Reuse of concrete for the construction of a retaining wall: a case study

A Collaud[1], M Mongillo[1], E L Niederhäuser[1], J Pathé[2], D Redaelli[1], H Buri[1],

[1] School of Engineering and Architecture HEIA, Fribourg, Switzerland
[2] 2401, Montreux, Switzerland

hani.buri@hefr.ch

Abstract. A promising strategy to reduce the environmental impact of the construction industry is the reuse of structural elements resulting from the deconstruction of existing buildings. However, despite a growing interest from the academic and industrial communities, practical examples of the reuse of structural elements remain very scarce at present, especially in the case of reinforced concrete buildings, which generally consist of a monolithic load-bearing skeleton that has not been designed for dismantling or reuse. This paper presents the results of a study on the reuse of concrete blocks from the deconstruction of an existing building as components for the in-situ construction of a new retaining wall. A real case study is considered. It consists of a building constructed in the 1970s. The developer of the new building wishes to reuse parts of the old building to create a new retaining wall on the boundary of the plot, with a length of 105 metres and a variable height between 60 and 250 cm. The dimensions and shape of the concrete blocks can vary considerably depending on the deconstruction technique used. In order to take into account this aspect, as well as the variable height and the mechanical support of the retaining wall, alternative solutions have been analysed. This paper presents the conceptual design and preliminary dimensioning of these solutions, as well as a discussion of their ability to meet all the technical and normative requirements.

1. Introduction

The built environment is a major contributor to greenhouse gas emissions: 40% of CO2 emissions are attributed to it [1]. In Europe, half of the materials used are attributed to the construction sector, and in Switzerland, two-thirds of the waste comes from construction sites [2]. In view of the climate emergency, reducing the CO2 impact of the construction industry is becoming a major challenge. Concrete is the dominant building material in Switzerland: its volume is 16 times higher than the volume of bricks and wood used annually [3]. Currently, a large proportion of demolished concrete is recycled. Unfortunately, recycled concrete requires a similar or higher amount of cement than normal concrete and doesn't offer a decisive advantage in terms of CO2 emissions [4]. Instead of recycling, reusing concrete blocks can provide much more effective environmental benefits.

Although examples of concrete reuse are relatively rare, a recent study has shown that the practice has existed since the early 1970s, is technically feasible, has high environmental benefits and is cost-effective [5]. Concrete reuse is an opportunity for local companies with complementary skills to develop and enrich their know-how and create a new value chain. Barriers to a wider application of re-used concrete elements are mainly related to project management, design and technical aspects [5]. In particular, the coordination between the availability of suitable elements in a donor structure and the technical and time constraints of the receiver project is perceived as a barrier. In addition, lack of

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practical experience, design codes and working procedures are identified as transitional barriers to the application of reused concrete elements.

The project presented in this paper is an example of the practical applicability of concrete block reuse and is the result of a collaboration between an academic partner, a local engineering and design firm and a local construction company. This paper describes the design process for a new retaining wall using reused concrete elements. This applied study and its investigations made it possible to experience the design process with reused concrete elements and to identify its main problems.

2. Case study for a retaining wall with reused concrete elements

The donor structure was designed for offices and large storage areas and was built in 1974. The load-bearing structure, with a span of 8 m in the longitudinal direction and 7 m in the transverse direction, consists of concrete slabs supported by mushroom-shaped columns. The slabs are 22 and 25 cm thick. The façade is partly glazed and partly covered with precast exposed aggregate concrete panels.

The receiver project is a retaining wall on the site boundary. The total length of the wall is 105 m with a variable height from 250 to 60 cm. The wall can be divided into three sections with different specifications. The first section has greater mechanical demands, as the average height of the retained soil is 2 m. The second and third sections have an average soil height of 60 cm and limited mechanical demands. In addition, in the third section, the retained soil is located on the opposite side of the wall with respect to the other sections.

2.1. Exploration of the donor structure and preliminary drafts

The donor structure was studied to identify possible locations for extracting elements that have the potential to be reused in the receiver project, according to [6]. In parallel, existing deconstruction methods were studied to know what kind of building blocks could be extracted. Based on this information, a set of preliminary design propositions was established. For each proposal, static and durability constraints were identified and discussed.

