**DTU Civil Engineering**
Department of CivilEngineering

# DET KLIMAVENLIGE LANDBRUGSBYGGERI
## Concrete quality in pig farms
## – Is reuse an option?

Rapport 10

Lisbeth M. Ottosen & Ana T. Lima, 2022

STØTTET AF
**Promille**afgiftsfonden for landbrug

# Concrete quality in pig farms – Is reuse an option?

Report
2022

By
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Projekt udarbejdet af SEGES Innovation P/S
Projektleder Kenneth Poulsen, Byggechef, SEGES Innovation P/S

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# Preface

This report documents and discusses the results from two projects carried out in collaboration between SEGES Innovation P/S (Projektleder Kenneth Poulsen, Byggechef, SEGES Innovation P/S) and DTU Byg/DTU Sustain (prof. Lisbeth M. Ottosen and senior researcher Ana T. Lima)

The project was financed through Promilleafgiftsfornden for Landbrug after an application from SEGES.

The work was made in two projects. It was initiated in the project “Climate friendly agricultural buildings” (2021-2022) as one of the work packages, and it was extended in the project “Concrete quality in pig farms” (2022).

Lyngby, December 2022

Lisbeth M. Ottosen & Ana T. Lima

# Content

# Summary

In Denmark, the average demolition rate for farm buildings is higher than the average for Danish buildings in general. At the same time, quite many new square meter of farm buildings are built (500,000 m2 in 2020). In a time, where we are facing resource scarcity – also for e.g. sand and gravel, it is worth investigating if some of the concrete elements from the demolished stables can be reused in the new.

This project served to compare the quality of concrete elements after 5, 15 and +30 years of exposure to animal livelihood and pig manure rejects. The ultimate goal of this comparison is to define the duration of concrete in these harsh environments and ***screen the possibility of reusing concrete elements***.

Concrete cores with a diameter of 10 mm were taken from inner and outer walls of the stables, as well as powder samples. Conductivity, pH, Cl and $SO_4^{2-}$, S, Cu and Zn concentrations were measured in the drilling powder samples, while the cores were tested for their compressive strength.

Results show that the older concrete elements of 30+ years were very damaged. The specimens were made of lightweight aggregate concrete and broke apart during the sampling – due to reinforcement corrosion and degradation in the concrete. The high level of sulphur found in the concrete may be part of the explanation on the degradation. The 30 year old concrete specimen had no reuse value.

The 15 and 4 year old concrete elements were in a better state. The investigated walls all had different compositions and material layers (as expected from the developments in the design over the years) so no comparison or evaluation of the degradation as result of the age was possible. However, this screening showed that the elements from the two investigated stables had reuse potential when considering the state of the concrete.

# 1. Introduction

## 1.1 Background

Resource scarcity is one of the global crises that we are facing. A strategy to combat the scarcity is the transition towards a circular economy, and the buildings and construction sectors are key product value chains in the transition towards a circular economy (CE) in the EU (European Commission 2015, 2020). Yet, the buildings connected to agriculture have not received major attention in the context of a circular economy. However, since farm buildings account for 17% of the building stock in Denmark (Andersen et al. 2022), it is relevant to consider circular principles for this type of buildings to buildings.

The average demolition rate for farm buildings in Denmark is 0.42%, which is higher than the average for Danish buildings in general (0.19%). Actually, farm buildings has the highest demolition rate among all different building types in Denmark (Andersen et al. 2022). This adds to the relevance of considering a circular economy strategy for farm buildings, and not at least because new farm buildings are build. In 2020, this accounted to about 500,000 m$^2$ new farm buildings (Andersen et al 2022).

This project was initiated by SEGES as a first screening of the quality of the concrete elements in pig stables in relation to possible reuse of the concrete elements in new buildings in the support of a circular economy. Stables are not designed for disassembly (i.e. reuse of the elements), but it might be a future option.

## 1.2 Degradation of concrete elements in stables

Pig stables are a harsh environment for concrete elements, which may hamper the reuse and recovery options.

