Reinforced Concrete (RC) Structures

Topic 9.
Environmental classes

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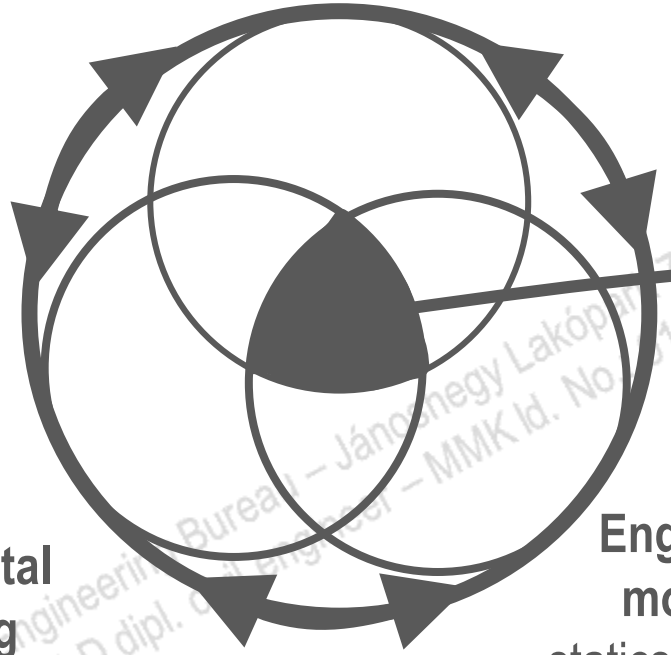
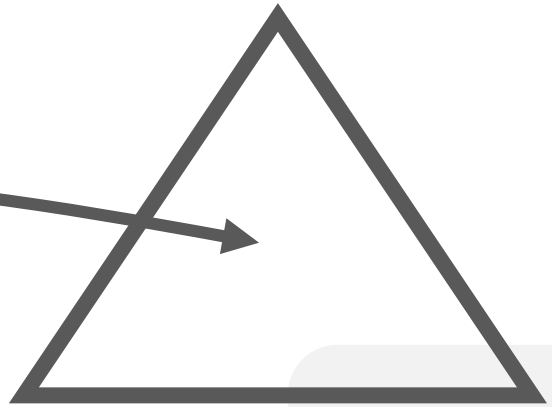
Modeling of structural behaviour of RC members

Numerical modelling
linear, non linear, plastic, 1st order theory, 2nd order theory, etc.

Material properties
homogen, inhomogen, izotropic, anizotropic
elastic linear, non linear elastic,
plastic, viscous, reological properties, etc.



Structural behaviour



Experimental modelling
full-scale,
non full-scale, etc.

Engineering modelling
statics, strength of materials, elasticity, plasticity, dynamics, etc.

Size effect

Environment
effects, loads,
durability properties, etc.

Environmental classes in the concrete notation

Environmental class(es)

MSZ EN 1992-1-1:2010

MSZ 4798:2016

LC40/44 – AC50(H) – D1,8 – expanded clay pebbles – XC4-XD2-XV2(H) – 24 – B curve

– 4,80 – F 4 – Cl 0,10 – CEM I 42,5 N-SR 0 – silica fume – 100 years – MSZ 4798:2016

No risk of corrosion or attack:	X0 XN(H) X0b(H) X0v(H)
Corrosion induced by **carbonation**:	XC1 XC2 XC3 XC4
Corrosion induced by **chlorides**:	XD1 XD2 XD3
Corrosion induced by chlorides from **see water**:	XS1 XS2 XS3
Freeze/thaw attack:	XF1 XF2 XF2(H) XF3 XF3(H) XF4 XF4(H)
Chemical attack (natural soils and ground water):	XA1 XA2 XA3

Environmental classes in the concrete notation

Environmental class(es)

MSZ EN 1992-1-1:2010

MSZ 4798:2016

LC40/44 – AC50(H) – D1,8 – expanded clay pebbles – XC4-XD2-XV2(H) – 24 – B curve

– 4,80 – F 4 – Cl 0,10 – CEM I 42,5 N-SR 0 – silica fume – 100 years – MSZ 4798:2016

Chemical attack (other agressive environment): XA4(H) XA5(H) XA6(H)
Wear-resistant concrete: XK1(H) XK2(H) XK3(H)
Waterproof concrete: XV0(H) XV1(H) XV2(H) XV3(H)

Environmental conditions – MSZ EN 1992-1-1:2010

(1)P Exposure conditions are **chemical** and **physical conditions** to which the structure is exposed **in addition to the mechanical actions**.

