GREAT POTENTIAL OF PRECAST CONCRETE STRUCTURES IN CARBON NEUTRALITY

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Dedicated to Prof. György L. Balázs
for his 65th birthday

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Cement used in structural concrete accounts for 60% of all cement. Thus, the amount of CO_2 emission by cement in structural concrete in a year is about 5% of the amount emitted by mankind. However, the LCA of structural concrete emits CO_2 not only at the product stage but also at the use stage after construction. In other words, LCA of structural concrete should consider not only the materials but also the maintenance phase. Then low-carbon technologies currently in use is introduced. Moreover, the need for multi-cycle structural concrete with a circular economy is presented. The carbon neutrality of precast concrete structure is not a risk but an opportunity for us.

Keywords: carbon neutrality, precast concrete, LCA, robotics, non-metallic bridge, zero cement concrete

1. INTRODUCTION

According to European data, 60% of cement is used in structural concrete [1]. Globally, cement emits 2.8 billion tons of CO_2 per year. If the ratio were the same as in Europe, cement in structural concrete would emit 5.2% of the amount of CO_2 emitted by mankind in a year. And a third of these emissions are from precast concrete (Favier, De Wolf, Scrivener, Habert (2018). We cannot just cross our fingers and wait for materials to go zero carbon. The countdown to carbon neutrality has already begun. Therefore, we must start now. Concrete structures have a long-life cycle. And the CO_2 emissions are significant when considering not only the materials, but also the construction, the long period of service afterwards and the demolition. In this paper, CO_2 emissions of precast concrete structures are considered in terms of its entire life cycle, and examples of measures to deal with this are presented.

2. ACCELERATED CONSTRUCTION BY PRECAST

Precast construction methods are suitable for lean construction, where stakeholders are involved from the design phase and aim to improve efficiency by reducing project extra costs, materials, time and labour. And this results in reduced CO_2 emissions. The three examples below are design-build projects by builders. The use of precast construction methods was considered from the design phase, and the result is that projects are being completed faster than ever before. The first example is the precast beams and columns of building. (*Fig. 1*) The joints of the precast members are made by grouting the rebars through voids and filling gaps of a few centimeters with grout. Using this method, a building frame can be constructed in three days per floor. (*Fig. 2*) In Japan, the number of buildings using this construction method has reached 52 since 2003, with a total floor area already exceeding 2 million square meters. The second example is the accelerated construction of a bridge pier. (*Fig. 3*) This pier is the tallest in Japan, at 125m. In order to reduce the weight of the precast members, the outer 14cm thick section from the vertical main reinforcement was precast. Within this 14cm, the horizontal hoop reinforcement is incorporated, so that only the 51mm diameter vertical rebar needs to be assembled on site. (*Fig. 4*) One lot is then completed by pouring concrete into the precast as a substitute for the formwork. The construction

Fig. 1: Precast beam and column method without cast-in-situ joints (SQRIM method)