2.1.1. Investigation of the donor structure

Five locations of interest for reuse in a retaining wall were identified in the donor structure (Fig. 1).

Three locations were identified in slabs (Fig. 1, Cases 1-3) of different thicknesses (22 cm for the roof and first floor slabs, 25 cm for the ground floor slab). The length of the extractable elements is limited by the arrangement of the mushroom columns and varies from 5 to 8 metres. The width can be chosen within a range of 2 to 4 metres. All the slabs could be used for the retaining wall and the quantity available exceeds the needs of the recipient project.

Another interesting location is the existing basement wall (Fig. 1, Case 4), as its actual function is close to that of the recipient project. Unfortunately, the plans available are incomplete and the outer part of the wall was underground and not inspectable before demolition.

The last location are precast elements of the façade cladding with exposed aggregates. They measure 450 cm x 136 cm and are 10 cm thick. Although they are too thin to be used as retaining wall elements, they can be easily dismantled and could be used to cover the top of the wall.

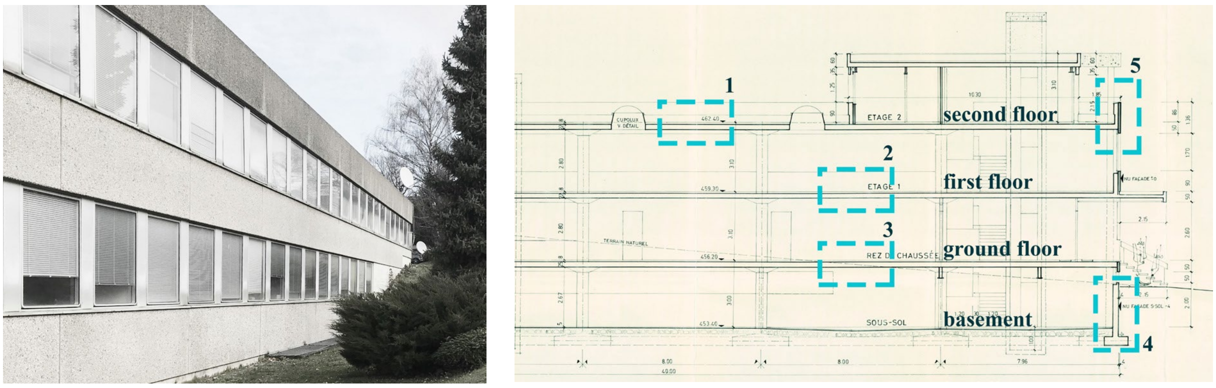


Figure 1. Donor structure and possible locations for the extraction of concrete blocks

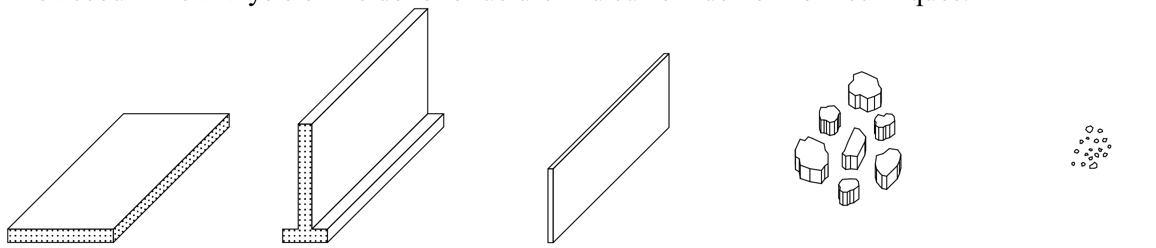
2.1.2. Concrete deconstruction techniques
Two main types of demolition techniques are used in practice.

Concrete crushing with a mechanical jaw is used for rapid demolition. Typically, concrete blocks are crushed to a size suitable for transport and then sent to a reprocessing centre where they are crushed for recycling into new concrete or other uses. Different types of jaws are used depending on the thickness of the concrete and the desired size of the crushed blocks. Typical block lengths and widths vary between 20 and 60 cm. Smaller blocks can be crushed on site if required.

Concrete sawing is used to extract larger elements of regular size and geometry. Floor saws can cut to a depth of 40 cm and are used for fast cutting without special requirements. Rail saws are used for precise cutting on horizontal and vertical surfaces, with cutting depths up to 100 cm and cutting angles up to 45°. For special shapes or very thick elements, cable saws are used, although their installation is more complicated and time consuming.

