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Sustainable civil engineering solutions

Achieving sustainability by using concrete with recycled aggregates in infrastructure projects

Sustainability in tunnelling is of crucial importance for long-term economic, social and ecological development. The basis is the Swiss climate strategy and the laws and standards that build upon it.
For tunnels, preliminary studies are crucial for a sustainable overall concept. Only after these studies does choosing building material or optimising concrete become relevant.

1 Sustainability and climate goals

Sustainable development means finding the best possible long-term solution in terms of the economy, society and environment. This is rarely as fundamental and important as it is in tunnelling, where projects have enormous economic, social and ecological consequences. The greatest influence on all of these factors is in the early conceptual project phases 1 – 3 after SIA 112.

If environmental sustainability is considered in the construction industry, it can be formulated as environmental impact per functional unit and service life.

$$\text{Ecological sustainability} = \frac{\underline{\text{Sum of environmental impacts}}}{\text{Functional unit x Service life}}$$

A functional unit can include, for example, one metre of tunnel road divided into two lanes. Alternatively, the tunnel can be considered globally as a single unit. In this context, particular importance is attached to service life. A standardised service life of 80 to 100 years can be used as a reference value.

Credit: an illustration

1 Economic, social and ecological sustainability

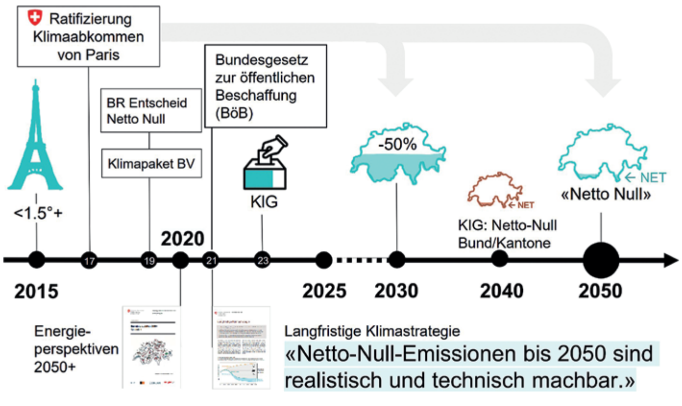
1.1 Sustainable public procurement in Switzerland

In its long-term climate strategy for 2021, Switzerland has adopted a target of zero greenhouse gas emissions by 2050 and has stipulated a 50% reduction in emissions by 2030 in its revised CO_2 Act.

The revised Swiss Federal Act on Public Procurement (PPA January 2021) builds upon this framework along with the general definition of sustainability, which, according to Art. 2, aims to ensure "the economically, ecologically and socially sustainable use of public funds" so that the most advantageous tender is awarded a contract.

In addition, the adoption of the Federal Act on Climate Protection Targets, Innovation and Strengthening Energy Security (CISA) in 2023 will define further measures and require net zero emissions for the Swiss Confederation and cantons from 2040. The Act is expected to come into force in 2025.

Overall, therefore, ever greater demands for sustainability can be expected from public contractors in the future.



Credit: Salome Schori, Federal Office for the Environment, Conference on Sustainable Public Procurement 2024; own additions to the BöB and Climate and Innovation Law

2 Sustainable public procurement in Switzerland

Solutions durables en matière de génie civil

Utiliser le béton et les matériaux recyclés dans les projets d'infrastructures pour parvenir à la durabilité

Les exigences en matière de durabilité pour les nouveaux projets de construction d’infrastructures deviennent plus strictes dans la loi fédérale suisse sur les marchés publics (LMP) et avec la future loi sur le climat et l’innovation. La SIA 112/2 a créé un cadre pour la construction durable dans le domaine du génie civil et de la construction d’infrastructures, dont les objectifs peuvent être intégrés dans les critères d’adjudication des futurs contrats. En conséquence, les décisions globales relatives au projet, telles que l’emplacement, le cubage et la gestion des matériaux, revêtent une importance significative. Les matériaux de construction et la construction elle-même doivent avant tout répondre aux exigences de durabilité écologique et peuvent ensuite être optimisés en conséquence.

