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USE OF NON-DESTRUCTIVE CONCRETE QUALITY ASSESSMENT FOR SELECTIVE DEMOLITION OF A HIGHWAY BRIDGE

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Abstract

Demolition and replacement of the existing transportation infrastructure have increased significantly due to ageing and growth of traffic loads. Consequently, a significant amount of demolition waste of unknown origin is produced. Without knowledge about parent concrete quality only a limited amount of recycled concrete aggregates is used in high-grade applications. This paper presents the framework for selective demolition of a highway bridge by systematic non-destructive concrete quality assessment.

Surface chemical composition of concrete structural members was tested with handheld X-Ray Fluorescence Analyzer. In total, 3 columns, 23 beams, one foundation slab and one abutment were assessed. Their compressive strength was estimated using developed conversion curves based on results from rebound hammer and ultrasonic pulse velocity tests and their correlations to cube compressive strength test results. Beams were classified as a high strength (> 80 MPa) members. Columns, foundations and abutments were of a strength lower than 75 MPa. Ordinary Portland cement and silicious aggregates were identified by their chemical composition for nearly all accessible concrete members surfaces. The concrete chemical composition serves as a criterion for future application of fine recycled material. Members were sorted based on strength before demolition. This approach is essential to maximize the potential of the recycled concrete.

Keywords: Non-destructive testing, concrete structures, selective demolition, strength, chemical composition, handheld X-Ray Fluorescence Analyzer

1. INTRODUCTION

A considerable amount of literature has been published on concrete performance with recycled concrete aggregates (RCA) of unknown origin from field [1]. Knowing the origin of RCA is usually not possible because the demolition and recycling processes often produce and merge the concrete streams of different qualities. Researchers demonstrated that with proper concrete rubble separation, RCA can substitute 100 % coarse natural aggregates in new concrete [2, 3]. Selective demolition aims to recovering materials with the greatest value. By testing concrete structural members in situ, it is possible to separate the concrete rubble into different stocks based on their qualities. Two parameters that are crucial for concrete quality assessment in structures before demolition are concrete strength and chemical composition [4]. Based on selective demolition, energy consumption in recycling can be

controlled because of known material input properties. Furthermore, selective demolition leads to the homogeneity in the properties and high-quality of RCA due to known properties of the parent concrete. The concrete compressive strength can assist recyclers in the selection of appropriate concrete crushing equipment and contribute to a sustainable production process [5]. Identification of cement type in parent concrete can assist in deciding on the application for recycled material (mineral addition for clinker manufacturing, pozzolanic materials, fillers) [4].
Previous studies have not dealt with selective demolition of concrete structures in engineering practice with the purpose of improved classification of recycled concrete aggregates. Thus, the goal of this study is to investigate the feasibility of using selective demolition for a highway bridge rather than conventional demolition. For this purpose, non-destructive testing techniques, handheld X-ray fluorescence (hXRF) analyser, ultrasonic pulse velocity, rebound hammer, were used for assessment of concrete quality prior demolition. Recently, non-destructive screening methodology based on handheld XRF for the classification of concrete has been demonstrated [6, 7]. Destructive testing was applied to confirm non-destructive testing results. The paper contributes to developing a workflow for selective demolition and to further develop and support future studies on selective demolition and the circular reuse of concrete.

2. BRIDGE DESCRIPTION

The Sluinerweg viaduct was built in 1970 and it was located at Dutch Highway A1. The concrete mix design for structural members were obtained from archive as shown in Table 1. The deck had 4 spans with a total length of 75.5 m and total width of 14.95 m and it consisted of 23 prestressed concrete T- beams per span. These prestressed beams are supported by support beams, columns, foundations, abutments and piles which were cast in situ. In 2023, the viaduct was destined for demolition and became available for this research. The reason for viaduct demolition was a highway widening from 2 x 2 lanes to 2 x 4 lanes to meet capacity increase. At the same location, a new viaduct will be built.

