CONCRETE
MORE THAN 100 YEARS OF DURABILITY

FROM Sika®-1 TO Sika® ViscoCrete®

BUILDING TRUST

BENEFIT OF OUR SOLUTION

Founded by Kaspar Winkler in 1910, the name Sika today stands for waterproof and durable solutions. Beginning with rendering mortar, used for the first time in the waterproofing of the old Gotthard Railway Tunnel, and extending to entire waterproofing systems for a wide number of applications, which also currently includes the Gotthard Base Tunnel, the longest high-speed railway tunnel in the world, Sika products contribute to building success. To seal durably against penetrating water, while in other instances to protect precious water and prevent its leakage; two sides of a comprehensive challenge present complex interfaces. Concrete has shaped Sika's development sustainably, and since 1910 Sika has made a notable contribution to the development of concrete as a durable building material!

CONTENT

CONCRETE TECHNOLOGY GUIDELINE

CONCRETE IS THE CONSTRUCTION MATERIAL OF THE CENTURY and it plays a crucial role in all our building and infrastructure requirements. In today's world, the use of concrete is universal and building without it would be unimaginable.

Concrete is a very durable material when properly formulated, quality controlled, professionally placed and cured. It is then capable of withstanding a majority of the demands placed upon it. Concrete building and infrastructure are exposed to a very wide range of stresses and strains. It starts at a very early stage with the cement hydration in the environmental conditions and continues throughout the life span of the structure. Forces, loads, thermal effects, water, contamination, erosion, traffic, abrasion, vibration, fatigue and impact all place huge demand on the concrete's ability to last. To resist all these factors water reducing admixtures play a significant role.

Durable concrete stands first and foremost for strength. "The stronger and more dense the concrete, the greater the resistance to outside attack". Strength for durable concrete is often expressed by the water to cement ratio (w/c) and high strengths can only be achieved with low water content. A low water content and modified binder composition are therefore the two most critical factors for a better durable and higher performance concrete.

Water reduction and porosity
Modern concrete admixtures can reduce water demand in fresh concrete by 40% without changing the workability. As a result, the pore quantity in the cement paste can be reduced by 75% by adding a superplasticizer.

Effect on water reduction on concrete quality

Calculation of water content (needed & surplus amount of water)

Mix 1: Initial mix design

Cement content	320	kg/m^2
Reference no water reduction	0%	
Water content 192 liter	0.60	w/c-ratio
Pore quantity (based on the concrete volume)	7.0%	
Pore quantity (based on the cement stone)	24.0%	

Mix 2: Optimized water content

Cement content	320	kg/m^2
Water reduction by using a WR/HRWR	28%	
Water content 138 liter	0.43	w/c-ratio
Pore quantity (based on the concrete volume)	1.7%	
Pore quantity (based on the cement stone)	6.9%	

Figure 1: Effect of water reduction on pore quantity

Water reduction limits in practice

When considering low water content to increase strength and durability, the performance requirements must be balanced with workability requirements. It is important to remember that the method of placement, and especially the quality of the aggregates, has a huge influence when utilizing the water reduction potential to the full.

Effect of minimum water demand for different binder contents

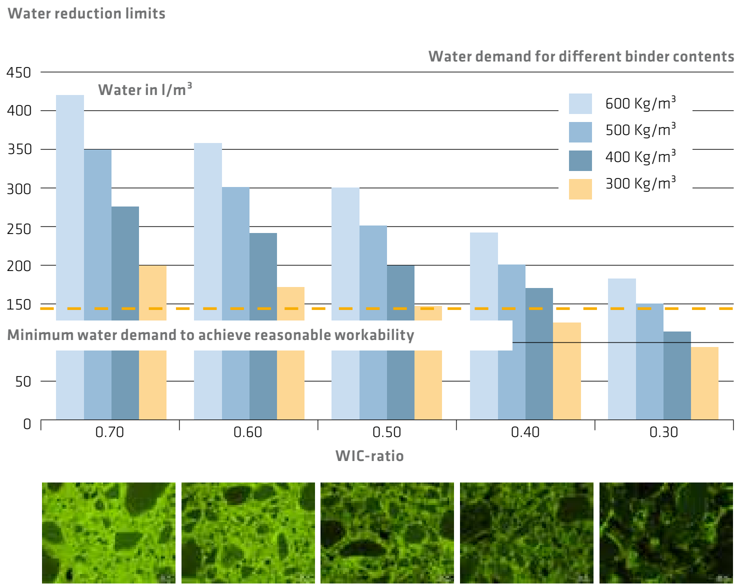


Figure 2: The water reduction potential to increase durability must be compatible with the placing practicalities

Durability and Workability

The influence of water reducers on durability and workability can never be under estimated. A durable concrete means a low water to binder ratio combined with specially selected constituent materials in the right quantity adjusted according to the environmental, ambient conditions and performance requirements. This must be balanced with the method of application and workability time which can only be achieved with the right admixture.

Water / Cement ratio determination

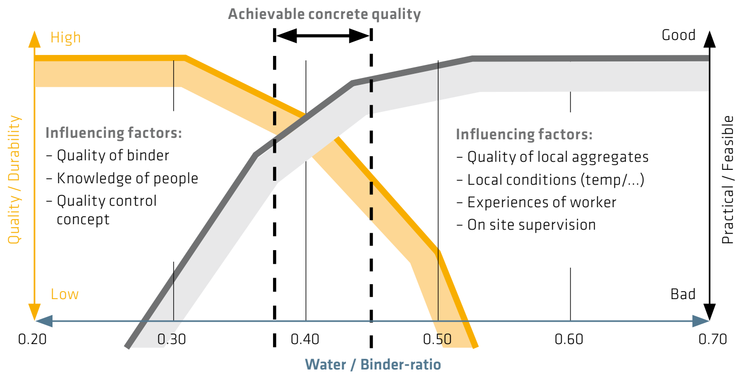


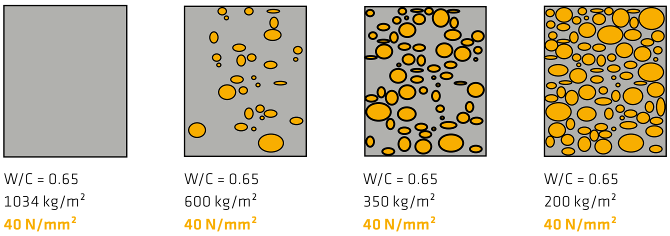
Figure 3: Achievable concrete quality

CONCRETE TECHNOLOGY GUIDELINE

Volume paste optimization to achieve concrete durability
Concrete is a mixture of paste and aggregates. The paste is composed of the binder and water. The paste coats the surface of the aggregates and through a chemical reaction called hydration; the paste hardens and gains strength. In some cases the binder is increased in the attempt to increase performances. In fact this process inevitably increases the cement paste volume, decreases the filler (aggregate) volume and has little influence on the strength. It is often more expedient to adapt the paste volume by reducing the water content. In doing so, this method is more effective in increasing strength and durability.
To produce a durable concrete care should be taken to select the right materials in the right proportions suitable for producing and placing. Mix design guidance is an efficient tool to start the durability process.

Effect of water content and cement quantity on concrete properties:

But concrete with different **paste volume but same paste quality** we will have "same" mechanical strengths



Concrete with **different paste quality** will have different mechanical strengths

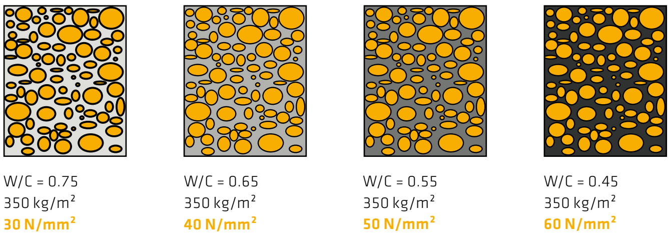


Figure 4: Visualization of cement paste according to cement content and w/c-ratio

Complex relationship between water content, fine content and workability

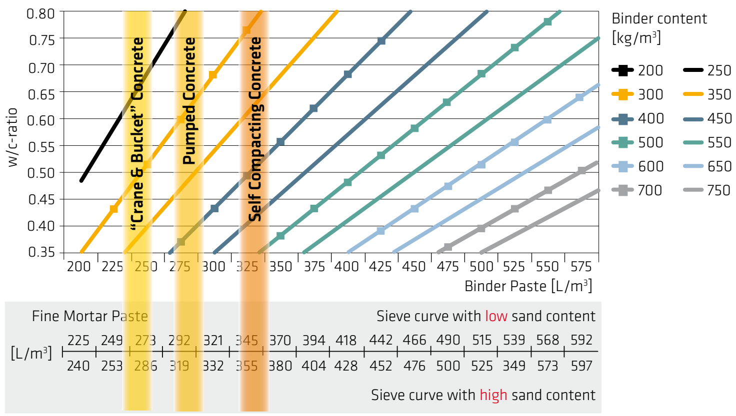


Figure 5: Relation between concrete compressive strengths of a specific cement, expressed in w/c-ratio, and the fine mortar quantity (L/m³) for a required cement content (kg/m³)

Minimizing chloride migration

Concrete is often exposed to water and within water there can contain some aggressive contaminants. Concrete, generally, has low resistance to aggressive chemical attack in the form of leaching, carbonation, chlorides and sulfates. These pollutants penetrate the concrete by many different transport mechanisms including diffusion, capillary suction, permeability, convection or electro-migration and react with the cement paste or corrode reinforcement. Reducing the water content and modifying the binder will increase the permeability and improve the chemical resistance.