Soluzioni sostenibili di ingegneria civile

Sostenibilità attraverso l'uso di calcestruzzo di materiali riciclati nei progetti infrastrutturali

Nella legge federale sugli appalti pubblici (LApub) e con la prossima SNC aumentano le esigenze di sostenibilità nelle nuove infrastrutture. Nel SIA 112/2 è stato elaborato un quadro per l’edilizia sostenibile sotterranea e infrastrutturale, i cui obiettivi possano essere integrati nei criteri di aggiudicazione degli incarichi futuri. Di conseguenza le decisioni progettuali globali come la posizione, la cubatura e la gestione dei materiali hanno un peso determinante. I materiali e la costruzione devono in primo luogo rispettare i requisiti di durabilità ai fini della sostenibilità ecologica e possono quindi essere ottimizzati.

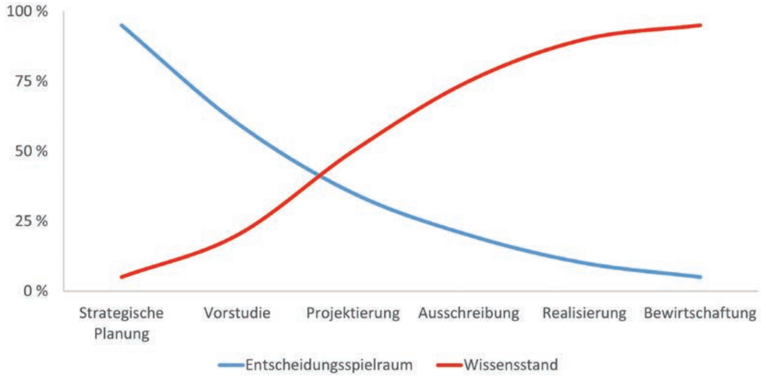
1.2 Sustainability in civil engineering and infrastructure construction in accordance with SIA 112/2 and the PPA

Sustainability criteria in civil engineering and infrastructure construction are defined in SIA 112/2. The guideline defines overarching goals for the sustainability of different types of infrastructure and then breaks them down into sub-goals in the areas of society, the economy and the environment. The focus here lies on aspects of spatial development and settlements, community interests, safety, business and economic costs, environmental pollution, energy, land and resource utilisation.

An in-depth situation analysis is carried out before any planning, in which infrastructure variants are evaluated according to the relevant sub-goals of sustainable construction. Additional services and evaluation criteria for the existing services can then be defined from the goals in procurement. For example, one sub-goal could include “environmentally friendly and resource-efficient use of materials” while an additional service could focus on a materials management concept. The measure (materials management concept) should be less important than the measure’s effect (e.g., actual reduction in material quantities). Compliance in the contract award process can then be controlled by prioritising the tender criteria.

1.3 Sustainability in tunnelling

Tunnels are the infrastructure projects with the greatest impact on space, landscape, safety and resource consumption; they also incur the highest costs. In addition, tunnels are infrastructure designed for the long term. Many of the requirements stipulated in SIA 112/2 have always been implemented in tunnelling due to social, economic and ecological dimensions. The concept phase with preliminary studies is of paramount importance, as the alignment or cross-section selection, influenced by the prevailing geological conditions, significantly impacts the tunnel length and the resulting construction measures. The impact on the landscape, the global excavation volume, the required concrete cubature and the resulting total costs are also already determined within these initial decisions.