Results from a survey, carried out by De Belie (1997) on farms with fattening pigs in Belgium, showed that even for high-quality precast-concrete slats, on 15% of the farms surveyed, the coarse aggregates of some slats were exposed within 2 yr of use. After 5 years, wear was observed on 40% of the farms. Consequences were an increased gap between the slats and increased surface roughness (resulting in animal injuries), corrosion of the reinforcement and a reduced slat stability. The reason for this degradation was the specific aggressive conditions occurring on floors in animal houses. Chemical components from feed residues and manure may attack the concrete floor surface. Animals and (high pressure) cleaning exert a mechanical impact.

It is well-known (Eglinton, 1987) that that no cementitious material can withstand lengthy exposure to acids. Portland cement concretes would not be resistant to pH values below 6.0 and it is considered that, where pH values are less than 3.5, there is a high risk of damage to concrete made with any type of cement. Prolonged exposure of concrete structures to animal manure, agricultural effluents, and other chemicals results in the hydration of the cement, the formation of calcite crystals, and the disintegration of the structure (Maraveas, 2022).

Reinforcement corrosion is also induced in the harsh environment in a stable. Poultry, cow, and pig manure contain variable quantities of corrosion-inducing chemicals, such as sulfates, nitrates, chlorides, hydrogen sulfide, and ammonia (Maraveas, 2020). Metallic structures are easily corroded by chemicals found in animal manure products, organic and inorganic acids (Maraveas, 2020).

## 1.3 Aim of investigation

The present project is an experimental investigation of the state of the concrete in three Danish stables from three different ages. ***The aim is to discuss and evaluate the possibility for reusing the concrete elements on basis of these specific cases***.

# 2. The investigated stables and concrete sampling

## 2.1 The stables and concrete sampling locations

The three investigated stables are listed in table 1. They are chosen so they represent the three different types of concrete used in stables. In appendix A, the different concrete types produced by Give Elementfabrik for stables in the periods (I) before 2004, (II) in the period 2004 – 2016, and (III) after 2018, and one stable from each period is investigated. All three stables are built with elements from Give Elementfabrik.

Core samples (paragraph 2.2) and drill powder samples (paragraph 2.3) were taken from walls of the investigated stables. Table 1 gives an overview of the amounts and heights in which the samples were taken.

*Table 1: Stables and sampling heights for core samples and powder samples*

| | **Stable A** | **Stable B** | **Stable C** |
|---|---|---|---|
| Year | Ca. 1992 | 2006 | 2018 |
| Core samples | Internal wall:<br>A1: H15; Ø100<br>A2: H20; Ø50<br>A3: H91; Ø50<br>A4: H155; Ø50 | Internal wall:<br>B1: H30<br>B2: H90<br>B3: H160<br>Outer wall:<br>B4: H30<br>B5: H90<br>B6: H160 | Internal wall:<br>B1: H30<br>B2: H90<br>B3: H160<br>Outer wall:<br>B4: H30<br>B5: H90<br>B6: H160 |
| Drill powder samples | Heights: 10, 64, 91, 125, 150,190 cm | Heights: 30, 60, 90,120, 160, 180 cm (from inner and outer wall) | Heights: 30, 60, 90,120, 160, 180 cm (from inner and outer wall) |

## 2.2 Concrete core specimens

### 2.2.1 Core sampling

Concrete cores were taken from the investigated walls with a core drilling maschine (Figure 1(a and b). Except from the first core the diameter of the cores were 50 mm (Ø50). The first core taken had a diameter of 10 mm (Ø100). The choise of the Ø50 for the investigation was based on the wish to make as little disturbance of the wall as possible. Compressive strength can be measured from the Ø50 cores. There were no structural risk in taking these core samples. After the core sampling, the wholes were filled with new concrete.

*Figure 1: (a) The core drilling mashine, (B) the core drilling mashine during sampling at a wall, and (c) the wall in Stable A after sampling,*

The core samples taken are shown in Figure 2. Three of the four cores from Stable A did not come out in one piece (Figure 2(a)), whereas all cores were intact for Stables B and C.