Extraction by sawing must be carefully planned. The panels and, if necessary, the surrounding surfaces must be supported. The size of the sawn element will depend on the lifting equipment and the ability to extract the blocks from the existing building.

Figure 2 shows concrete elements that could be extracted and reused in the retaining wall design, taking into account the analysis of the donor structure and current demolition techniques.



a) slab 22-25cm b) basement wall c) facade cladding d) crushed blocks 20-60cm e) crushed blocks 5-20cm

Figure 2. Extraction material

2.2. Preliminary sketches for retaining walls with reused concrete blocks.
Based on existing retaining wall construction techniques, several concepts were evaluated.

Gravity walls (Fig. 3, a-b) Two types of gravity walls were considered: simple walls obtained by piling up medium sized crushed blocks, with or without mortar (Fig. 3, b) and gravity walls made of gabion baskets filled with small sized blocks (Fig. 3, a). In both cases, the bearing capacity of a wall is achieved by its weight and geometry (width) and by friction between the layers. The design can be based on graphical static principles.

Cantilever and pile retaining walls (Figure 3, c-d) The load bearing capacity of these types of walls is provided by vertical bending. Recycled concrete slabs must be monolithic in the vertical direction, while their horizontal width can be freely chosen according to availability. In the case of pile walls, the total height of the panels must ensure a sufficient fixed length in the ground. In the case of cantilever walls, the vertical section must be anchored to the ground with continuous reinforcement and appropriate detailing. In both cases, the load-bearing rebars are on the back of the wall and must be protected from corrosion as they are in contact with soil and moisture.

Soldier pile wall (Figure 3, e) The main load-bearing capacity is provided by wide flange steel sections embedded in concrete piles drilled into the ground. Concrete panels support the backfill pressure by bending in the horizontal direction. The length of the panels corresponds to the distance between the steel profiles and can be chosen to fully utilise the available bending strength of the panels. The height of the panels can be freely chosen. The main load bearing bars are on the front face of the wall. Even though this face of the wall is exposed to water splashes with de-icing salts in the vicinity of the car park ramp, the possibility of easily observing and inspecting this face is considered a significant advantage for this type of wall in terms of durability.

In all propositions the façade cladding can be used as protection layer on top of the wall.

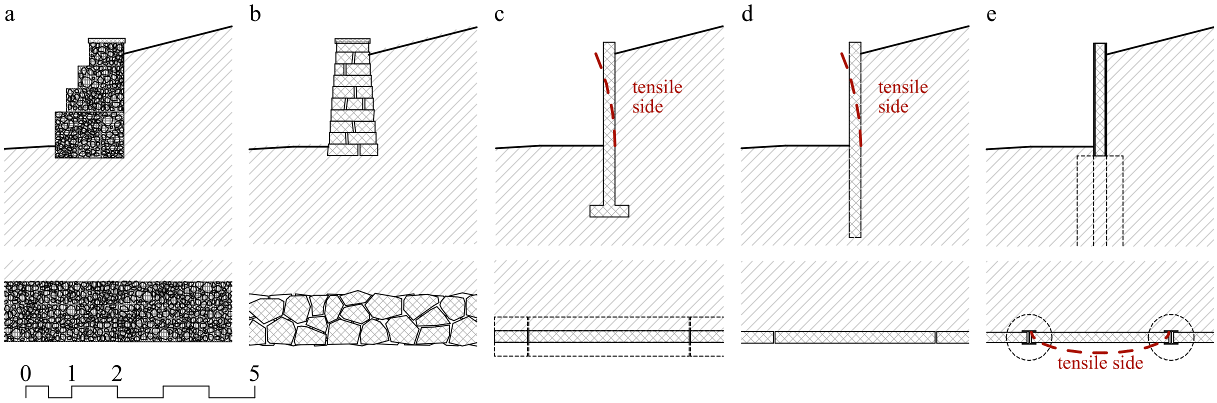


Figure 3. Preliminary design propositions, a) gravity wall with medium size blocks b) gravity wall with gabion basket c) cantilever wall d) piled wall e) soldier pile wall (red: deformation)

2.2.1. Preliminary evaluation of durability and protection methods

The exposure classes describe the environmental actions and the resulting risks to durability. For exterior concrete elements that are vertically positioned and not exposed to chlorides, the main risk is reinforcement corrosion due to concrete carbonation, corresponding to exposure class XC4 [9]. To ensure a service life of 50 years, the standards recommend the use of carbonation-resistant concrete and a minimum reinforcement cover of c = 40 mm. For elements exposed to chlorides, exposure classes XC4, XD3 and a minimum cover c = 55 mm are required.