(3) In addition to the conditions in **MSZ EN 1992-1-1:2010 Table 4.1,** particular forms of aggressive or indirect action should be considered including:

- **Chemical attack**, arising from e.g.:
  - the **use of the building** or the **structures** (storage of liquids, etc),
  - solutions of **acids** or **sulfate salts** (**EN 206-1, ISO 9690**),
  - **chlorides** contained in the concrete (**EN 206-1**),
  - **alkali-aggregate** reactions (**EN 206-1**, National Standards).
- **Physical attack**, arising from e.g.:
  - **temperature change**,
  - **abrasion** (see MSZ EN 1992-1-1:2010 - 4.4.1.2. Section - (13) Paragraph),
  - **water penetration** (**EN 206-1**).

[MSZ EN 1992-1-1:2010 – Section 4.2 – Paragraph (1)P, (3) – Page 46.]

Environmental classes – EN 206-1 – MSZ 4798:2016 – MSZ EN 1992-1-1:2010

Exposure classes related to environmental conditions in accordance with **EN 206-1**, **MSZ 4798:2016** (**MSZ EN 1992-1-1:2020**) are the following:

1.	**No risk** of corrosion or attack	**X0**
2.	Corrosion induced by **carbonation**	**XC**
3.	Corrosion induced by **chlorides**	**XD**
4.	Corrosion induced by chlorides from **see water**	**XS**
5.	**Freeze/thaw** attack	**XF, XF(H)**
6.1	**Chemical attack** (natural soils and ground water)	**XA**
6.2	**Chemical attack** (other agressive environment)	**XA(H)**
7.	Corrosion induced by **abrasion**	**XK**
8.	**Water** penetration	**XV**

X0 – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
1. NO RISK OF CORROSION OR ATTACK		
X0	For concrete without reinforcement or embedded metal: all exposure except where there is freeze/thaw, abrasion or chemical attack. For concrete with reinforcement or embedded metal: very dry.	Concrete inside buildings with very low air humidity.
XN(H)	For concrete with subordinate importance where there is no averse environmental impact.	Substrate concrete of subordinate strength, concrete base layer, cement stabilization.
X0b(H)	Adverse environmental impact does not affect the concrete.	Foundation concrete, infill and leveling concrete, back concrete, masonry element.
X0v(H)	Reinforced concrete is not affected by any other adverse environmental effects other than carbonation.	Under reinforced concrete element.

XC – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
2. CORROSION INDUCED BY CARBONATION		
When reinforced concrete or other concrete containing embedded metal is exposed to air and moisture, the environmental effect shall be classified as follows:		
XC1	Dry or permanent wet	Concrete inside buildings with low air humidity. Concrete permanently submerged in water.
XC2	Wet, rarely dry	Concrete surfaces subjecz to long-term water contact. Many foundation.
XC3	Moderate humidity	Concrete inside buildings with moderatet or high air humidity. External concrete shelteres from rain.
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2.

XD – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
3. CORROSION INDUCED BY CHLORIDES		
When reinforced concrete or other concrete containing embedded metal is exposed to chloride-containing water, including de-icing salting, and which is not derived from seawater, the environmental effect shall be classified as follows.		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools. Concrete components exposed to industrial waters containing chlorides.
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides. Pavements. Car park slabs
NOTE: Concretes that are exposed to frost in addition to salts from non-seawater are classified in one of the environmental classes XF2, XF2 (H), XF4, XF4 (H) instead of environmental classes XD1-XD3.		

XS – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
4. CORROSION INDUCED BY CHLORIDES FROM SEA WATER		
When concrete containing reinforced concrete or other embedded metal is exposed to air containing chloride from seawater or salt from seawater, the environmental effect shall be classified as follows.		
XS1	Exposed to airborne salt but not in direct contact with sea water.	Structures near to or on the coast
XS2	Permanently submerged.	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures

XF and XF(H) – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
5. FREEZE / THAW ATTACK		
When concrete is significantly affected by freeze / thaw cycles when wet, the environmental effect shall be classified as follows:		
XF1	Moderate water saturation, without de-icing agent.	Vertical concrete surfaces exposed to rain and freezing.
XF2	Moderate water saturation, with de-icing agent.	Vertical concrete surfaces of road structure exposed to freezing and airborne de-icing agents.
XF2(H)		Prefabricated elements made of vertical or steeper surfaces steeper than 5%, and monolithic and prefabricated structures of bridges with steeper surfaces steeper than 5%, exposed to frost and salt water spray.

XF and XF(H) – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
5. FREEZE / THAW ATTACK		
When concrete is significantly affected by freeze / thaw cycles when wet, the environmental effect shall be classified as follows:		
XF3	High water saturation, without de-icing agents	Horizontal concrete surfaces exposed to rain and freezing. Concrete surfaces made with an air bubbling admixture, with a horizontal or slope not exceeding 5%, which are directly exposed to frost and precipitation or water. Concrete surfaces with a horizontal slope of not more than 10 meters or a slope of not more than 5% which are exposed to water splashing from the traffic surface or water spray from the traffic surface.
XF3(H)		Prefabricated elements made without air bubbling additives, horizontal or with a slope of up to 5%, and horizontal monolithic and prefabricated structures of bridges with a slope of up to 5%, which are directly exposed to frost and precipitation or water.