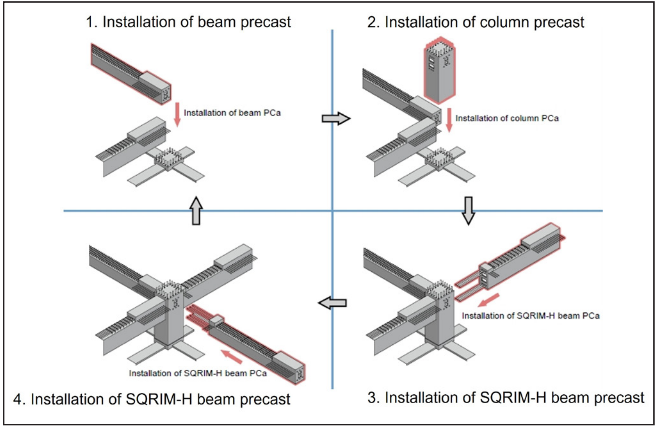

Fig. 2: Construction of a precast beam

speed of this method is 1m per day, which means that it can be constructed in half the construction time compared to the usual cast-in-situ method. The final example is the special precast bridge girders. (*Fig. 5*) Panels called butterfly webs (Kasuga, 2016) are used for the web of the bridge. (*Fig. 6*) And the precast segments, except for the upper slab, (*Fig. 7*) are transported to the bridge site. (*Fig. 8*) The bridge is formed once with the U-shaped cross section beam, and the upper slab is then constructed with cast-in-situ concrete. (*Fig. 9*) In Japan, where transport weight regulations are strict, the number of segments can be reduced by using the U-shape. In addition, the construction of the upper slab can be carried out afterwards and is not critical. This viaduct has a bridge deck area of 35 000 m^2, but was completed in 18 months, including detail design. Thus, accelerated construction by precast can optimize the project. And, although further research is needed, the impact on surrounding social activities can also be minimized by reduced construction time, with the consequent potential to reduce CO$_2$ emissions.

3. ROBOTICS FOR PRECAST SEGMENTS IN CONCRETE FACTORIES

Alongside accelerated construction, the introduction of robotics also improves productivity. This section presents an example of the use of robots for the assembly of rebar cage in the precast members of the upper slab of a steel girder bridge. As shown in *Fig. 10*, the robot consists of two arms. It is equipped with a rebar supplier and the arms are fitted with a

Fig. 3: The highest bridge pier In Japan

Fig. 4: Partial precast construction method for bridge piers

Fig. 5: Okegawa Viaduct (2015)

Fig. 6: Stock yard of butterfly web panels

Fig. 7: U-shaped precast segment without upper deck

Fig. 8: Construction of U-shaped precast segments

Fig. 9: Construction of cast-in-situ upper deck

Fig. 10: Robotics for rebar cage of the precast bridge deck

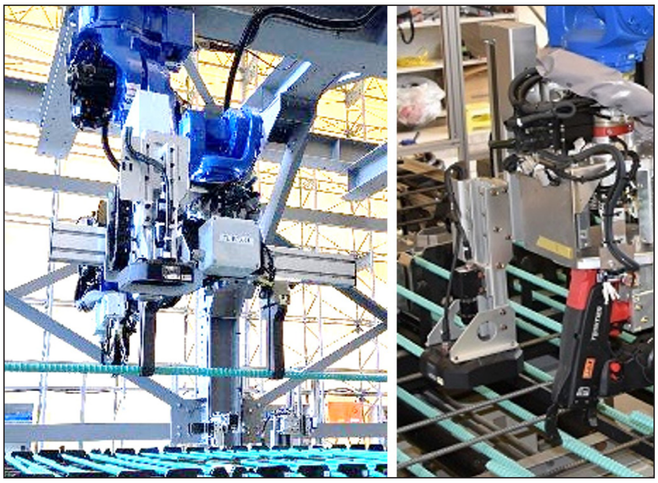

Fig. 11: Rebar holder (left) and rebar binder (right)

rebar holder and a rebar binder. (*Fig. 11*) The upper slab rebar cage is approximately 10 m wide and 1.75m long and usually takes six workers to assemble two cages a day. However, assembly robots can increase this productivity by three times. In the future, it will be possible to check workability on a computer in advance by linking the robot arm's movements with three-dimensional data.

4. LOW CARBON TECHNOLOGIES FOR CONCRETE STRUCTURES

Fig. 12 shows the construction supply chain according to EN15978. Also shown below is the sorting of each player in the construction supply chain by CDP (Carbon Disclosure Project) and SBT (Science Based Target). In A1 to A3, steel and cement industries are already taking action with government support to achieve zero carbon emissions. However, we, as users, cannot wait for these carbon neutral achievements. This is because the demand for low carbon from the business sector has already begun. Therefore, we must meet this demand by bringing together low carbon technologies for structural concrete. The conceptual relationship between structural concrete durability and CO_2 emissions is shown in *Fig. 13*. As shown in *Fig. 14*, we must aim to reduce CO_2 emissions at all stages.