Concrete elements in the donor building have a cover of c = 20 mm. Even if such a cover is still applicable today for concrete elements placed indoors with low humidity (exposure class XC1), this solution is not acceptable for classes XC4 or XD3 according to the current standards.

Based on in-situ measurements and analytical modelling of the propagation of aggressive agents in the concrete cover, the risk of corrosion of reused concrete blocks in their future environment is currently being evaluated. A priori, however, it is expected that reused concrete blocks will require surface protection to ensure a remaining service life of 50 years. Several options are available to increase the resistance of concrete to aggressive agents.

Surface treatments such as protective coatings and impregnating agents are effective in reducing the access of aggressive agents, but have a short life and need to be reapplied periodically. Long-lasting solutions can be achieved by applying a protective and reinforcing layer in mortar, epoxy resin, fibre reinforced concrete (FRC) or ultra high performance fibre reinforced concrete (UHPC). These solutions require a preliminary surface treatment to achieve a minimum roughness (micro-blasting, water jetting). They incur higher economic and environmental costs, which may be competitive in cases where an increase in durability and mechanical strengthening of existing concrete blocks is required.

2.2.2. Discussion and comparison of the preliminary design

The preliminary design proposals are compared taking into account the durability of the construction, ease of execution, material efficiency and efficiency of reuse.

Gravity walls: The advantage of reusing crushed pieces is the simplicity and speed of extraction. On the other hand, since the crushed pieces are of arbitrary shape and size, only part of the extracted material is suitable for reuse. In addition, gravity walls require more material and high walls in particular are not material efficient. The gabion basket technique has already been implemented [7], in contrast to the use of larger blocks, whose stacking must be experienced. Gravity walls don't need reinforcement, which is a great advantage. If reinforcements are present, their corrosion can lead to unsightly rust marks and, over time, to the loss of concrete fragments due to corrosion-induced spalling, which can be compensated for by slightly oversizing the initial width of the wall. The crushing of the concrete must be considered as downcycling. Nevertheless, gravity walls could be constructed using concrete that cannot be recycled for equivalent reuse.

Cantilever walls and piled retaining walls: Although the extraction of the elements is more complex and time-consuming than for gravity walls, the material efficiency is much higher and the reuse can be considered equivalent to the previous use for these proposals. Their main problem is the change in the physical environment, which alters the normative requirement for durability. The lack of reinforcement protection cannot be adequately compensated by additional layers over a long period of time, which means that the normative requirements cannot be met. However, it is plausible that the durability of the rebar protection is greater than the conservative estimate of the code requirement. It is therefore important to be able to visually inspect the ageing and physical behaviour of the wall over time. As the load bearing rebars are on the back of the wall, this is not possible with these solutions.

Soldier pile wall: The advantages and disadvantages are similar to the previous proposals. The main difference is that the load bearing bars are on the face of the wall, which allows visual inspection and monitoring and the application of additional protective layers if required. This can be seen as a major advantage of this solution, which was chosen for the final design.

2.3. Definitive project

The chosen solution (pile soldier wall) consists of two supporting elements: steel columns embedded in concrete piles and slabs placed between the steel columns. The design of the piles and steel sections was carried out in a traditional way and will not be described in detail here. It resulted in the choice of HEA 300 steel sections for the columns, which also allowed the slab to be placed in the space available between the flanges of the section (Figure 3.e).