3 *Development of decision-making processes and knowledge about the course of the project*

Credit: an illustration

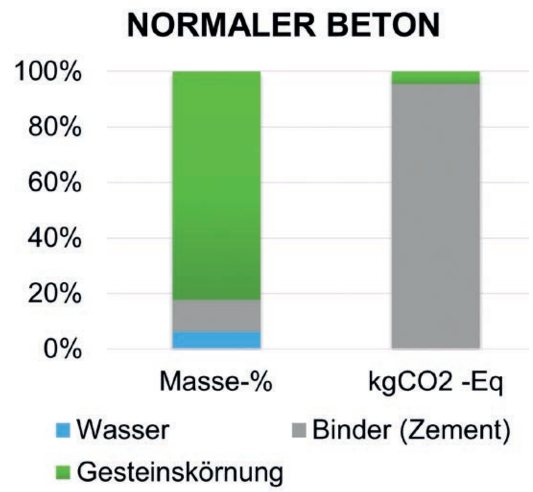
The detailed implementation of these sub-goals takes place during project planning. For example, choosing building materials and testing suitable variants could be a priority here.

2 Sustainable concretes in tunnelling

The assessment of types of concretes used in tunnelling is limited in this article to the consideration of ecological sustainability.

2.1 Types of concrete with reduced CO_2 emissions

Concrete is responsible for around 8% of global and Swiss CO_2 emissions. This is due to the process of creating conventional cement, which is heated to around 1500 °C in a cement kiln with the help of fuel so that the limestone ($CaCO_3$) can calcinate to produce CaO and CO_2. Around 95% of CO_2 emissions from concrete are attributable to cement. Therefore, reducing CO_2 emissions can only be achieved through changing the way cement is used.



Credit: an illustration

4 *Mass proportions of concrete constituents and their CO_2 emissions*

here are four main approaches to producing types of concrete with reduced CO_2 emissions:

1. Low-clinker composite cement and alternative, more sustainable binders
2. Higher packing density in the aggregate
3. Re-absorption of CO_2 through carbonation of the hardened cement paste
4. Compensation of CO_2 emissions, for example through vegetable carbon

Ideally, the first three measures can be combined. When it comes to optimising packing density, the grading curve is optimised and filler is added so that the hollow content in the concrete is reduced, meaning less cement paste and therefore less cement required. However, the aggregates must have a consistent grading curve and the concrete must be mixed with greater precision, as such types of concrete become unstable more quickly. The reduced clinker content of a mixture tends to go hand in hand with reduced chloride and carbonation resistance. As optimised mixes can quickly economise 20% or more on cement, they are still an attractive option. In terms of standards, this process will be possible to a greater extent if the new ND Annex of SN EN 206 overturns the minimum cement quantities and water/cement values and the new versions of the SIA 215/1 (revision) and SIA 215/2 (new) standards also enable the approval of new cements and additives. The OST University of Applied Sciences is currently researching an AI-based tool for optimising recipes that concrete plants will be able to use in the future.

The reabsorption of CO_2 – also known as CO_2 uptake – takes place when the calcination process in the hardened cement paste (clinker component) is reversed and neutral limestone is produced once again. In reinforced concrete, corrosion protection is thus lost and should therefore only be enforced in the recycling process. When using unreinforced concrete, carbonation in the set form can be advantageous, as the structure becomes denser.

As the amount of CO_2 that can be chemically absorbed through carbonation is limited by the amount of clinker in the concrete, and because carbonation takes place slowly on the surface, the clinker is never fully carbonated. Up to 60% can carbonate in the recycling process. The process can be accelerated and made more effective with additional treatments, such as CO_2 treatment.

Zement	Menge [kg/m³]	w/z [-]	Zementsteinvolumen [l/m³]	CaO im Klinker [kg/m³]	$CO_{2,abs}$ BG2 [kg/t]	$CO_{2,abs}$ BG3 [kg/t]
CEM I	*300*	*0.55*	*276*	*185*	*5.6*	*11.3*
CEM I	290	0.64	288	179	5.1 (-0.5)	10.4 (-0.9)
CEM I	310	0.49	266	191	6.0 (+0.4)	12.1 (+0.8)
CEM II/A-LL	300	0.55	277	160	4.8 (-0.8)	9.7 (-1.6)
CEM I*	300	0.55	276	185	7.0 (+1.4)	14.1 (+2.8)