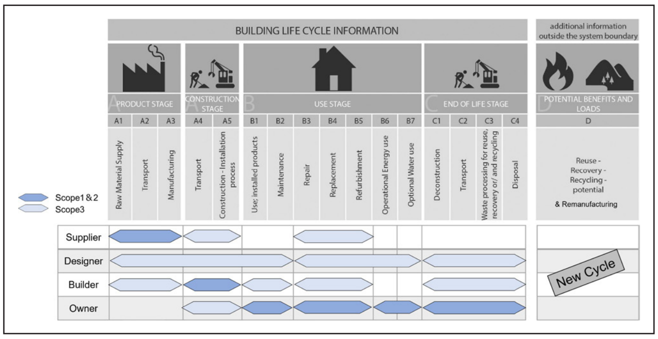

Fig. 12: Construction supply chain (EN15978)

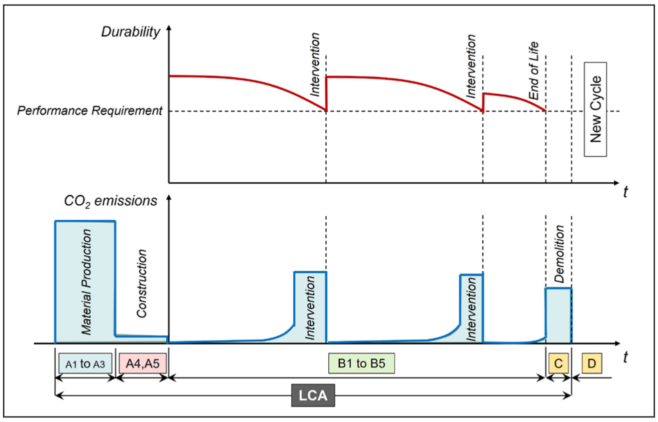

Fig. 13: Conceptual relationship between durability and CO_2 emissions of conventional technologies

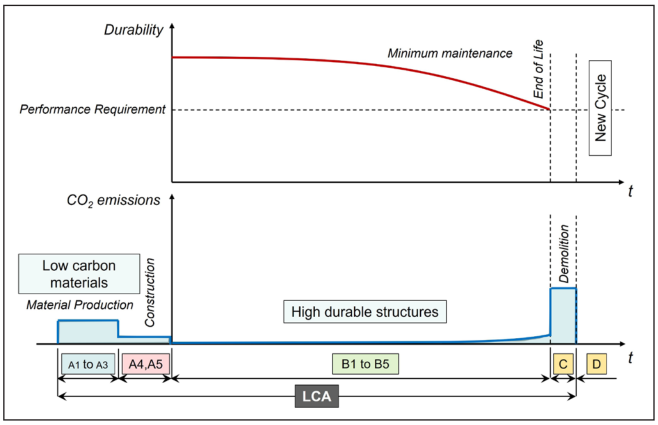

Fig. 14: Conceptual relationship between durability and CO_2 emissions of low carbon technologies

4.1 Low Carbon Technology in the Product Stage

The first step is to deal with the product stage. The low carbonization of stages A1 to A3 must be promoted until steel and cement achieve zero carbon. Concrete that replaces cement as a by-product has already been studied and proven in many cases. Of course, it is not possible to substitute all

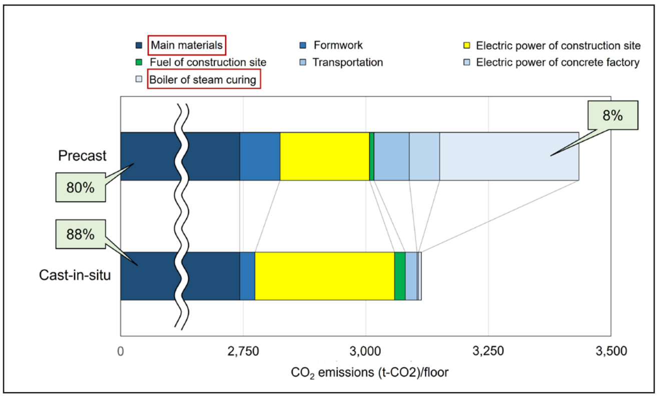

Fig. 15: CO_2 emissions of precast and cast-in-situ per a typical floor of building

Fig. 16: Hydrogen boiler

Fig. 17: Zero cement concrete panel

current cement with by-products, but it is a transition until zero-carbon cement is achieved. In addition, as low carbon concrete is slow to develop its strength, steam curing is required when used in precast products due to restrictions on the conversion of formwork. However, steam curing using boilers emits as much CO_2 in the exhaust gases as the amount of CO_2 reduced by the concrete itself.