XF and XF(H) – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
5. FREEZE / THAW ATTACK		
When concrete is significantly affected by freeze / thaw cycles when wet, the environmental effect shall be classified as follows:		
XF4	High water saturation with de-icing agents or sea water	Rad and bridge decks exposed to de-icing agents. Concrete surfaces exposed to direct spray containing de-icing agents and freezing. Splash zone of marine structures exposed to freezing. Pavements made with an air bubbling additive, with a horizontal or slope of up to 5%, and other traffic and other surfaces, as well as bridge decks and curbs exposed to freezing and precipitation and de-icing agents. Concrete surfaces with a horizontal slope of up to 10 meters or a slope of up to 5% not more than 10 m from the pavement that are exposed to salt water splashing from the traffic surface or salt water from the traffic surface.
XF4(H)		Prefabricated elements without air bubbling additives, horizontal or with a slope of not more than 5%, and horizontal monolithic and prefabricated structures with bridges with a slope of up to 5%, directly exposed to freezing and precipitation and de-icing agents.

XA – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
6. CHEMICAL ATTACK		
6.1 Corrosion induced by materials from natural soils and ground water		
When concrete is subjected to chemical corrosion of materials from natural soils and ground water, the environmental effect shall be classified as follows:		
XA1	Sligthly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water.
XA2	Moderately aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water.
XA3	Highly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water.

Chemical corrosion effect of natural soil and ground water – MSZ 4798:2016

Exposure environmental classes depending on the characteristic values of the natural soil and groundwater causing chemical corrosion				
Chemical characteristics	**Method of analysis**	**XA1**	**XA2**	**XA3**
Ground water				
SO_4^{2-} **[mg/l]** / swelling corrosion	MSZ EN 196-2	≥ 200 and ≤ 600	> 600 and ≤ 3000	> 3000 and ≤ 6000
pH / soluble corrosion	ISO 4316	≤ 6,5 and ≥ 5,5	< 5,5 and ≥ 4,5	< 4,5 and ≥ 4,0
agressive CO_2 **[mg/l]** soluble corrosin	prEN 13577:1999	≥ 15 and ≤ 40	> 40 and ≤ 100	> 100 until saturation
NH_4^+ **[mg/l]** / soluble corrosion	ISO 7150-2	≥ 15 and ≤ 30	> 30 and ≤ 60	> 60 and ≤ 100
Mg^{2+} **[mg/l]** / soluble corrosion	ISO 7980	≥ 300 and ≤ 1000	> 1000 and ≤ 3000	> 3000 until saturation
Soil				
SO_4^{2-} **[mg/kg]** / swelling corrosion	MSZ EN 196-2	≥ 2000 and ≤ 3000	> 3000 and ≤ 12000	> 12000 and ≤ 24000
acidity, [ml/kg] / soluble corrosion	DIN 4030-2	> 200 Baumann Gully	**It does not occure in practice!**	

XA(H) – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
6. CHEMICAL ATTACK		
6.2 Corrosion induced by other agressive environment (industrial waters, liquids, etc.)		
When concrete comes into contact with aggressive rainwater, aggressive municipal water, aggressive industrial and agricultural waste water or other aggressive liquids, condensation water, the environmental effect shall be classified as follows:		
XA4(H)	Rainwater, municipal waste water, or their vapor or spray reaches moderately corrosion-resistant and moderately acid-resistant concrete.	Rainwater storage structures, communal sewerage elements, manure storage basins according to NAD Table 2.
XA5(H)	Industrial and agricultural waste water and other aggressive liquids, or their vapors or sprays, reach moderately corrosion-resistant and moderately acid-resistant concrete.	Sewerage elements, septic tanks, leachate storage pools for landfills, crop storage according to NAD Table 2.
XA6(H)	Highly aggressive industrial effluents or liquids, or their vapors or sprays, are exposed to highly corrosion-resistant concrete.	Concretes in contact with untreated wastewater and chemicals, cooling towers with flue gas discharge, animal feed troughs and agricultural fermentation silos, NAD Table 2szerint.