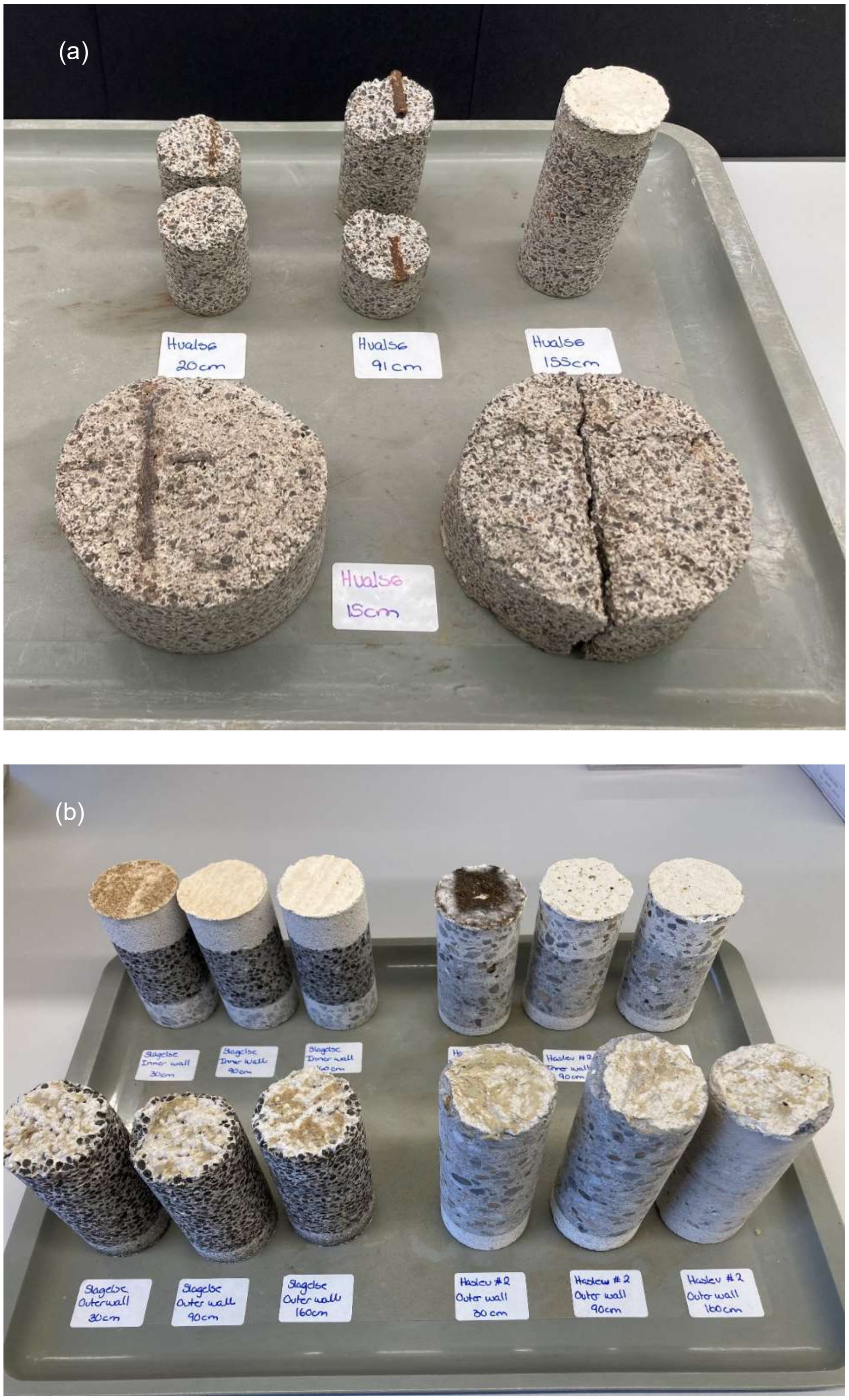


*Figure 2: (a) the core samples from Stable A, and (b) the core samples from Stables B and C (at the back from the inner walls and in front from the outer walls.*

### 2.2.2 Compressive test measurements

The cores were dried at room temperature in a fume cupboard for about 1 month before compressive test measurements.

The cores from Stable B - outer wall and Stable C - outer wall  had angled surfaces and about 0.5 cm were cut from these to smoothen them out before compressive test measurements. The remaining specimens were tested as they were after the drilling.

The compressive strength of the core samples was measured on a MATEST Cyber Plus Progress - model: E161 (Figure 3) with a load speed of 1.2 kN/sec.

*Figure 3: MATEST Cyber Plus Progress used for compressive test measurements*

### 2.2.3 Density of cores from Stable A

An approximate density of the core samples from Stable A was flund on basis of weighing and measureing the height of the broken parts of the specimmens taken at 20 and 90 cm height.