Table 1: Archive data on concrete mixtures

Structural member	Cement	Aggregates	Chemical admixtures	Compressive strength
Beams	360 kg Portland cement Class B	Fine aggregate (0 – 5.6 mm) Coarse aggregate (5.6 – 32 mm)	-	min 40 MPa at 28 days
Columns	325 kg Portland cement Class A			
Abutment	325 kg Portland cement Class A			
Foundations	325 kg Portland cement Class A		Cretoplast; Cretobel (3 to 4% air)	

3. CONCRETE QUALITY ASSESSMENT

This section summarizes characterization methods for in situ concrete quality investigation of the Sluinerweg viaduct. Two parameters, concrete compressive strength and chemical composition were investigated. The investigation was performed on the northern side of the viaduct, see Figure 1 and Figure 2. The following methods were used, visual inspection, non-destructive testing, destructive testing. A spatial distance between measurements were fixed to 5 cm.



Figure 1: Overview of bottom bridge structure.


Figure 2: Core extraction and non-destructive measurement techniques of concrete quality in situ, handheld X-Ray Fluorescence, Silver Schmidt Hammer, Ultrasonics Pulse Velocity Pundit PL-200.

3.1 Estimation of in situ compressive strength using Schmidt hammer

The rebound numbers were determined according to EN 12504–2:2021 [8] using Proceq Silver Schmidt OS8200. A minimum of 20 readings were recorded. The median of the readings was taken as the representative rebound number for the tested concrete structural member. Correlation curves were created in accordance to EN 13791 [9] for concrete mixtures with compressive strength ranging from C20/25 to C80/95.

3.2 Determination of ultrasonic pulse velocity in concrete

The ultrasonic pulse velocity in concrete was tested according to EN 12504–4:2021 [10] using proceq Ultrasonics Pulse Velocity Pundit PL200. Pulse velocity was measured by placing the two transducers on opposite faces of the concrete member (direct transmission) for beams and abutment walls. It was decided not to measure UPV on foundations and columns as direct transmission was not possible.

3.3 Handheld X-ray fluorescence (hXRF) analyser in situ

The concrete surfaces were analysed using a Bruker S1 TITAN 800 handheld Energy Dispersive X- ray Fluorescence analyser, equipped with a rhodium tube from which X-rays are emitted, and a high- resolution Silicon Drift (SDD) detector. The instrument produces an X-ray beam at a 45° angle from the centre of the analyser's tip [6]. The decision for surface treatment was dependent on initial measurement and potential presence of coatings. When coating was detected, then it was necessary to search for a surface that was free of coating or to remove coating using sand paper with grit of 180.

More than 10 measurement points were taken with handheld X-ray fluorescence (hXRF) from the columns, the abutment, the bottom and sides of 23 beams. More details about the concrete investigation with hXRF at Sluinerweg viaduct are given in the research of Gomez Jaramillo [7].

3.4 Core extraction

For the determination of the concrete compressive strength and density, cores with a diameter of 100 mm and a length up to 200 mm were drilled from the prestressed T-beams, columns, abutment, and foundation. Cores were taken from carefully preselected locations, close to the support beam, so that the prestressing tendons would not be damaged. In total 35 cores are drilled, 8 in the T-beams, 9 in the columns, 6 in the foundations and 12 in the abutment walls. In-situ compressive strength was assessed based on standards EN 12504-1:2019 and EN 13791:2019. The coring orientation was vertical for beams and foundations. For columns and abutment walls, it was horizontal. Cores were sealed, transported to the laboratory and cured at relative humidity ≥ 95 % at (20 ± 2) °C. Ends of the cores were cut and surfaces were mechanically ground before testing.