XK(H) – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
7. CORROSION INDUCED BY ABRASION		
When the concrete is subjected to abrasive effects, sliding, rolling, frictional stress, impact or rolling sediment moved under water flow, the resulting environmental effect shall be classified as follows.		
XK1(H)	Abrasive effect of light granular materials. Abrasive effect of pedestrian traffic, blown wheeled vehicles.	Light additives, crops, etc. silos, bunkers, tanks suitable for storage; sidewalks, stairs, garage floors.
XK2(H)	Abrasive effect caused by rolling stress under heavy loads, solid wheeled vehicles.	Concrete roads, concrete surfaces in contact with rolled sediment, forklift traffic.
XK3(H)	Abrasive effect caused by sliding-rolling stress under very heavy loads, steel wheeled forklift traffic.	Airport runways as well as taxiways, heavy industry assembly halls, container storage stations.
XK4(H)	Abrasive effect due to sliding-rolling stress under very heavy loads, requiring high surface accuracy and dust-free.	Concrete for pavements, halls and warehouses exposed to heavy loads, crawler vehicles. Hard-surfaced, dust-free industrial floor coverings.

XV(H) – Environmental classes – MSZ 4798:2016

Class designation	Description of the environment	Informative examples where exposure classes may occur
8. WATER PENETRATION		
When concrete is subjected to the effect of water pressure, the environmental effect shall be classified as follows:		
XV1(H)	Water column pressure less than 2 m	Basement walls, drainage ditches, water storage pools, culverts, rainwater channels, stormwater reservoirs, rainwater collection shafts.
XV2(H)	Water column pressure between 2 m and 10 m	Structures of waterworks, canals, dams, bank walls, underground garages and underpasses, water storage pools.
XV3(H)	Water column pressure greater than 10 m	Underground garages, external boundary structures of tunnels, hydraulic structures.

Indicative strength classes for durability – MSZ 1992-1-1:2010

(1) The choice of adequately durable concrete for corrosion protection of reinforcement and protection of concrete attack, requires consideration of the composition of concrete. This may result in a higher compressive strength of the concrete than is required for structural design. The relationship between concrete strength classes and exposure classes may be described by indicative strength classes according to MSZ EN 1992-1-1:2010, Annex E, Table E.1N.

[MSZ EN 1992-1-1:2010 – Annex E – Paragraph (1) – Page 194.]

Indicative strength classes for durability – MSZ 1992-1-1:2010

INDICATIVE STRENGTH CLASSES FOR ENVIRONMENTAL CLASSES									
Corrosion									
Carbonation-induced corrosion				**Chloride-induced corrosion**			**Chloride-induced corrosion from sea water**		
XC1	XC2	XC3	XC4	XD1	XD2	XD3	XS1	XS2	XS3
C20/25	C25/30	C30/37		C30/37		C35/45	C30/37	C35/45	
Damage to Concrete									
No risk				**Freeze / Thaw Attack**			**Chemical Attack**		
X0				XF1	XF2	XF3	XA1	XA2	XA3
C12/15				C30/37	C25/30	C30/37	C30/37		C35/45

[MSZ EN 1992-1-1:2010 – Annex E – Table E1.N – Page 194.]

Example for associating environmental classes and concrete grade

Concrete notation: XC4-XF1-XA2-XV1(H) – Structure: Reinforced concrete retaining wall:

Determined **environmental classes** according to the environmental effects	**Minimum strength class** of concrete according to indicative strength classes	**Minimum cement content** according to the indicative strength classes [kg/m^3]	**Maximum water to cement ratio** according to the indicative strength classes	Mean value of the average total **air content of fresh concrete** [V%]
XC4	**C30/37**	**300**	**0,50**	According to MSZ 4798:2016, Table NAD F2
XF1	**C30/37**	**300**	**0,55**	
XA2	**C30/37**	**320**	**0,50**	
XV1(H)	**C25/30**	**300**	**0,55**	
XC4-XF1-XA2-XV1(H)	**C30/37**	**320**	**0,50**	

[MSZ 4798:2016 – Annex F – Table NAD F4 – Page 138.]

Example for associating environmental classes and concrete grade

Concrete notation: XC4-XF4-XK3(H) – Structure: Wear resistant bridge element induced by freeze/thaw, affected by de-icing agents

Determined **environmental classes** according to the environmental effects	**Minimum strength class** of concrete according to indicative strength classes	**Minimum cement content** according to the indicative strength classes [kg/m^3]	**Maximum water to cement ratio** according to the indicative strength classes	Mean value of the average total **air content of fresh concrete** [V%]
XC4	**C30/37**	**300**	**0,50**	According to MSZ 4798:2016, Table NAD F2
XK3(H)	**C40/50**	**350**	**0,40**	
XF4	**C30/37**	**340**	**0,45**	According to MSZ 4798:2016, Table NAD F3
XC4-XF4-XK3(H)	**C40/50**	**350**	**0,40**	

[MSZ 4798:2016 – Annex F – Table NAD F5 – Page 139.]

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Thank you for your kind attantion!