Effect of water content on chloride migration

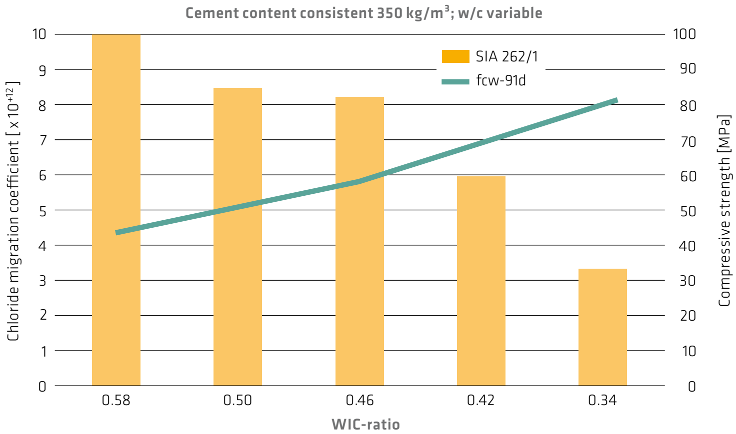


Figure 6: Concrete tests according to SIA 262/1 Annex B (similar to NT BUILD 492)

Nowadays, pure Portland cement has almost ceased to be used alone for durable requirements. Instead, the resistance of the cement binder to external attack is greatly increased by the use of specially selected additives (e.g. fly ash and slags) and performance enhancing admixtures (e.g. water reducers). The binder to the water content is a very important factor and is known as the water binder ratio (w/b ratio).

Effect of ground-granulated blast-furnace slag (GGBFS) on chloride migration

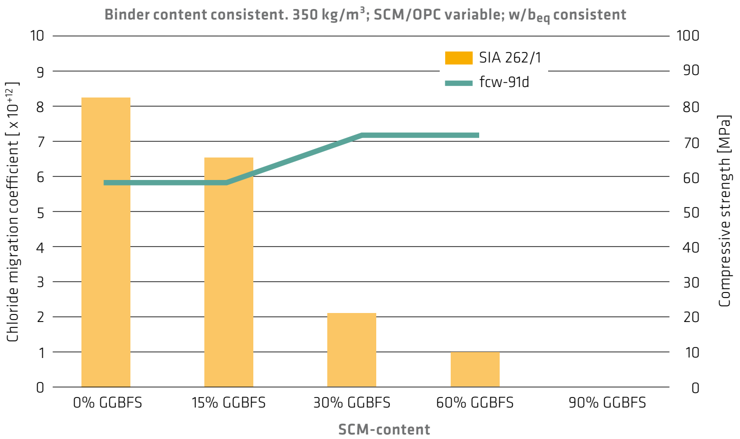


Figure 7: Concrete tests according to SIA 262/1 Annex B (similar to NT BUILD 492)

WATERPROOF CONCRETE STRUCTURES

DESIGN AND CONSTRUCTION OF A WATERTIGHT CONCRETE STRUCTURE is a system approach. The water-impermeability of a construction is determined by fulfillment of the decisive requirements regarding limitation of water permeability through the concrete, the joints, installation parts as well as cracks. Long lasting, durable watertight constructions are achieved by application of a well defined, engineered system. All involved parties have to closely interact in order to minimize the probability of mistakes.

Sika Waterbars are flexible preformed PVC waterstops for the water-proofing of both movement and construction joints which can be sub-jected to low and high water pressure.

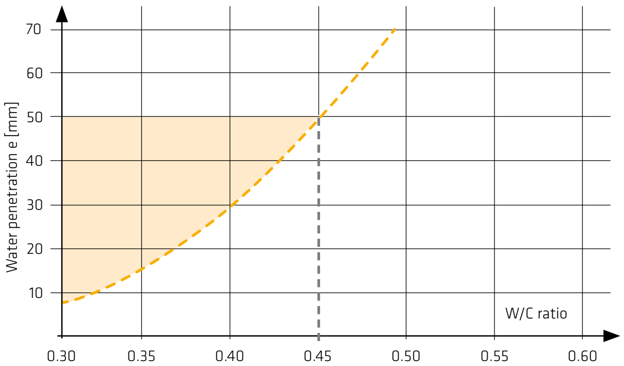
CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula	
Aggregates	Any quality aggregates possible	All aggregate sizes are possible	
Cement	Any cement meeting local standards	Target cement paste volume as low as possible for the respective placing method	350 kg/m^3
Powder additives	Fly ash, ground granulated blast furnace slag	Sufficient fines content by adjustment of the binder content	
Water content	Fresh water and recycling water with requirements regarding fines content	Water/cement ratio according to standards with regard to exposition	≤ 0.45
Concrete admixtures	Superplasticizer Type dependent on placement and early strength requirements Waterproofing agent	Sika® ViscoCrete® or SikaPlast® or Sikament® Sika® WT	0.60 – 1.50% 1.50%
Installation requirements	 Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces. Sika Antisol®	
Joint sealing	Sealing of movement joints, penetrations and construction damage	Sika® Waterbars Sikadur® Combiflex® Sika® Injectoflex System SikaSwell®	
Waterproofing systems	Flexible Waterproofing membrane systems, if required with single or double compartment	Sikaplan®/SikaProof®	

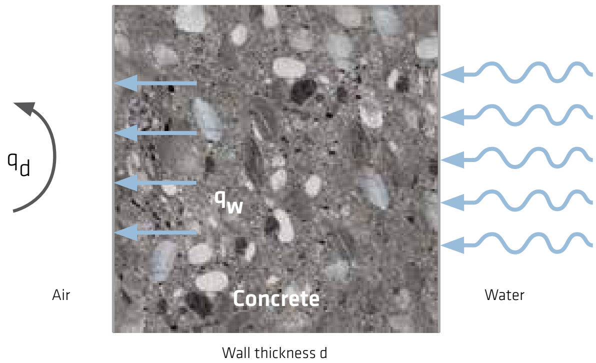
Referencing Standards, publications
- DIN 1045: Tragwerke aus Beton, Stahlbeton und Spannbeton, Beuth-Verlag, Berlin
- DIN EN 206: Tragwerke aus Beton, Stahlbeton und Spannbeton, Teil 1: Beton – Festlegung, Eigenschaften, Herstellung und Konformität (2001-07), Beuth-Verlag, Berlin
- DAfStb Heft 555 «Erläuterungen zur DAfStb-Richtlinie Wasserundurchlässige Bauwerke aus Beton»
- US Army Corps of Engineers (USACE) CRD- C48-73 "Permeability of Concrete"
- British Standard BS 1881 Part 122

Impermeability of concrete against water is determined by the impermeability of the binder matrix, i.e. capillary porosity. Decisive factors for the capillary porosity are the water/binder ratio as well as the content and type of pozzolanic or latent hydraulic materials. A powerful superplasticizer is used to lower the water/binder ratio. This in turn decreases the volume of capillary pores within the concrete matrix, while lending the concrete high workability. These pores are the potential migratory paths for water through the concrete. The choice of superplasticizer is important to aid the contractor on site in concrete placement. Issues such as high consistency class, retention of consistence, high early strength and good surface finish may be influencing factors. A water resisting admixture reacts with the calcium ions in the cement paste to produce a hydrophobic layer within the capillary pores. This consequently blocks the pores and provides effective protection even at 10 bar (100 meters head of water). On arrival at site the concrete can be pumped or handled in conventional ways. The concrete should be placed, compacted and cured in accordance with good concrete practice.
The correct system for jointing (movement joints, construction joints) is the key to achieving a watertight structure. Concrete pour sequences and bay sizes need to be considered in order to reduce the risk of plastic shrinkage cracking. As a guide, an aspect ratio not exceeding 3:1 is suggested for wall pours in particular. This means that construction joints will almost inevitably be required within the structure.
Correct design of any joints is essential on the one hand. On the other hand proper and careful installation of the jointing system is decisive for achieving water tightness of constructions. If watertight concrete leaks, then most often this is due to poor joint construction. In addition other details such as tie bar holes and service entries need to be considered.
Depending on the level of protection against water, i.e. outside water pressure as well as intended utilization of the construction, different joint systems are available. Non-movement joints are usually sealed using hydrophilic strips which come in various shapes and sizes and swell on contact with water. The strips often have a protective surface coating to reduce the risk of premature swelling should, for example, rainfall occur prior to casting the concrete.
Where a structure requires a higher level of protection, more advanced joint systems are available which may offer a combination of hydrophilic elements built into a resin injected hose. This provides an excellent secondary line of defense.
Where movement joints are necessary, these can be sealed using hypalon strips secured internally or externally using specialist epoxy adhesives, or traditional PVC water bars.

Water absorption of concrete under pressure measures the maximum water penetration in mm after a defined time with a specified pressure. (24 hours with 5 bar according EN12390-8)



Water penetration under hydrostatic pressure. The water permeability limit for water tightness is defined as a maximum water penetration into the concrete under a specific pressure over a defined period.



Immersion and permanent water contact. The water permeability limit for water tightness is defined as g/m² x hours, where water permeability is smaller than vaporizable volume of water without pressure over a defined period.

