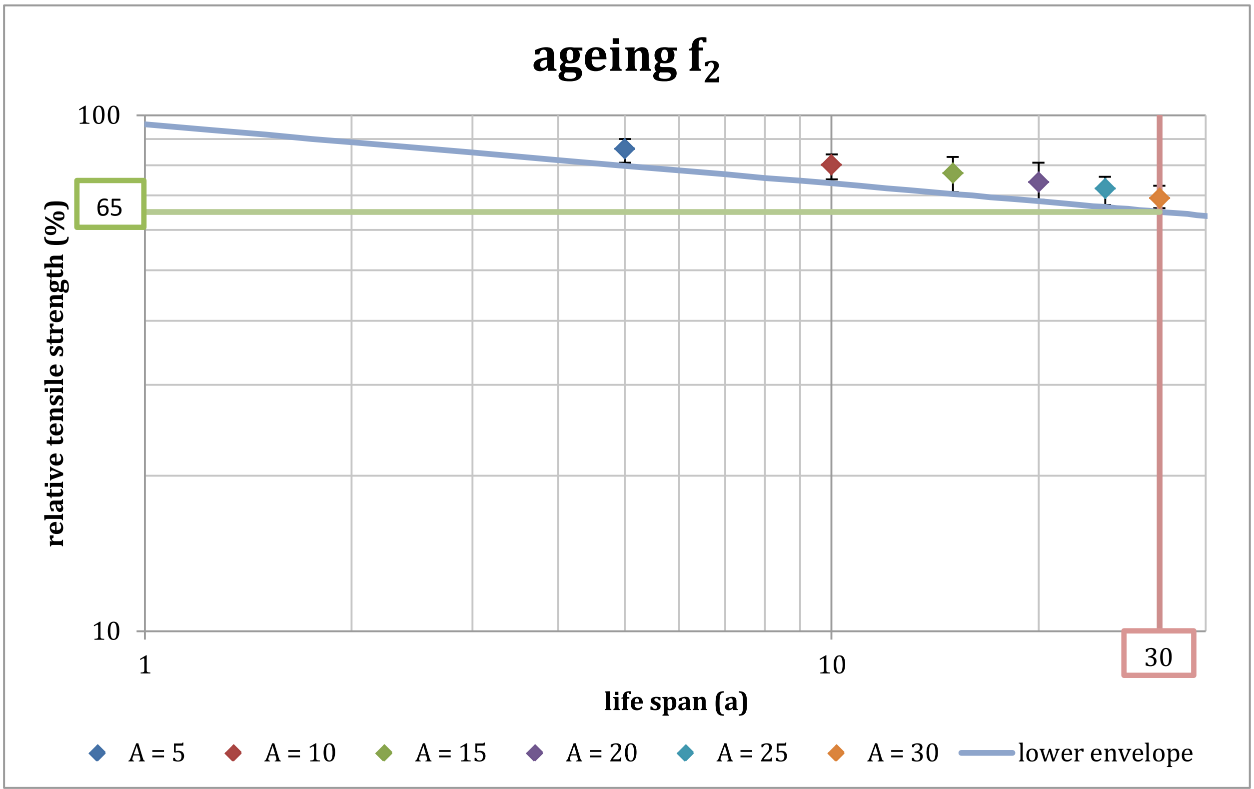

Figure 5: Example of determining the reduction factor f_2 for ageing over a 30-year period

Example: $f_2 = \frac{1}{0.65} = 1.55$

Re (6): The values given for γ_{M} and $\gamma_{\mathrm{M,joint}}$ for the preliminary design are obtained on the basis of the both of the following points:

a) It was not possible to derive a partial safety factor γ_{M} greater than 1.1 for the tensile tests conducted hitherto by the BAW on specimens of rubber gate membranes without joints.

b) A partial safety factor $\gamma_{\mathrm{M,joint}}$ of 2.0 shall be taken for the strength of joints between manually produced fibre composite materials in accordance with the specifications set out by the (Bau-Überwachungsverein e.V. 2010).

In order to derive the material-related partial safety factors for the rubber membrane concerned, reference should be made to (DIN EN 1990) and the explanations in Beton-Kalender 2013 (Ahrens et al. 2013).

Re 3.4 Verification of rubber membranes in the ultimate limit state

Re (1):
The STR verification format (see (DIN EN 1990)) shall be used to verify the load-bearing capacity of rubber membranes as failure of the membrane material in the ultimate limit state must be ruled out. The required "reliability" in the ultimate limit state is achieved if the requirements for the entire rubber membrane in the warp and weft directions and at the joints are fulfilled.

Re 4 Verification of the clamping system

Re (2):
Care shall be taken to ensure that the membrane forces are transmitted to the clamping lines by adhesion only. The rubber membrane must not be subjected to bearing stresses.

Re (3):
Owing to its creep characteristics, the elastomer will possibly want to escape the load.