** gerechnet mit einer CO_2 Absorption im karbonatisierten Zementstein von 75 anstatt 60%*

Table 1 *Values of CO_2 absorption in relation to the total emission of concrete granulates*

Credit: Leemann; Carbonation degree of concrete granulate; Cemsuisse, 2021 [1]

The EMPA (Swiss Federal Laboratories for Materials Testing and Research) published the following in a study [1]: a total of 5–14 kg CO_2-eq./tonne of concrete granulate is absorbed under natural conditions.

Other measures, such as reducing transport of raw materials or optimising production, only have minor impacts under normal conditions.

2.2 Concrete with recycled aggregates

Concrete has become the standard construction material of modern times. With an annual output of around 15 million cubic metres throughout Switzerland according to the Association of the Swiss Gravel and Concrete Industry, concrete is the most widely used construction material. At the same time, around 5 million tonnes of concrete demolition waste (CDW) are produced in Switzerland, which represents the largest amount of construction waste. Recycled aggregates are particularly produced in the more densely populated regions of Switzerland. In total, around 85 – 90% is returned to circulation.

Concrete with recycled aggregates can be made from purely concrete demolition waste or mixed demolition waste containing also brick components. As the particles of recycled aggregates and, in particular, the adhering hardend cement paste are softer and more porous than the primary aggregate, they absorb two to seven times more water. Concrete with recycled aggregates therefore has a higher water demand, which generally results in a higher quantity of cement paste. For this reason, concretes with recycled aggregates generally have a slightly lower compressive strength, a lower modulus of elasticity, increased creep and shrinkage values, lower frost resistance and reduced chloride resistance. The verification of alkali-aggregate reaction resistance is very time-consuming for recycled aggregates. Consequently, concrete with recycled aggregates is not authorised for civil engineering concrete types E, F and G in accordance with SIA Guideline 2030. concrete with recycled aggregates is quite suitable for frequently used structural types of concrete, pile concrete or lean and filling concrete with low durability requirements.

Concrete with recycled aggregates content > 25% does not tend to have lower CO_2 emissions. A higher quantity of cement paste means that more cement needs to be added, which in turn increases CO_2 emissions. Depending on the quantity, CO_2 emissions can be offset once again with the recycled aggregates' CO_2 uptake. For example, concrete with 300 kg of cement, which emits around 210 kg CO_2-eq. /m³ of concrete during production, can compensate for around 10 kg CO_2-eq./m³ of concrete with a recycled aggregates content of 50% [1]. According to current standards, some manufacturers are able to produce recycled concrete with the minimum amount of cement and also take advantage of recycled aggregates carbonation.

Recyclingbetonklasse	Betonsorte gemäss SN EN 206:2013+A2:2021, Tabellen NA.5 und NA.8								
	0	A	B	C	D	E	F	G	Pfahlbeton P1, P2, P3, P4
RC-C25	zulässig				1)	unzulässig			zulässig
RC-C50	zulässig				1)	unzulässig			1)
RC-M10	zulässig			1)	unzulässig				1)
RC-M40	zulässig	1)			unzulässig				1)

Credit: SIA Guideline 2030, 2021

Table 2 *Using recycled concrete in accordance with SIA Guideline 2030*

Concrete made from excavated material from a tunnel can be considered a form of recycled concrete. The properties are highly dependent on the aggregate encountered and can be the same for crushed rock as for concrete made from primary material with crushed aggregate.