CORROSION RESISTANT CONCRETE

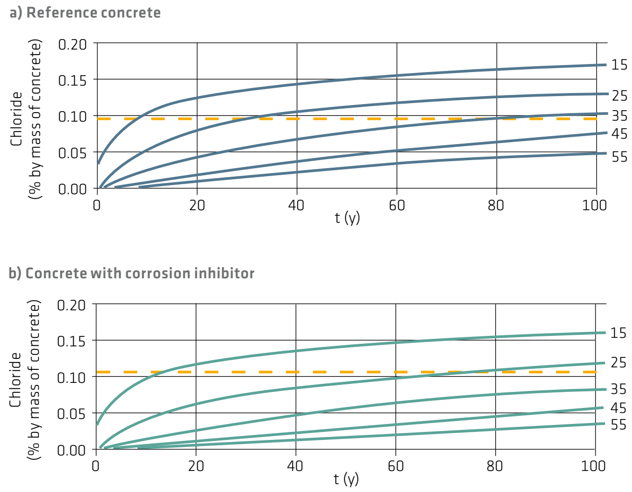
CONCRETE IS AN INGENIOUS BUILDING MATERIAL, also because in combination with reinforcing steel it exhibits tremendous load-bearing capacity. The combination of steel in concrete has the advantage that under normal conditions the high pH value of concrete creates a passivating layer of iron hydroxides on the steel surface which protects it from corrosion. Particularly steel, however, can be compromised in its durability of performance by the presence of moisture and salt. Projects in coastal locations in agressive soil conditions or in areas where de-icing agents are used must be permanently protected against the consequences of steel corrosion.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

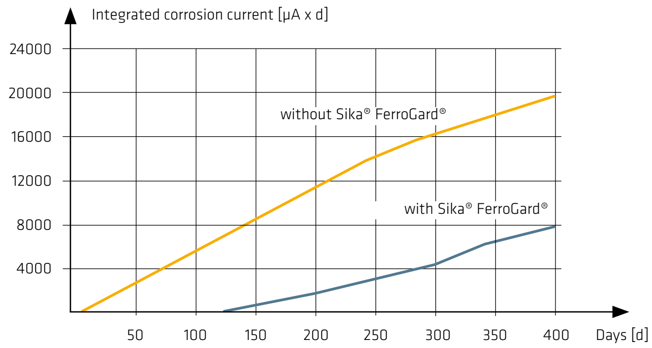
Components	Description	Example formula	
Aggregates	Any quality aggregates possible	All aggregate sizes are possible	
Cement	Any cement meeting local standards	Cement replacement UP to > 60% by GGBFS, SF and/or FA	
Powder additives	Fly ash, ground granulated blast furnace slag, silica fume, natural pozzolanes		
Water content	Fresh water and recycling water with requirements regarding fines content	Water/cement ratio according to standards with regard to exposition	< 0.45
Concrete admixtures	Superplasticizer, type dependent on placement and early strength requirements Corrosion inhibitor	Sika® ViscoCrete® or SikaPlast® or Sikament® Sika® CNI Sika® FerroGard®-901	0.60 – 1.50% 13 – 40 kg/m² 10 – 12 kg/m²
Installation requirements	Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces. Sika Antisol®	
Protective system	Surface protection against ingress of chlorides, CO_2 and water	Sika offers a wide range of rigid and flexible solutions to prevent the penetration of water Sika Solution: Sikagard®	

Referencing Standards, publications
- ASTM C1202 – Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
- ACI 222 – Protection of Metals in Concrete Against Corrosion
- ASTM C1582 / C1582M – Standard Specification for Admixtures to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete
  "Corrosion Costs and Preventive Strategies in the United States" PUBLICATION NO. FHWA-RD-01-156;
  Authors Gerhardus H. Koch, Michiel P.H. Brongers, and Neil G. Thompson, CC Technologies Laboratories, Inc., Dublin, Ohio Y. Paul Virmani U.S. Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, Virginia J.H. Payer Case Western Reserve University, Cleveland, Ohio
- WT Build 492 – Chloride migration coefficient for: Concrete, Mortar and cement

Standard construction practices ensure that corrosion of steel reinforcements is limited. These practices include observance of minimum concrete quality (water/binder ratio, cement content, minimum strength) and minimum concrete cover of rebars. However, in many cases, especially in environments with high levels of chlorides (de-icing salts, contaminated grounds seawater or even contaminated concrete mix components), these basic protection procedures prove insufficient.
In order to prevent corrosion or delay its start and thereby extend the life of a structure, four additional steps can be taken to protect the steel from corrosion: increase concrete quality, utilize corrosion inhibitors increase concrete cover and application of protective coatings.
Increasing concrete quality means reduction of the number and size of capillary pores. This increases the density in the concrete matrix and as a result hinders the transport of chlorides or CO_2 into the concrete. Reduction of the water/cement ratio through application of high range water reducers and use of supplementary cementitious materials like fly ash or silica fume or natural pozzolans represent opportunities in concrete technology to better the mix design.
When choosing improved concrete quality to protect against corrosion, extra attention must be given to proper placement, curing of concrete and shrinkage potential of the concrete mix, as small cracks can allow chlorides or CO_2 to penetrate to the reinforcing steel regardless of the density of the concrete mix.
Corrosion inhibitors are added to the concrete mix during the batching process. Inhibitors do not significantly influence the density of concrete or impact the ingress of chlorides or CO_2, but act directly on the corrosion process. Corrosion inhibitors are defined in a number of ways. On one hand either as an admixture which will extend the time before corrosion initiates, or as one which reduces the corrosion rate of the embedded steel, or both, in concrete containing chlorides.
By another definition a corrosion inhibitor must reduce the corrosion rate and the corroded area of rebars in concrete containing chlorides.
The main products used as corrosion inhibitors today are either calcium nitrite based products or aminoester organic corrosion inhibitors.
Protective coatings are used to reduce the ingress of chlorides or carbon dioxide. Coatings can be applied according to two basic options, either to the surface of the concrete or to the steel rebars themselves before they are embedded in the concrete.



Projected chloride content in the concrete over time for a) the reference concrete, and b) the concrete with the corrosion inhibiting admixture. Plotted for different cover depths 15, 25, 35, 45, and 55 mm as indicated by the numbers on the lines. The dashed blue lines represent the estimated chloride threshold values.



The Sika Research Department in Zurich tested the anticorrosive effect of Sika® FerroGard® on cracked concrete beams. The specimens were produced in accordance with ASTM G 109 and were cyclically treated with road salts. Periodic measurement of the corrosion current confirms the protective effect of Sika® FerroGard®.

Damage to concrete structure due to insufficient concrete cover and low concrete quality

FROST & FREEZE / THAW RESISTANT CONCRETE

DE-ICING SALT ATTACKS CONCRETE SURFACES, one of the most damaging strains for concrete structures, though underestimated for decades also due to the periodically extreme quantities of de-icing salt applied. Through appropriate structural technique and observance of basic technological measures pertinent to concrete, the building material can demonstrate permanently high resistance to frost and to the strain which de-icing salt represents.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

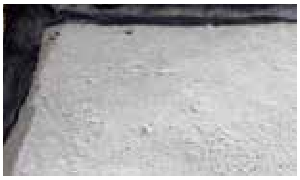
Components	Description	Example formula	
Aggregates	Any quality aggregates possible	All aggregate sizes are possible	
Cement	Any cement meeting local standards Pure Portland cement for highest resistance	Target cement paste volume as low as possible for the respective placing method	
Powder additives	For increased compactness	Sikafume®	up to max. 4%
Water content	Clean mixing water, free of fines	Water/cement ratio according to standards with regard to exposition	< 0.45
Concrete admixtures	Superplasticizer Dosing dependent on formula (superplasticizer and air entrainer must be adapted to each other)	Sika® ViscoCrete® or SikaPlast® or Sikament®	0.60 – 1.50%
	Air entrainer (mixing time approx. 90 sec.) Required quantity of air entrainer is highly dependent on cement and the fines portion in sand	Sika® Control Aer® dosing: Air void content with - max. particle diameter 32 mm - max. particle diameter 16 mm	0.10 – 0.80% approx. 3.0 – 5.0% approx. 4.0 – 6.0%
Installation requirements	Frost resistant concrete should only be transported in ready mix trucks, and should be mixed again thoroughly (approx. 30 sec./m^3) before unloading. Standard air void measurement should follow.	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces	
	Curing compound	Sika Antisol®	

Referencing Standards, publications

– Merkblatt für die Herstellung und Verarbeitung von Luftporenbeton, Forschungsgesellschaft für Straßen-und Verkehrswesen (FGSV) 2004
– ACI 306R – Cold Weather Concreting
– ACI 201.2R – Guide to Durable Concrete, Chapter 1 – Freezing and Thawing of Concrete
– ASTM C 457 – Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete
– ASTM C666 / C666M – Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

Especially in the areas of road and runway construction, but also for structures particularly burdened by exposure to spray and drizzle such as retaining walls, roadway galleries, bridges or the portals of tunnels, as well as on buildings themselves, extremely cold temperatures impose high strains on the concrete structure due to freezing water.
In the areas of concrete near to its surface, water is drawn into the concrete as a result of capillary action. If the water freezes, it increases its volume in the formation of ice by roughly 10%. This means that high pressure develops in these water-filled voids. Depending on the mechanical properties of concrete (transfer of tensile forces), this pressure can result in minimal changes in volume or in fine cracks in the concrete microstructure. An isolated occurrence of strain could be considered insignificant, but temperature fluctuations throughout a cool-weather season and over an extended number of years recur numberless times. Tiny cracks can thus lead to surface spalling, while the zone of attack shifts farther into the concrete until reinforcement zones are also eventually affected.
De-icing agents are very often employed to prevent ice formation on sidewalks or road surfaces. These agents effect rapid melting of ice on concrete surfaces, a process which extracts considerable heat from the concrete within a very short time period. This means that in areas of the concrete near the surface, the temperature plunges by more than 10°C within 1 – 2 minutes. The use of de-icing agents results in even greater stress peaks when the water freezes.
From the standpoint of concrete technology, this strain can be met with two primary measures, though each in itself is insufficient. On one hand, the water content of concrete with high resistance to frost and de-icing salt exposure should be kept as low as possible. This strongly reduces the amount of free water in the concrete structure. In addition, the residual water always present in concrete must be provided with space for expansion, so that upon freezing the increase in volume can be absorbed without generating internal stresses. These artificially introduced voids, created during the concrete manufacturing process with air entrainer, must be as fine, closed and spherical as possible, with a size of 0.02 – 0.3 mm in diameter. Voids of a size outside this range do not contribute to the frost resistance of the concrete. The quantity of voids introduced, measured by means of the air pressure meter test, is dependent on the quantity of cement paste (15 – 20% of the cement paste volume) and accounts in relation to the concrete for 4 – 6% of volume, measured before installation.