4. RESULTS AND DISCUSSION

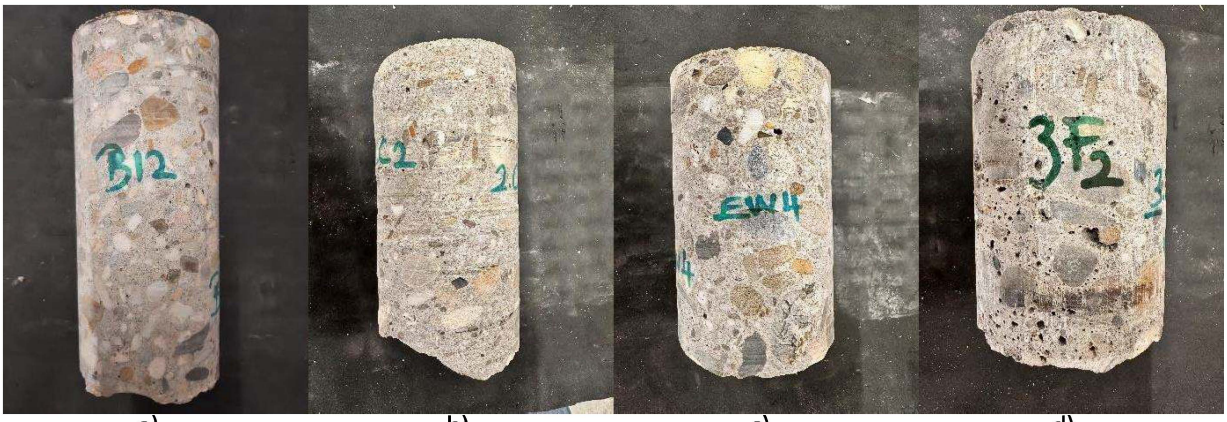
4.1 Visual inspection of concrete surfaces and concrete cores

The visual inspection is the starting point for an initial assessment of the concrete quality. In general, the concrete surfaces did not show any signs of deterioration, cracking or corrosion of the reinforcement. In case of beams, a localised black crust was observed sporadically, see Figure 3a.



a) b) c) d)

Figure 3: Concrete surfaces of a) beams, b) columns, c) abutment wall, d) foundation.



a) b) c) d)

Figure 4: Concrete cores from a) beams, b) columns, c) abutment wall, d) foundation.

In case of columns and abutment walls surfaces, crystalline cement granite coating was observed when an unexpected high amount of SiO_2 was measured, see Figure 3b, c. This coating protected concrete from different deterioration mechanisms. The surfaces of foundations were painted and covered with soil layer, see Figure 3d. The cores were also visually inspected and in general, the concrete is well compacted and did not show any signs of deterioration, cracking or corrosion of the reinforcement, see Figure 4a-d. In case of foundations (6 cores), great amount of large pores was observed, see Figure 4d. Finally, large maximum aggregate sizes (D_{max}) are observed in the range of D_{max} = 32–46 mm.

4.2 Compressive strength

The results for the average values of measured concrete compressive strength and density, estimated compressive strength based on rebound numbers and UPV values are given in Table 2. After 54 years, the current strength for the prefab prestressed concrete T-beams has more than doubled over time compared to the design strength of 40 N/mm^2. The prefab beams were prefabricated under controlled conditions. Therefore, it was expected that the beams have a high compressive strength as seen in Table 2. Compared to beams, other structural members have an average compressive strength lower than 75 MPa. Non-destructive test results are comparable to destructive test results for compressive strength except for columns. This can be attributed to the test region with Schmidt hammer. The test region was at the bottom of the columns where the reinforcement configuration is the densest. This configuration could influence energy impact of Schmidt hammer measurements, leading to higher rebound numbers. The ultrasonic pulse velocity (UPV) increased with an increase in compressive strength, indicating denser concrete.

Table 2: Compressive strength results (average ± standard deviation)

	Destructive testing results			Non-destructive testing results		
Structural member	Number of cores	In situ cylindrical compressive strength [MPa]	Density [kg/m^3]	Rebound number Q (RN)[-]	Estimated compressive strength based on RN [MPa]	UPV [m/s]
T-beams	8	87 ± 10	2432	72	92	4651 ± 57.3
Columns	9	71 ± 6.2	2397	69	90	-
Abutment	12	64 ± 3.0	2380	58	71	4341 ± 46.6
Foundations	6	67 ± 5.3	2327	57	71	-

4.3 Chemical composition

The hXRF measurements performed in situ were organized into distinct subsets for each structural member. Details on each of these can be found in the research of Gomez Jaramillo [7]. Each distinct data set is comprised of a set of spectra that provide the raw data, and files containing quantitative data on chemical composition. The only exception to hXRF measurements was the surface of foundation that was contaminated with soil. After removal of soil, a black paint at the surface disabled to obtain a correct chemical composition of the concrete surface.

Aggregate chemical composition was measured on all members and it was found to be silicious for all of them. Table 3 presents the aggregate composition equal for all members.