The comparison of CO_2 emissions between cast-in-situ and precast construction is shown in *Fig. 15*. The most of CO_2 emission comes from materials, but 8% comes from curing. Therefore, it is necessary to consider the re-use of CO_2 by means of CCUS (Carbon dioxide Capture Utilization and Storage). One method is hydrogen boilers (*Fig. 16*). Hydrogen is still expensive and supplies of hydrogen, especially green hydrogen, are limited. However, if inexpensive, green hydrogen becomes widespread in the future, it will become an established decarbonisation technology. Alternatively, the use of alkaline solutions from cleaning equipment in large quantities in precast concrete plants could be considered. For example, CO_2 from boilers is separated by a special membrane and submerged in this alkaline solution to produce calcium carbonate. ($CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$) The 8% disadvantage shown in *Fig. 15* can then be solved.

When low carbon concrete is used in structures, a challenge is its strength. There are examples of concrete without cement that has achieved a strength of over 100 MPa, and concrete can reduce CO_2 emissions by about 70% (Matsuda , Mine, Geddes, Walkley, Provis, 2022). (*Fig. 17*) Furthermore, fibre reinforced concrete has also been used in actual bridge components without steel reinforcements (Ashizuka, Miyamoto, Kata, Kasuga, 2012).

4.2 Low Carbon Technology in the Use Stage

At present, there is very little data on the relationship between durability levels and CO_2 emissions in stages B1 to B5. Therefore, information on CO_2 emissions by interventions and maintenance during that time is lacking. And these vary greatly depending on the level of durability decided at the time of design. The biggest challenge in conservation is how to prevent the reinforcing steel from deterioration. The Pantheon in Rome, for example, is an unreinforced structure, so it still functions as a structure after 2000 years. And even if steel and cement achieve zero carbon, durability and CO_2 emissions in the use stage remain issues. Therefore, the high durability of structural concrete is essential to reduce CO_2 emissions at the use stage. Currently available technology, such as stainless steel or aluminium reinforcement and coated steel re-bars, can be used to some extent. Increasingly, FRPs (Fibre Reinforced Plastics) such as carbon, aramid and basalt are being used as reinforcement materials. In 2020, non-metallic bridges with aramid FRP tendons have been constructed as the motorway bridge (Matsuo, Wada, Fujioka, Nagamoto, 2021) (*Figs. 18 &19*). There is also a report of

Fig. 18: Bessodani Bridge (2020)

Fig. 19: Aramid FRP tendons in a butterfly web panel

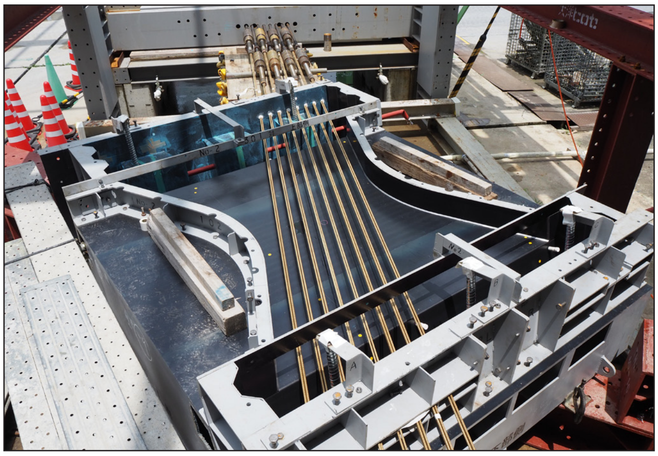

Fig. 20: Girder using zero cement concrete and aramid FRP tendons (2019)

a pretention girder combining high-strength zero-cement concrete and aramid FRP tendons (Shinozaki, Matsuda, Kasuga (2022) (*Fig. 20*). This technology has reduced CO_2 emissions by about 80 to 90% compared to conventional technology in the LCA.