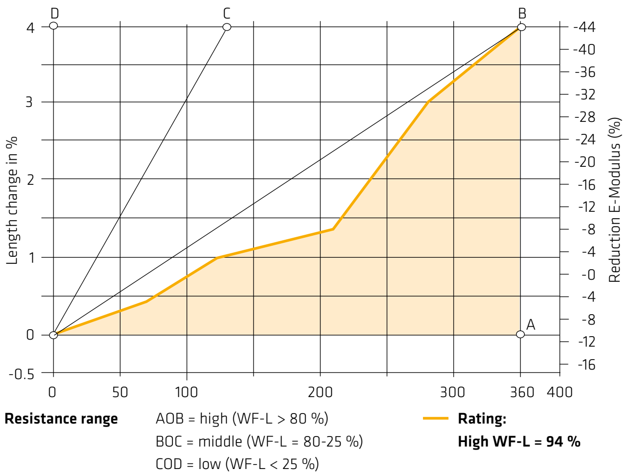
A widely employed method of testing concrete's frost and de-icing salt resistance consists of successive freezing and thawing in a water bath, with subsequent measurement of the difference in weight before and after the test.

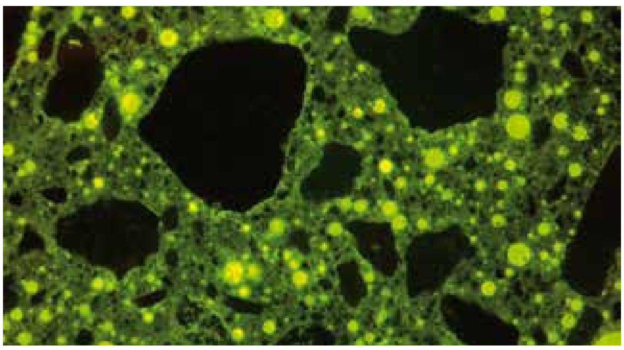


Practically no surface weathering

Very severe surface weathering

Scattered de-icing agent considerably intensifies the reaction upon freezing of water and leads to substantially greater damage in areas of concrete close to the surface.





Artificially introduced air voids, caused by an air entrainer, generate space for expansion in the concrete structure to allow for the roughly 10% increase in volume when water freezes to become ice.
In test BE II according to D-R 400, the test prisms are subject to alternating loads between +20°C and -20°C, the change in length is measured and judged between three ranges of durability (low / middle / high). Calculation according to ASTM C666.

SULFATE RESISTANT CONCRETE

PARTICULARLY IN UNDERGROUND CONSTRUCTION, concrete structures are exposed alongside loads and wear of decade-long use to influences emerging from the subgrade such as permanent mechanical stresses and aggressive water. Concrete is nevertheless characterized by its outstanding durability. Solutions containing sulfates, such as in natural or polluted groundwater, represent a considerable deteriorating impact on concrete. This can eventually lead to loss of strength, expansion, spalling of surface layers and ultimately to disintegration.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula	
Aggregates	Any quality aggregates possible	All aggregate sizes are possible	
Cement	Compliance with EN 206 with moderate to high sulfate resistance ASTM C-150 sulfate resistant cements	Target cement paste volume as low as possible for the respective placing method	
Powder additives	Fly ash, ground granulated blast furnace slag, silica fume, natural pozzolanes	Sikafume®	4.0 – 8.0%
Water content	Compliance with EN 206, depending on exposition class Compliance with ASTM, depending on exposure class	Water/cement ratio XA1 XA2 XA3 Moderate Typ 2 Severe Typ 5 Very severe Typ 5	 < 0.55 < 0.50 < 0.45 < 0.50 < 0.45 < 0.40
Concrete admixtures	Superplasticizer Type dependent on placement and early strength requirements	Sika® ViscoCrete® or SikaPlast® or Sikament®	0.60 – 1.50%
Installation requirements	Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces Sika Antisol®	
Protective system/ Special curing system	Concrete's resistance to chemicals is highly limited. Appropriate coatings can durably protect the concrete surface against exposure	Special curing of precast tunnel segments immediately after demolding with Sikagard®	

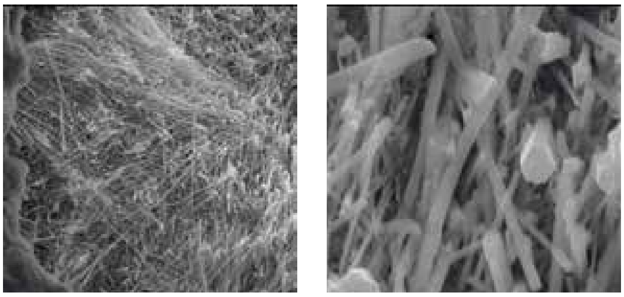
Referencing Standards, publications
- DIN EN 206: Tragwerke aus Beton, Stahlbeton und Spannbeton, Teil 1: Beton – Festlegung, Eigenschaften, Herstellung und Konformität, Beuth-Verlag, Berlin
- ACI 201.2R – 08 Guide to Durable Concrete, Chapter 2 – Chemical attack
- ASTM C 452 – Standard Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate
- ASTM C 1012 – Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

The intended life cycle of a concrete structure is ensured by a suitable concrete mix design that is adapted to the expected exposition to various impacts. Sulfate contained in water reacts with the tricalcium aluminate (C_3A) in the cement to form ettringite (also thaumasite under certain conditions), which leads to increases in volume. This volume increase results in high internal pressure in the concrete structure which induces cracking and spalling. Such attack is classified among types of chemical attack under which standard concrete designed without dedicated measures can experience significant damages. Field experience demonstrates that loss of adhesion and strength are usually more severe than concrete damage resulting from expansion and cracking.

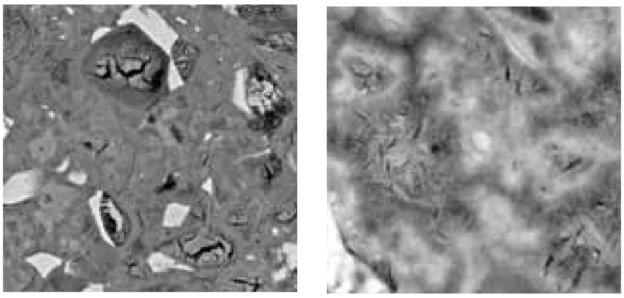
Sulfate resistance of concrete is determined by the sulfate resistance of the cement matrix as well as its ability to withstand diffusion of sulfate ions through the matrix. Concrete intended to be sulfate-resistant should therefore be characterized by high impermeability as well as compressive strength on the one hand. In addition, cements with low C_3A and Al_2O_3 content should be used. Doing so reduces the potential for any deteriorating reactions. In addition the inclusion of silica fume is favorable, since this contributes to higher density of the cement matrix in conjunction with enhanced bonding between the cement matrix and aggregates, and thus leading to higher compressive strength.

Sulfate attack is designated as exposure class chemical attack according to EN 206-1. Therefore the exposition class is determined by the expected sulfate content in the water contacting the concrete. Depending on the exposition class, a minimum cement content in combination with a maximum water/cement ratio is required, as well as a mandatory utilization of cement with high sulfate resistance.

In tunneling, durability is of decisive importance and sulfate attack is a constantly occurring and challenging phenomenon. This is especially true in the case of production of precast tunnel lining segments for TBM and rock support applied by sprayed concrete. In excavations in which high sulfate attack is anticipated, it is difficult to fulfill all technical requirements unless appropriate measures regarding the concrete mix design are also taken. For sprayed concrete the use of alkali free accelerators is mandatory to achieve adequate sulfate resistance. The industrialized, swift production of tunnel lining segments requires production cycles of only a few hours, with a maximum temperature development of 60°C in the concrete. This is very difficult with conventional sulfate resistant cements, due to the fact that these cements exhibit slow strength development. A concrete mix containing silica fume and a superplasticizer fulfills both criteria, productivity and sulfate resistance, but this system is very sensitive to proper curing due to crack formation. With the application of a water-based epoxy emulsion immediately after formwork release of the segments, micro-crack free concrete can be produced.



Classic form of sulfate attack associated with ettringite or gypsum formation. Flurry of ettringite rods grown in mature cement pastes subjected to external sulfate solutions.



Ettringite cores forming into aged cement pastes. Right picture is a 2 years old paste subjected to sulfate attack. One clearly sees the ettringite cores forming within the C-S-H.