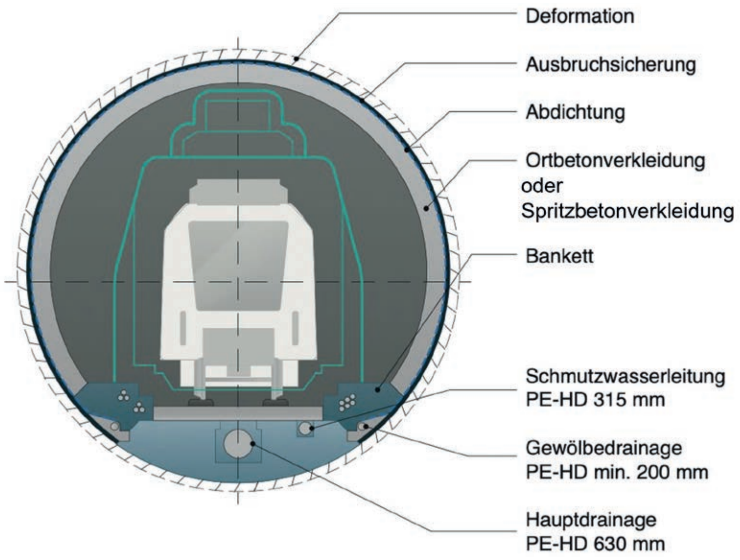
2.3 Sustainable concrete in tunnelling

Concrete is used for many different purposes in tunnelling. Fig. 5 provides an overview.

Depending on the tunnel and application in the tunnel, aggressive incoming water (dissolving and sintering effects, possibly sulphate), carbonation and chloride effects (reinforced concrete), frost, fire or other influences from usage have an impact on the concrete.

2.3.1 Sprayed concrete

Sprayed concrete is mixed on site as a special type of concrete and already needs to fulfil numerous processing requirements. Fine material from the excavated material



Credit: BauPraxis – Underground Construction, Volume 2; Heinz Ehrbar, Olivier Böckli, Christian Ammon

5 *Concrete in tunnel cross-section* has already been used. Recycled concrete aggregates are less recommended, as this can have an unfavourable effect on consistency and workability.

2.3.2 In-situ concrete

In-situ concrete can be used for very different applications.

Reinforced in-situ concrete components, especially with higher exposure classes and aggressive water, can be implemented with excavated material if suitable, but they are less suitable for using recycled concrete agregates. Cement should be used according to technical requirements, as cost savings at the expense of service life reduce sustainability.

Concrete including excavation materials and recycled aggregates can be effectively used for unreinforced concrete exposed to lower quantities of aggressive water. For largescale tunnelling projects in mountainous regions, however, the regional availability of recycled aggregates should be examined. For unreinforced filling and lean concrete, the cement content should also be checked for optimisation potential or alternative filling material.

2.3.3 Prefabricated components

Prefabricated components for tunnelling are rarely produced in a factory in the field and are usually manufactured in a more remote prefabrication plant. Recycled aggregates could potentially be used in the prefabrication plants if they were available regionally.

Segmental tunnel lining in particular is used as prefabricated components in tunnelling, which are usually reinforced and exposed to various types of stress depending on the water conditions. These components are not suitable for the use of recycled aggregates. Gutters and hard shoulders are also exposed to harsh fluids or increased use and are less suitable for this purpose.

Using recycled aggregates is conceivable for other concrete products.

3 Conclusion

In tunnelling, the first three project phases according SIA 112 are decisive for the sustainability of a tunnel. Considerations regarding the route, cross-section, cubature or materials management and logistics are of crucial importance.

From an ecological point of view, tunnel structures should focus on service life and material optimisation should always comply with durability requirements. Suitable excavated material or, if necessary, demolished concrete from temporary components of the tunnel or the region can be used for in-situ concrete.

In principle, regional recycled concrete aggregates can be used for prefabricated components; however, their often high technical requirements must also be met. There is potential for fill and lean concrete, which can either be replaced by alternative materials or produced using excavated material or recycled aggregate.

In principle, for all types of concrete, a review should be carried out to determine whether the cubature can be reduced, alternative materials used or the amount of cement reduced.

References

[1] Leemann, A.: Carbonation degree of concrete granulate; Cemsuisse Project 201906 – May 2021