With CaO > 60.6 wt.% and SiO_2 > 19.2 wt.% the type of cement can be defined as Portland cement (CEM I), according to EN 197-1:2011. Table 3 shows that measured cement chemical composition met

this criterion for all structural members surfaces. The results are comparable with chemical composition of laboratory made Portland cement (CEM I)-based concrete cubes [6]. Note that, results with the assumption of perfectly cured, free of efflorescence, dried concrete surfaces should be for CaO in the range of $CaO_{min-max}$ = 60.6–63.9 wt.%. This assumption does not consider the effect of efflorescence on the chemical composition analysis of concrete surfaces. Efflorescence has large impact on the hXRF measurements, when concrete is cured in the conditions of relative humidity higher than 75% [7]. In conditions outside, such as at the bridges, higher content of CaO, is therefore, expected.

For existing bridges and viaducts with service life more than 50 years, it is atypical that the original documents are available for research. For Sluinerweg viaduct, the data, as presented in Table 1, can be readily compared to the results with hXRF. Compared to the original documents, the Ordinary Portland cement is proven to be in line with archive data, see Table 1. Aggregates were silicious, with SiO_2 > 95 wt.%.

Table 3: Concrete chemical composition (wt.%)

In situ hXRF chemical composition	Aggregate type		Cement type			
	Average composition for all members	Chemical composition of aggregates according to [6] for reference round river aggregates	Beams	Columns	Abutment walls	Chemical composition of OPC-based concrete according to [6]
MgO	0.4	1.7	-	1.5	-	1.3
Al_2O_3	0.9	0.8	3.6	5.0	4.8	3.9
SiO_2	98.6	95.5	19.4	21.2	27.4	24.1
P_2O_5	-	-	0.3	0.8	1.4	0.3
SO_3	0.0	0.1	1.9	1.1	1.0	-
K_2O	0.1	0.5	2.4	0.7	0.7	0.6
CaO	0.2	0.8	66.2	66.8	62	66.2
TiO_2	0.0	0.1	0.4	0.3	0.3	0.4
MnO	-	-	0.1	0.1	0.1	0.0
Fe_2O_3	0.2	0.5	5.2	2.9	2.7	3.2
	100.0	100.0	100.0	100.0	100.0	100.0

5. SELECTIVE DEMOLITION

For the concrete quality assessment on the Sluinerweg viaduct, four months were available for the planning and preparations before the actual selective demolition. The decision for selective demolition of beams, columns, abutments and foundations was based on results for compressive strength. The information on chemical composition of concrete was provided to recycler so that proper application of recycled materials, specifically, of fine fraction, can be selected. Actual demolition sequence started with the demolition of T-beams by means of a multi-jaw, see Figure 5. Thereafter, the columns were demolished again with a multi-jaw. Finally, the foundations and abutments were demolished with a

jack hammer, see Figure 5. Most of the prestressing steel and reinforcement was separated from the concrete and stored separately. Total weight of 2378 tonne of concrete rubble and 60 tonne of metals was obtained. After each structural member was demolished the obtained concrete rubble was placed into specific containers for later transport to the recycling plant.



Figure 5: The demolition of T-beams with multi-jaw (left) and foundation slab with jack hammer (right).

6. SELECTIVE RECYCLING

For each structural member, a minimum of 30 tonnes of concrete was recycled. Fragmentation of large demolition concrete blocks to sizes less than 500 mm was performed to fit the concrete blocks into the feeder. Subsequently, the concrete rubble was recycled with rotor crusher into recycled concrete aggregates, see Figure 6.



Figure 6: Fragmentation of large demolition beam concrete blocks with sizes less than 500 mm (left). Crushing of demolition rubble into recycled concrete aggregates with sizes less than 60 mm (right).

After recycling it could be observed that there is a significant increase in the 0/4 mm fraction for concrete from the foundation in comparison to the others, see Figure 7. The demolition should focus as much as possible on the production of coarse fraction, and decrease of fine fraction 0/4 mm production. Fraction 0-4 mm cannot be used in high-end applications, it becomes too wet to be processed as a high-end product [11]. The reason for the larger share of fine fraction is considerable hammering required to loosen the concrete from the foundation piles. More intense hammering produces more fine fraction. Consequently, when the input material has a lower fineness module, then that will also hold for the output recycled material. Additionally, it can be found that smaller feed material will generate smaller output material [12, 13]. Note that demolisher deliberately grabbed the concrete rubble from above to ensure that no adhering sand came with it.