Concrete deterioration due to sulphate attack before & after the load shows a strong increase in length because of the spalling attack. First cracks have appeared in sample.

Immediately following curing in a steam channel, the concrete surface of tunnel lining segments is coated with water-based epoxy emulsion that is absorbed even into the smallest pores, thereby generating a sealed, protective coating.

FIRE RESISTANT CONCRETE

THE DANGER OF FIRE IS PRESENT ALWAYS AND EVERYWHERE. The imminent danger depends upon actual exposure, and naturally differs if the threatened construction is a pedestrian subway, a roadway tunnel or a subterranean garage in a skyscraper. Concrete is the load-bearing material in nearly all built structures and is therefore at high risk, since the entire structure would collapse upon its material failure. Concrete must therefore, independent of the danger scenario, be properly formulated or protected by external measures, in order to hinder failure at high temperature in case of fire.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula
Aggregates	Aggregates of the carbonate type – limestone, dolomite, limerock, tend to perform better in a fire as they calcine. Types containing silica perform less well.	All aggregate sizes are possible
Cement	Any cement meeting local standards	Target cement paste volume as low as possible for the respective placing method
Water content	Fresh water and recycling water with requirements regarding fines content	Water/cement ratio according to standards with regard to exposition < 0.48
Concrete admixtures	Superplasticizer, type dependent on placement and early strength requirements Polymer or polypropylene monofilament fibres	Sika® ViscoCrete® or SikaPlast® or Sikament® 0.60 – 1.20% Sika® Fiber PPM 1.5 – 2.0 kg/³
Installation requirements		Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces.
Passive protection of the concrete	Sprayed-applied lightweight mortars	Sikacrete®-F

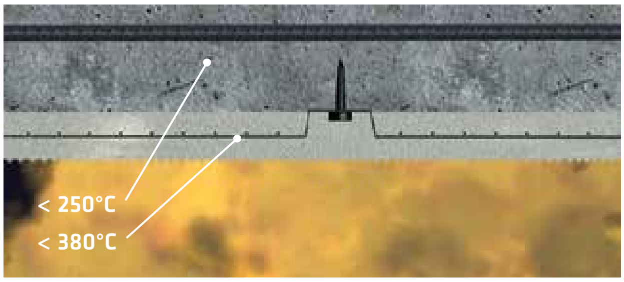
Referencing Standards, publications

– ZTV-ING Teil 5: Tunnelbau
– ACI 216 - Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies
– ASTM E119 - Standard Test Methods for Fire Tests of Building Construction and Materials
– ÖVBB Merkblatt, Schutzschichten für den erhöhten Brandschutz für unterirdische Verkehrsbauwerke, 2006
– VDV-Förderkreis, Fire Protection in vehicules and tunnels for public transport, 2005

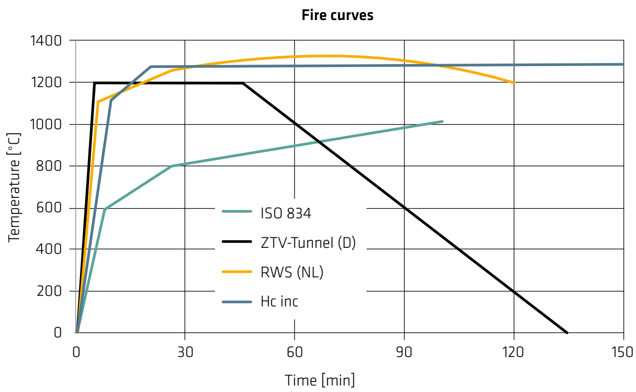
Concrete is a construction material manufactured from non-combustible components such as cement, aggregates and water. The thermal conductivity of concrete is approximately 1.5 to 3.0 W/m°C, making concrete suitable as a protective fire shield to withstand the effects of direct heat before underlying steel softens to the point of potential structural collapse. Fire resistance is defined as the ability of a structure to fulfill its required functions (load bearing function and/or separating function) for a specified fire exposure and a specified period (integrity). Fire resistance applies to building elements and not the material itself, but the properties of the material affect the performance of the element of which it forms a part (Eurocode 2). The time vs. temperature models relate to the type of fuel being consumed, the volume of fuel, the effects of ventilation and the fire location. In most cases fire temperature increases rapidly in minutes, leading to the onset of explosive spalling as the moisture inherent in the concrete converts to steam and expands. The most severe fire scenario modeled is the RWS fire curve from the Netherlands and represents a very large hydrocarbon fire inside a tunnel.
There are various options available to improve the fire resistance of concrete. Most concretes contain either Portland cement or Portland blended cement which begins degrading in important properties above 300°C and starts to lose structural performance above 600°C. Of course the depth of the weakened concrete zone can range from a few millimeters to many centimeters depending on the duration of the fire and the peak temperatures experienced. High alumina cement used to protect refractory linings reaching temperatures of 1600°C has the best possible performance in a fire and provides excellent performance above 1000°C.
The choice of aggregate will influence the thermal stresses that develop during the heating of a concrete structure to a large extent. Aggregates of the carbonate type such as limestone, dolomite or limerock tend to perform better in a fire as they calcine when heated, liberating CO_2. This process requires heat, so the reaction absorbs some of the fire's exothermic energy. Aggregates containing silica tend to behave less well in a fire.
Polymer or polypropylene monofilament fibers can significantly contribute to the reduction of explosive spalling and thus improve the "fire resistance" of the concrete. In a fire, these fibers melt at around 160°C, creating channels which allow the resulting water vapor to escape, minimizing pore pressures and the risk of spalling.
Under conditions in which the risk of structural collapse is unacceptable, designers examine other ways to protect the concrete from the effects of fire. Alternatives range from local thickening of the concrete, cladding using heat shields coated with intumescent paint, use of protective board systems and spray-applied lightweight mortars. The purpose of these passive fire protection systems depends on the type of tunnel as well as the form being protected.

Fire exposure trials for concrete containing various aggregates. Surface spalling and sintering, and a range of temperature developments at differing depths can thereby be compared.

1 Gneis	Fuseo surface	No spalling
2 Limestone 1	Disintegration	17 mm spalling
3 Granite	Fuse surface	25 mm spalling
4 Limestone 2	Disintegration	14 mm spalling



If a soffit requires protection, the use of wire mesh reinforcement is recommended.



These fire exposure rating curves all simulate the temperature profile of a tunnel fire. The example of the RWS curve defines the maximum exposure which can be expected in the worst case scenario: Defined as a fire of a tank truck with a load capacity of $50m^3$ which is 90% full of liquid hydrocarbon fuel (petrol).

In special furnace chambers fire trajectories can be replicated, panels tested and subsequently evaluated. Temperature development is measured at various depths and recorded.

ALKALI-SILICA-REACTION RESISTANT CONCRETE

AGGREGATES CONSTITUTE a major portion of concrete. Their influence on the fresh and hardened concrete is considerable. To save costs and energy, concrete producers target the use of the most proximal sources of aggregates. Sources of high quality aggregates are gradually dwindling in number, as a result of which the building and construction materials industry and builders of major infrastructure projects seek solutions for the use of aggregates with lower quality. The Alkali Silica Reaction (ASR), which can occur with aggregates, presents a particular challenge and can affect the durability of concrete.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula	
Aggregates	The ASR potential of aggregates should be previously determined	All aggregate sizes are possible	
Cement	Preferably cements with ground granulated blast furnace slag or fly ash content	Target cement paste volume as low as possible for the respective placing method	
Powder additives	Silica fume, fly ash or ground granulated blast furnace slag	Sikafume®	3.0% – 6.0%
Water content	Clean mixing water, free of fines	Water/cement ratio according to standards with regard to exposition	< 0.48
Concrete admixtures	Superplasticizer Type dependent on placement and early strength requirements Special admixtures limiting ASR Shotcrete accelerator in case of shotcrete	Sika® ViscoCrete® or SikaPlast® or Sikament® SikaControl®-ASR Sigunit®-AF	0.60 – 1.20% 2.0 – 10.0 kg/m³ 3.0% – 6.0%
Installation requirements	Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces Sika Antisol®	
Protective system	Beside free alkalines and reactive aggregates, the concrete must contain moisture for ASR to occur. If a structure is exposed to water the concrete surface needs to be protected.	Sika offers a wide range of rigid and flexible solutions to prevent the penetration of water. Sika Solution: Sikagard®, SikaPlan®	

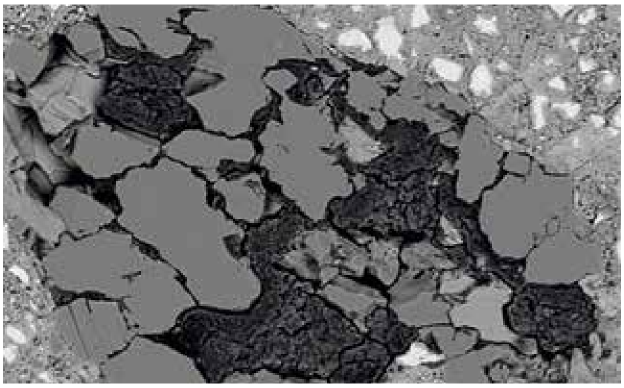
Referencing Standards, publications

- ASTM C 1260 – Standard test method for potential alkali reactivity of aggregates (mortar-bar method), ASTM Standards in Building Codes 681–85.
- ASTM C 1293 – Standard test method for concrete aggregates by determination of length change of concrete due to alkali-silica, ASTM Standards in Building Codes 686–691.
- AFNOR P18-594 Granulats: Méthodes d'essais de réactivité aux alcalis, Association Française de Normalisation, Paris, France.
- AFNOR P18-454 Béton: Réactivité d'une formule de béton vis-à-vis de l'alcali- réaction (essaie de performance). Association Française de Normalisation, Paris, France.