The slab elements take the pressure from the soil and transfer it to the steel columns. The key design criteria for slab design are: a) bending strength of the slab; b) detailing of force introduction and reinforcement anchorage at the slab support on steel sections.

a) Bending. The areas previously identified in the donor building as possible locations for the removal of concrete blocks were subjected to more detailed investigations such as ultrasonic scanning of the reinforcement and localised destructive testing to determine the amount and arrangement of reinforcement. The spacing of the steel sections was then determined to fully utilise the available flexural strength.

b) Detail of slab support on steel sections. Due to the sawing process, the reinforcing bars are cut straight at the edge of the concrete blocks. This makes steel corrosion problems even more critical at these points, as there is no cover. What's more, cut rebar does not have adequate anchorage details such as bends, loops or hooks. Anchorage can only be achieved by bonding between the reinforcement and the concrete over the length of the support area, which is less than half the width of the H-beam flange. For the type of retaining walls considered in this study (height, diameter of the rebars), the HEA 300 profiles ensure a sufficient length of the bearing area for the anchorage of the rebars and the introduction of forces into the slab.

In order to enforce the coherence of the circular approach of this project, used steel profiles were searched for. As no used HEA 300 profiles could be found, the design of the wall was adapted to the use of available profiles, consisting of used railway rail profiles of the type shown in Figure 4.b. For each column, two rail profiles are placed face to face and welded over their height to provide sufficient mechanical stiffness and strength, as well as sufficient space to fit the slab between the flanges of the rails. The flange width of the rail sections is not sufficient for reinforcement anchorage. The design approach had to be adapted to take into account an arching action within the concrete slab and self-equilibrating compression struts between adjacent wall panels, which doesn't require full anchorage of rebar over the length of the support area.

The decision to adapt the design to availability reinforces the design proposition, which is clearly visible as a re-use project (Figure 4.c). The concept is completed by the use of bands of cladding facade elements to cover and protect the wall.

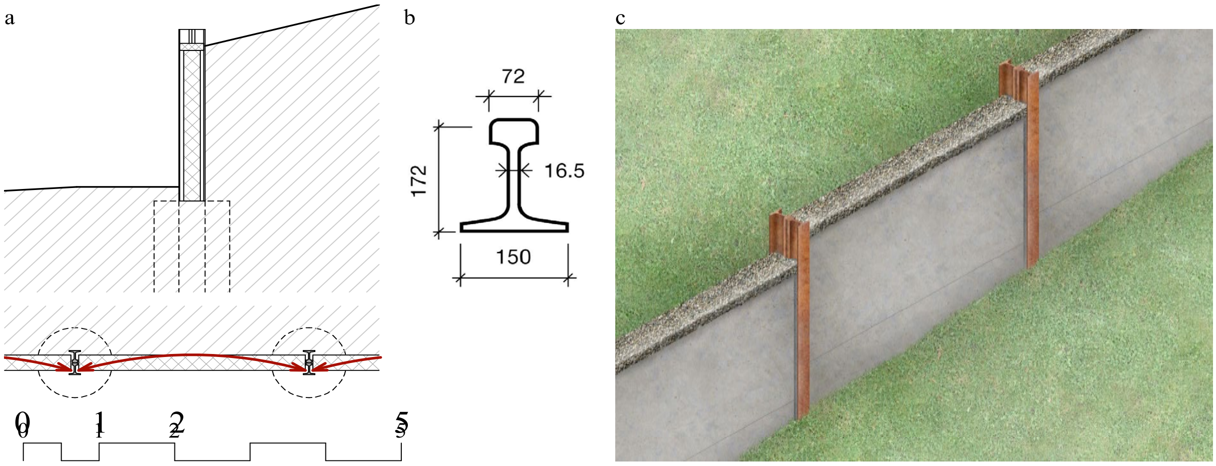


Figure 4. a) final design (red: arching action) b) railway profile c) rendering of the final design

3. Conclusions

Several methods of constructing retaining walls with reused concrete were presented and discussed. The investigations showed that retaining walls with reused concrete are feasible.

The durability of the concrete due to the change from indoor to outdoor environment and the detailing are the main design issues. If concrete blocks are reused without special protective measures, the reinforcing bars are stressed, but their exposure to aggressive agents does not meet the normative requirements. Therefore, the proposed solution is experimental and needs to be monitored over time.

Gravity walls using crushed concrete blocks are also likely to be feasible. Their construction needs to be experienced. This type of reuse corresponds to the downcycling of concrete. Nevertheless, it could be interesting, especially for small retaining walls, as it could be widely used.

Reuse changes the design process: the form follows the availability of materials and leads to unattended and interesting solutions.

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