4.3 Low Carbon Technology in the End-of-Life Stage and the Next Cycle

The life cycle of concrete structures is long and involves social and environmental changes due to various factors in the use stage. In other words, changes in population, climate and technological paradigm shifts are expected to force changes in the function of the structure. At this time, for example, bridges may be increased or decreased in width, or routes merged or abolished, while buildings may be extended or reduced, demolished and relocated, etc. It is important to design the first cycle with a view to minimizing CO_2 emissions at that time. Concrete structures that are easy to dismantle are required. And as shown in *Fig. 21*, the multi-cycle use of dismantled components by "remanufacturing" (https://www.remanufacturing.eu/about-remanufacturing.php) can bring the CO_2 emissions of A1 to A3 as close to zero as possible. However, various technologies for multi-cycle concrete structures, including standards, are issues that need to be addressed in the near future. New challenges include in-service monitoring, evaluation of components after demolition, techniques to remanufacture them to be equivalent to new ones, and standardization of structures.

5. CONCLUDING REMARKS

It will still take time for reinforcing steel and cement to achieve zero carbon. However, those of us involved in the structural concrete cannot just sit back and wait for that to happen. We are already beginning to be asked for solutions. From now on, we need not local optimization, but global optimization, in other words, "Think globally, build locally". In addition to CO_2 emissions, concrete currently has problems with its materials, water and sand. Drinkable water is used for mixing concrete, but there are more than 2 billion people in the world without access to safe water. Furthermore, 7.5 billion tons of sand is used annually, which is equivalent to building a 10m x 10m wall on the equator (40,000 km). Sand is in short supply worldwide. And while countries that import sand make fine concrete structures, countries that export it may risk serious environmental damage. In non-metallic structures using FRP as reinforcement, as discussed above, the concrete can be mixed by seawater, as was the case with Roman concrete, because there is no deterioration factor. Research is also underway to use by-product fine aggregates and desert sand in concrete (Othman, Yehia, Elchalakani, 2022). As described above, precast concrete could be said to have great potential in a world where sustainability is becoming more and more important.

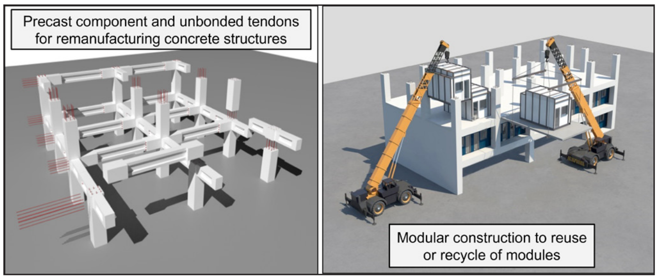

Fig. 21: Concept of remanufacturing of concrete structures for multi-cycle use

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Ashizuka K, Miyamoto K, Kata K, Kasuga A. (2012), "Construction of a butterfly web bridge", *Proceedings fib* Symposium in Stockholm. 2012 Jun.

Favier A, De Wolf C, Scrivener K, Habert G. (2018), "A sustainable future for the European cement and concrete industry", ETH, EPFL. 2018.

https://www.remanufacturing.eu/about-remanufacturing.php

Kasuga, A. (2016), "Effects of butterfly web design on bridge construction", *fib Journal Structural Concrete* Vol.18/1. 2016. https://doi.org/10.1002/suco.201600109

Kasuga A. (2023), "Great potential of precast concrete structures for carbon neutrality", CPI – Concrete Plant International, 3 | 2023

Matsuda T, Mine R, Geddes D, Walkley B, Provis J. (2022), "Development of ultra-low shrinkage and high strength concrete without Portland cement with experimental study on its fabrication", *Proceedings, fib* Oslo Congress. 2022 Jun.

Matsuo Y, Wada Y, Fujioka T, Nagamoto N. (2021), "Construction of non-metal bridge", *Proceedings fib* Symposium in Lisbon. 2021 Jun.

Othman O, Yehia S, Elchalakani M. (2022), "Development of high strength concrete with fine materials locally available in UAE", *Proceedings fib* Oslo Congress. 2022 Jun.

Shinozaki H, Matsuda T, Kasuga A. (2022), "Construction of non-metallic bridge using zero-cement concrete", *Proceedings fib* Congress 2022 in Oslo. 2022 Jun.

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