Major infrastructure projects such as dams, roadways or airport runways require enormous quantities of aggregates, sought in closest proximity to construction sites. Some aggregates can exhibit an increased or high risk of ASR. Alkali Silica Reaction is a chemical reaction which occurs between the amorphous silica in the aggregate and the pore solution (alkalis) of the cement matrix. The reaction results in an increase in concrete volume, causing cracking and spalling when the generated forces exceed the tensile strength of the concrete. Essential conditions for occurrence of ASR are moisture within the concrete, a high alkaline content in the pore solution and reactive aggregates. Selection of the correct concrete mix design is critical for avoidance of ASR. Choice of the right solutions can prevent damages resulting from ASR even if highly reactive aggregates are used.

Cement clinker contributes the greatest proportion of alkaline material. The higher the cement content is, the more alkaline the mix will be. Blended cements introduce a lower alkaline content. A low water/cement ratio is considered the central factor for achievement of dense, watertight concrete. Dense concrete slows the diffusion of free alkalines and the migration of water to aggregates. For ASR to accur it requires aggregates particularly sensitive to alkalines, such as siliceous limestone, sandy limestone, limestone, gneisses and strongly deformed quartzite. Porous, cracked, weathered or crushed aggregates are more reactive than those with dense structure and rounded surfaces. Pozzolanic additives such as fly ash, granulated blast furnace slag or silica fume react with and consume hydroxyl (alkaline) ions during hydration. This reaction lowers the pH value of the pore solution, suppressing the occurrence of ASR. Pozzolanic additives differ in shape and reactivity depending on their source, but generally their effect is more homogeneous if added to the cement grinding process as opposed to the concrete mix. There remains however some dispute regarding the efficiency of additives in lowering the speed of ASR.

Admixtures such as traditional accelerators for shotcrete may introduce considerable quantities of alkalines, greatly increasing the reactivity of the pore solution. In case of aggregates considered sensitive, alkaline-free accelerator should be used. Experience has shown that inclusion of special admixtures can hem the ASR reaction, thus preventing expansion. A further possible solution is proposed with the addition of an air entrainment agent to create artificial expansion room (air voids) for the reaction products. If the possible occurrence of ASR represents a major concern, reaction trials are suggested to define the ASR potential.



Amorphous silica spots within the aggregate have reacted with alkali ions and formed a gel that expanded upon ingress of water. The aggregate has subse-quently swelled and cracked while the amorphous region (black cracked masses) expanded.

The increase in volume due to the strain resulting from ASR becomes perceptible by measurement of a change in length of test specimens. Ordinarily the specimens are stored under intensified conditions (temperature, humidity, applied load) in order to accelerate the reaction.

The appearance of ASR damage can be assessed very well on the drying concrete surface of this bridge pylon. Damage can appear within years or only after decades.

Sulfate damage is often only visible after decades. Precise clarification of risk is therefore necessary in order to estimate the potential of aggregates for ASR damage reliably.

ABRASION RESISTANT CONCRETE

AWE-INSPIRING GORGES AND VALLEYS are nature's testimony to the undeniable strength of water. Primarily in technical hydraulic engineering, but also in traffic zones with high loads or hard rolling bodies, concrete surfaces experience considerable and at times extremely abrasive pressure. The mechanisms of damage thereby depend centrally on the type of burden. Whether the surface is exposed to rolling, rubbing or percussive influences differentiates the possible patterns of damage as well as any preventive measures substantially.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula	
Aggregates	Aggregates employed must be as hard as possible	All aggregate sizes are possible	
Cement	Any cement meeting local standards	Target cement paste volume as low as possible for the respective placing method	
Powder additives	Silica fume for enhanced compactness	Sikafume®	up to max. 8%
Water content	Clean mixing water, free of fines	Water/cement ratio according to standards with regard to exposition	< 0.45
Concrete admixtures	Superplasticizer Type dependent on placement and early strength requirements Steel fibers	Sika® ViscoCrete® or SikaPlast® or Sikament® Sika® Fiber Force	0.80 – 1.60% 4 – 8 kg/m³
Installation requirements	 Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces Sika Antisol®	
Surface coating	Scattering material for surface hardening Protective coating	Sikafloor®	0.3 – 1.5 mm

Referencing Standards, publications
– DAfStb-Richtlinie „Betonbau beim Umgang mit wassergefährdenden Stoffen (2004)
– Betonabrasion im Wasserbau; Dr. Frank Jacobs; TFB Technische Forschung & Beratung für Zement und Beton, Wildegg Schweiz; TEC21 2004
– ACI 201.2R – 08 Guide to Durable Concrete, Chapter 8 – ABRASION
– ASTM C 779 - Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces
– ASTM C 1138 - Standard Test Method for Abrasion Resistance of Concrete (Underwater Method)

Over the course of decades and even centuries, exposure to abrasion can yield the most varied experiences with damage patterns. Above all the difference between rolling loads in roadway traffic, heavy traffic including steel wheels or exposure to water, with or without the additional transport of sediment, must be considered. In traffic zones the intensity, weight and the type of wheels are decisive for the overall load. In the case of abrasion by water, it is the velocity of flow, the quantity and type of sediment that are crucial.
In order to boost concrete's abrasion resistance, in most cases provision for hard surfaces is the proper dimensioning approach. If, however, handling the exposure involves percussive or bumping assault, then in addition the adsorptive capacity of the surface plays a role, which can stand in contradiction to surface hardness. The most critical basic principle in the concept is the expert installation of the concrete (prevention of a rising up of fines to the surface due to excessive vibration) and excellent curing, so that the desired concrete properties can emerge above all in areas close to the surface. Furthermore, the surface should offer the lowest resistance possible to abrasive attack. Surfaces that are as level as possible provide the smallest potential for attack.
Ascertaining damage patterns is rather straightforward, and is carried out by assessing the abrasion of the surface, the condition of the cement laitance skin and of aggregates near to the surface.
Concrete with enhanced or high abrasion resistance should demonstrate a target compressive strength of roughly 50 MPa. The surface can be considerably enhanced against grinding abrasion through the use of micro silica and/or surface hardener scattered on the surface. In order to boost resistance against percussive or striking attack, the toughness and flexural strength of the concrete must be improved. This can be achieved with the use of fiber reinforcements in the mix. Improving the general working capacity of concrete can be accomplished by mixing in synthetic polymers to strengthen the hardened cement paste matrix, which furthermore enhances adhesion (entanglement) with aggregates. Finally there must be additional differentiation between transport distances and areas that are built to facilitate the dissipation of energy. In these areas, the use of high strength, steel-fiber-reinforced concrete with a strength above 80 MPa and corresponding flexural strength is recommended.
In construction the design of edges must be given particular attention. Whether this concerns dilatation joints in roadway surfaces or tearing edges in hydraulic construction, these must usually be handled specially; construction in concrete alone is normally insufficient. Special joint profiles must be incorporated, often made of steel.

Concrete roadways and other publicly accessible areas, especially those experiencing high volumes of traffic or concentrated loads, are subject alongside high mechanical burdens also to strong abrasion, often presenting the risk of a smooth, slick surface.

Particularly in whitewater, concrete surfaces are subject to massive additional strains by rubble, sharp edges and abrasion, as well as possible temperature stresses due to frost exposure.

Due to continuous exposure, the cement film is eroded in an initial step, and thereafter larger and larger aggregates are rubbed, knocked or washed out of the hardened cement paste

Industrial flooring surfaces also experience strong abrasion due to constantly rolling and striking loads in the same places. Hard concrete coatings and special dispersants can enhance the flooring grip and minimize wear.

CHEMICAL RESISTANT CONCRETE

WATER IS THE SOURCE OF ALL LIFE as well as a scarce commodity. Clean drinking water should therefore be protected against contamination, while waste water must be treated before being released into a discharge system. The waste water itself as well as the treatment measures undertaken represent an exposure to chemically and microbiological for concrete surfaces. Through sensible planning and proper concrete design concepts, the surfaces can be designed for durability. Concrete's resistance to chemical and microbiological attack is nevertheless limited, so that surface protection systems must be foreseen in case of heavy exposure.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula	
Aggregates	Any quality Aggregates possible	All aggregate sizes are possible	
Cement	Sulfate resistant cements Cements with high proportion of calcium carbonate Cements containing silica fume	Target cement paste volume as low as possible for the respective placing method	
Powder additives	Silica fume, fly ash or ground granulated blast furnace slag	Sikafume®	3.0 – 6.0%
Water content	Clean mixing water, free of fines	Water/cement ratio according to standards with regard to exposition	< 0.45
Concrete admixtures	Superplasticizer Type dependent on placement and early strength requirements	Sika® ViscoCrete® or SikaPlast® or Sikament®	0.80 – 1.60%
Special admixtures limitting MIC		Sika Control MIC	1 – 4%
Installation requirements	Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces Sika Antisol®	
Protective system	The chemical resistance of concrete is limited. If exposure limits are exceeded, concrete surfaces can be durably protected with coatings.	Sika offers a wide range of solutions to prevent the penetration of chemicals. Sika Solution: Sikagard®, Sikafloor® & Sikalastic®	