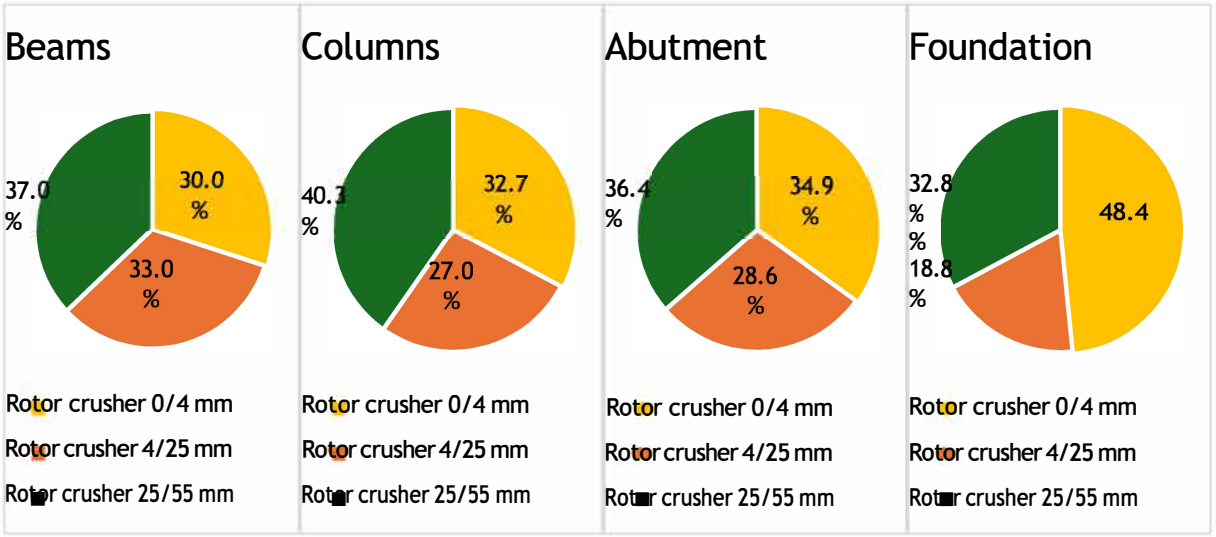


Figure 7: Variability of fractions after selective recycling of structural members. The numbers in the pie charts show the abundance of different fractions as a percentage of the total feed concrete weight used for production of recycled concrete aggregates.

11. CONCLUSIONS

- Selective demolition requires quality assessment of concrete structural members. Compared to traditional demolition, no additional equipment, except containers for placing the concrete rubble, and no additional time for separating different structural members was needed for selective demolition.
- Non-destructive testing (NDT) of concrete quality guided the selective demolition, and it was verified with destructive testing. New NDT developments included handheld XRF, a portable device, which measured chemical composition of concrete in situ. Rebound hammer measurements were performed for compressive strength estimation. Transmission measurement device was used for the determination of ultrasonic pulse velocity (UPV) at the same location of rebound hammer measurements. UPV was used for homogeneity control of concrete quality. Non-destructive test results were comparable to the archive data and destructive test results. It has become apparent that in practice it is difficult to drill a sufficiently large number of cores per T-beam in relation to the selection process of coring location. Non- destructive testing of concrete compressive strength is in these cases advantageous.
- This study demonstrated that chemical composition of aggregates and cement are the same for all structural members, however, compressive strength differed. This is in line with archive data,

the same type of cement was used for the whole structure of the viaduct. However, different cement contents were used for concrete structural members which resulted in their different compressive strengths. Beams were classified as a high strength (> 85 MPa) members. Columns, foundations and abutments were of a strength lower than 75 MPa. Based on strength classification, but also presence of coatings at different structural members, ground in case of foundations, structural members were demolished separately.

The potential of selective demolition will be demonstrated with future characterization of recycled concrete aggregates 0/4 mm and 4/22 mm from demolished beams, columns, abutment walls, foundations. All individual fractions with known quality of the parent concrete will be used in new concrete mixtures. Their performances will be compared with the performance of recycled concrete with recycled concrete aggregates of unknown quality originating from mixed concrete streams.

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