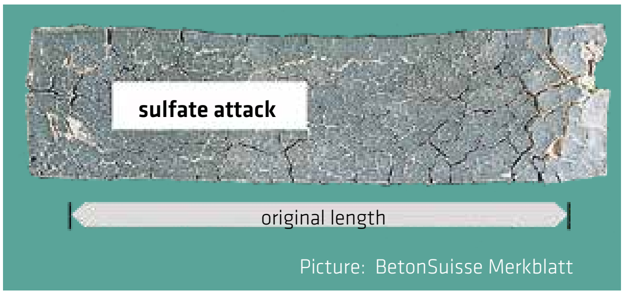
Referencing Standards, publications

- ACI 201.2R – 08 Guide to Durable Concrete, Chapter 6 - Chemical attack
- ASTM C 88 - Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
- Cemsuisse Leaflet MB 01 Concrete erosion in biological basins in wastewater treatment facilities June 2010
- Chemischer Widerstand: DAfStb-Richtlinie „Betonbau beim Umgang mit wassergefährdenden Stoffen (2004)

Water has its greatest significance in its employment for irrigation and as drinking water. Alongside these applications, water is used in industry, in agriculture, as a means of transport and in a multitude of other ways in daily life. Water and other fluids are pumped through pipelines and stored in tanks; this holds true for clean as well as for waste water. Concrete's interface with water occurs mainly in such capacities as medium of conduit or storage. Usually the tanks used for storage of drinking water and for purification of wastewater, and often also the transmission pipelines are made of concrete. Above all in wastewater treatment in settling basins, aeration basins (organic substance decomposition), the nitrification and denitrification (aluminum and nitrate conversion) or even in subsequent cleaning, concrete is an important building material. The challenge thereby is to design these concrete structures to withstand exposure to diverse chemicals and at the same time to withstand concomitant mechanical stresses. The chemically and microbiologically resistant concrete formula and the expert treatment and cleaning of the basin must be adapted to one another, or in locations where the resistance of the concrete is insufficient, must be supplemented by means of appropriate protective coatings.
Chemical resistance in this case signifies resistance to corrosion and erosion of concrete. Alongside known types of spalling attack such as frost (with and without de-icing agents), ASR (alkali silicate reaction), sulfate exposure and mechanical surface abrasion, in wastewater treatment facilities particularly, chemical and solvent aggression is also prevalent. The water treated in such facilities, however, varies too greatly to describe the attack on concrete surfaces as uniform. Decisive in addition to the general quality of the water is also its hardness (°fh). On one hand the surface of the concrete is attacked by a cocktail of chemicals, while on the other mechanical stress (e.g. high pressure cleaning) also occurs at the surface. Thereby fines are washed out that have already been dissolved but remained adhered within the concrete structure. This entire process is additionally accelerated by softened water (hardness < 15°fh or 8.4°dH) and the reduction of the pH value on the surface of the concrete (e.g. in biofilm). The concrete design, curing and foremost the cleaning of the surface must be adapted to the respective exposure.
While for resistance to mechanical cleaning a hard and compact concrete surface is considered optimal, chemical cleansing is best tolerated by concrete with a high calcite content. Concrete's chemical resistance is limited. If exposure limits are exceeded, concrete surfaces can only be durably protected with appropriate coatings.

Heavy leaching and damage to the structural concrete are observed particularly in the water splash zone of biological treatment basins.

Epoxy resin-based protective coatings are applied over the entire surface following reprofiling of the concrete surface with sulfate-resistant repair mortar enhanced with synthetic material.



Sulfate driven attack is caused primarily by sulfates dissolved in water. By reacting with the hardened cement matrix, an increase in volume is induced which damages the structure.

Acidic solvent attacks which dissolve calcium compounds out of the hardened cement matrix can be caused by acids, exchangeable salts, vegetable or animal fats or oils. Degradation of the concrete usually occurs very slowly.

HIGH STRENGTH CONCRETE

HIGH STRENGTH AND ULTRA HIGH STRENGTH CONCRETE are not just cutting edge technologies for scientific research, but also continue to find new applications in praxis. Whether in dealing with the slenderness of building components (e.g. design) or dimensioning under extreme conditions (e.g. earthquake stresses), high and highest material properties (compressive and flexural strength, elasticity and ductility) are finding entry in concrete technology. Durability and high strength of concrete are thereby inter-dependent.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula	
Aggregates	Exceptional concrete strength can be achieved using high strength, crushed aggregates	Well distributed grading curve with low amount of fines	
Cement	Utilization of higher cement content and high grade	Partly cement replacement by GGBFS or FA	
Powder additives	Increased bond between aggregates and cement matrix-silica fume	Sikafume®	5.0 – 10.0%
Water content	Clean mixing water, free of fines	Water/cement ratio according to standards with regard to exposition	< 0.38
Concrete admixtures	Superplasticizer Type according to target flowability and slumplife Fibers	Sika® ViscoCrete® Sika® Fiber (Steel)	1.0 – 4.0% up to > 150 kg/m³
Installation requirements	Thorough curing which starts as early as possible and is extended to two days for interior elements or three days for exterior elements, especially when silica fume is used Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces Sika® Antisol®	

Referencing Standards, publications

- ACI 211.4R - Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement and Other Cementitious Materials
- Technische Universität München, Hochfester Beton, 2004

In concrete technology high strength concrete (HSC) usually is defined by its compressive strength between 60 and 120 MPa after 28 days. Designated as ultra high strength concrete (UHSC) in contrast are concretes with compressive strength far above 150 MPa. High strength concretes are characterized by increased compressive, tensile as well as flexural strength, as well as their ductility in combination with enhanced durability. Dense cement and binder matrix with extremely low permeability are factors which improve the strength of hardened concrete. Furthermore, high strength concrete exhibits significantly increased bonding between the binder matrix and aggregates. Higher density binder matrix is achieved by employing low water/binder ratios. Bonding between the matrix and aggregates is enhanced through utilization of pozzolanic materials. Total shrinkage of such concrete is equal to that of normal concrete, whereas chemical shrinkage values are higher, among lower-drying shrinkage values. Creep deformation is reduced.

Challenges are stretched along the entire production process. Special formulas with high concentrations of known materials (cements, additives or fibers) and other new materials previously unknown in concrete (ceramic aggregates) must be manufactured in improved mixing facilities and placed as self-compacting mixtures. Concrete admixtures have not only the task of an extraordinary reduction of water; the flowability of such "tough" mixtures is also a great challenge.

High strength concrete offers a wide range of application possibilities due to its versatile technical characteristics.

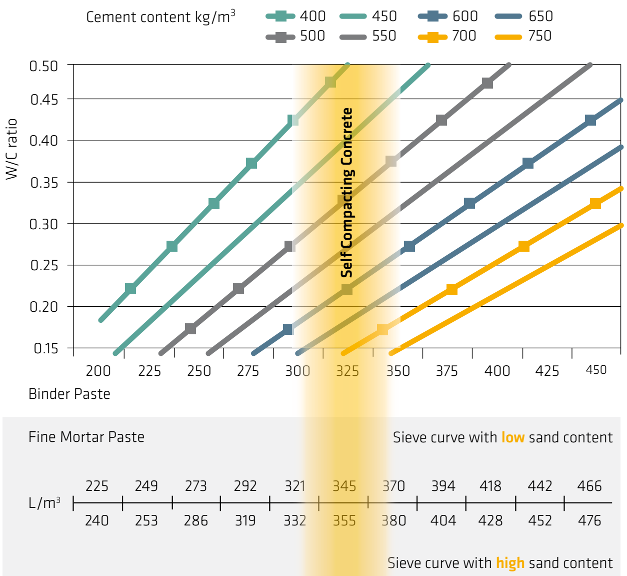
Its primary application field today is in the precast concrete business. It is particularly suitable for compression elements such as highly loaded columns and walls in high rise buildings, especially in areas vulnerable to earthquake. Moreover bridge constructions designed with prestressed concrete require increased compressive strength. This in particular facilitates construction of bridges with wide spans and slender dimensions.

Structures which must withstand certain severe exposures require application of high strength concrete, examples being elements subject to high mechanical and chemical loading such as industrial floors, traffic areas, offshore structures or sewage treatment plants.

Furthermore high strength concrete is required in construction of special engineering structures like hydropower plants, cooling towers or chimneys.

At compressive strengths above 150 Mpa one is no longer concerned with commonplace concrete. Stone aggregates are replaced for example by fine aggregates of ceramic origin, and the entire binder matrix is only slightly reminiscent of classical concrete. Shown in the illustration is the flow behavior of a UHPC of 200 MPa.

Highly stressed building components such as columns and beams are made of high strength concrete. High resistance to external influences also makes high strength concrete an ideal protective coating for exposed construction elements.



High strength and above all ultra high strength concrete are practically always also fiber-reinforced. Depending on the requirements, synthetic and/or steel fibers are thereby employed in large quantity. The high flexural strength of UHPC can be achieved in this way.

Of central significance for achievement of high mechanical material properties is the targeted determination of a concept of fines and the cement paste volume. Only in this way can the highest possible packing density be achieved.

SHRINKAGE CONTROLLED CONCRETE

PREVENTION OF CRACKS contributes to the durability of concrete structures, because cracks promote the ingress of water and pollutants. Current construction codes specify limits for the width of cracks depending on environmental conditions in which a structure is built and its intended service life. A main reason for cracks in concrete is due to shrinkage related deformation in early age concrete. These cracks not only compromise aesthetic appearance, but can decrease durability as well as serviceability of a concrete element. There are different types of shrinkage and with the right measures the various phenomena can be controlled.

CONCRETE MIX DESIGN ADVICE AND RECOMMENDED MEASURES:

Components	Description	Example formula	
Aggregates	Large volume of aggregates can reduce drying shrinkage	All aggregate sizes are possible	
Cement	Preferably binders with reduced portland clincker content	Target cement paste volume as low as possible for the respective placing method	
Water content	Low water content is favorable to reduce plastic shrinkage and drying shrinkage. At water/cement ratios lower than 0.4 autogenous shrinkage can occur	Water/cement ratio	< 0.45
Concrete admixtures	Superplasticizer Type dependent on placement and early strength requirements Shrinkage reducing agent Polypropylene short fibers can reduce effects of plastic shrinkage Steel fibers to ensure even distribution of cracking Synthetic fibers for crack bridging by high deformation	Sika® ViscoCrete® or SikaPlast® or Sikament® Sika® Control Sika® Fiber PPM Sika® Fiber Steel Sika® Fiber Force	0.80 – 1.50% 0.5 – 1.5% 1 – 3 kg/m³ 20 – 40 kg/m³ 4 – 8 kg/m³
Installation requirements and curing	Curing that starts as early as possible and is maintained for a sufficient period of time has significant influence on plastic and drying shrinkage Curing compound	Careful installation and compaction. Subsequent curing to ensure high quality (compactness) of surfaces Sika® Antisol®	

Referencing Standards, publications

– Aïtcin, P.C et Al, Integrated view of shrinkage deformation, Concrete International, September, 1997.
– Al-Manaseer, Akthem et Al, conclusions of the ACI-RILEM Workshop on Creep and Shrinkage in Concrete Structures, ACI Concrete International, March, 1999.
– Helene, Paulo R.L, Carbonatación del Concreto y corrosión del acero de refuerzo. Asocreto, Memorias de la Reunión del Concreto, Cartagena, Septiembre 2000.
– Neville, Adams, Tecnología del concreto, IMCYC, México, 1984. Book 2.
– ACI 223R – Standard Practice for the Use of Shrinkage-Compensating Concrete

The prevention of shrinkage cracks demands consideration of several factors starting with suitable structural design, specification of the concrete and ends with good construction practice including correct concrete installation, compaction and thorough curing. The identification of different concrete shrinkage types leads to introduction of appropriate actions with regard to concrete technology. Concrete shrinkage types include chemical shrinkage, plastic shrinkage, autogenous shrinkage, drying shrinkage and carbonation shrinkage. The most important types with the most severe impact are chemical shrinkage, plastic shrinkage and drying shrinkage.

In the case of chemical shrinkage, hydration products built up during the hydration process occupy lower volume than the total volume of individual raw materials. This results in a decrease of overall concrete element dimensions as long as the concrete is still soft. After setting of the concrete, this volume decrease leads to small pores and cracks. An effective measure is recompaction of the concrete.

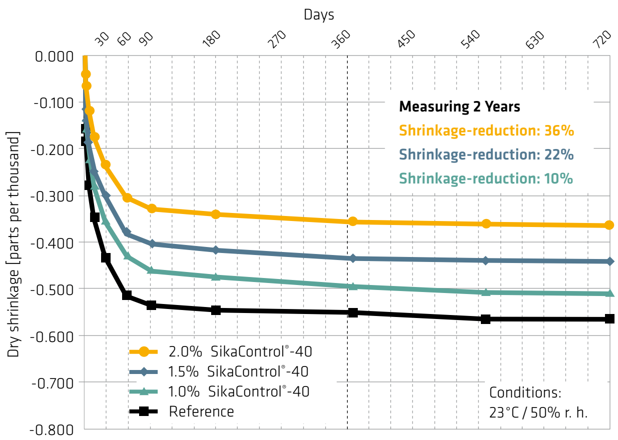
Plastic shrinkage exhibits itself through a decrease in volume caused by evaporation of water, leading to concrete contraction in all directions. The major portion of shrinkage at early ages is in the horizontal plane, mainly in the surface in contact with the air. This is one of the most common and important types of shrinkage. Influencing factors are relative humidity, temperature and ambient wind. More severe drying conditions increase the shrinkage value. Shrinkage deformation doubles at 1 m/s wind speed and is five times higher at wind speeds of 3 m/s. Plastic shrinkage can be controlled by initiating curing as early as possible as well as restriction of the water content of the concrete mix.

Autogenous shrinkage is a change of volume that occurs after the initial setting of concrete due to hydration, since this process requires water and therefore reduces the internal free water. This has the same effect as a water loss caused by surface evaporation; the concrete shrinks. Concrete mixes having a water/cement ratio larger than 0.4 are not affected by this phenomenon. This kind of shrinkage is gaining importance with utilization of high strength concrete types with very low water/ cement ratios.

Drying shrinkage in hardened concrete is usually caused by evaporation of water through existing capillary pores in the hydrated cement paste. The loss of water is a progressive process that tends to stabilize with time, depending on the dimensions of the structural element.

The main influencing factors are the concrete element dimensions, the relative ambient humidity and the water/cement ratio. Possible measures include a reduction of cement paste volume and application of shrinkage reducing admixture.

Immediate coverage or curing of concrete surfaces exposed to the elements is the most crucial step for protection of such surfaces.



Shrinkage behavior of concrete containing shrinkage-reducing admixtures, measured 2 years to complete abatement of shrinkage due to drying.

Cracks due to plastic shrinkage in a concrete pavement caused by insufficient surface protection prior to premature drying.

Interlaboratory comparison from experiments at the Federal Institute of Technology Zurich to determine the performance of shrinkage-reducing concrete admixtures.

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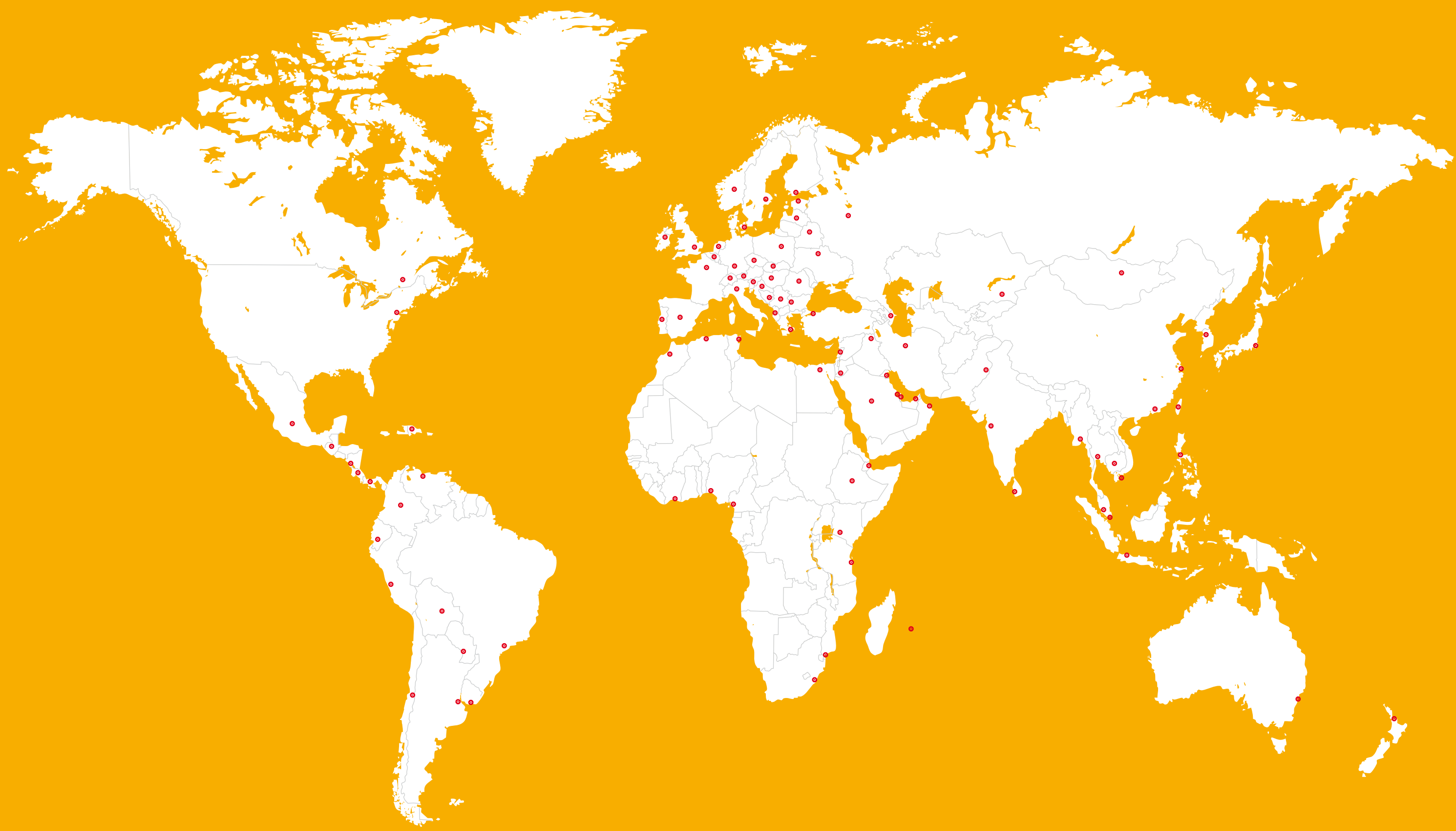

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