## 2.3 Drilling powder samples

Drilling powder samples were taken at different heights from the investigated walls (see Table 1). The sampling was done using a 10 mm drill and a powder collection unit (Figure 2). The samples were into the depth of 15 cm. The drilling powder samples were taken from the side turning down in Figure 2(a and b).

Conductivity, pH, Cl and $SO_4^{2-}$ concentrations were measured in the drilling powder samples. The procedure was to suspend 2.0 g of dried powder into 15 ml distilled water, place the suspension on an agitating table for 1 hour where after the pH and conductivity were measured directly in the suspension with the respective electrodes.

The total content of different elements were measured after pre-treatment of the powder samples according to the US EPA 3015A method (U.S. EPA., 2007) with a Varian 720-ES ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometry). Sulphur, copper and zinc concentrations are chosen here.

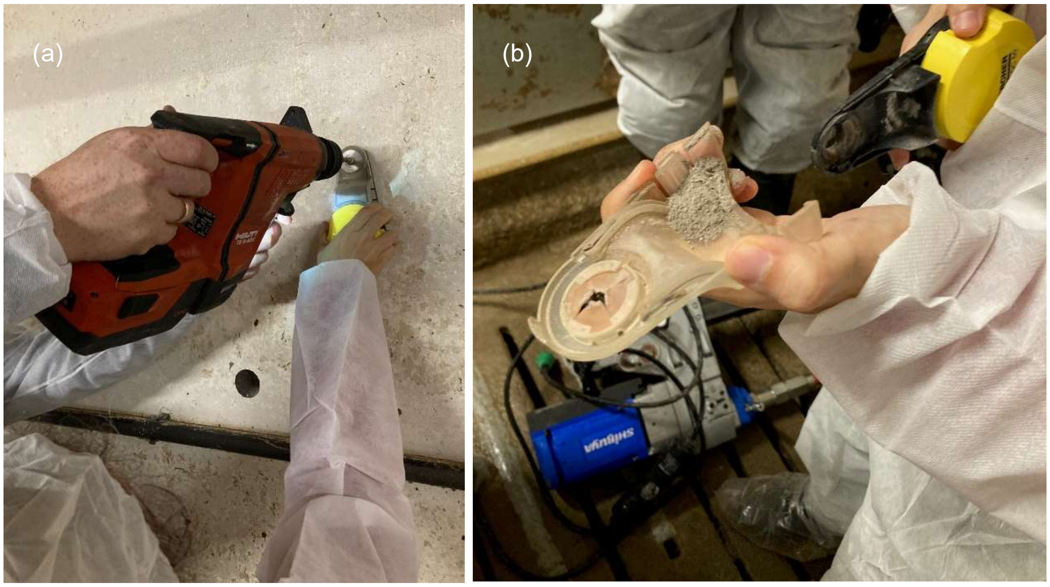


*Figure 4: Drilling powder samples (a) sampling from the wall and (b) the powder in the powder collection unit after drilling.*

# 3. Results and discussion

A photo of each of the core samples before test are given in Figures 5 – 9 (upper part of the figures) and just below is the expected basic composition (referring to Appendix A) of a wall of the same type and from the same time period. At first, it is interesting to see if the different layers in the core specimens reflects the expected:

- Stable A - Inner wall (Figure 5). The core sample had two layers; a plaster layer of about 1.5 cm and a lightweight aggregate concrete (about 8.5 cm). The expected 1 cm of concrete was not present.
- Stable B – Outer wall (Figure 6). The core sample had two layers: a plaster layer of about 2 cm and a lightweight aggregate concrete of 8 cm. This is as expected.
- Stable B – Inner wall (Figure 7). The core samples had three layers: A layer of plaster about 2.5 cm, a layer of lightweight aggregate concrete (about 5 cm) and a layer of concrete (about 2.5 cm). The three layers were as expected, however the mutual thicknesses of the layers were slightly different as the plaster and concrete layers were expected to be 1 cm thick and the lightweight aggregate concrete 8 cm.

- Stable C – Outer wall (Figure 8). The core samples had two layers: plaster of 1.5 – 2 cm. and a layer of concrete. This was as expected.
- Stable C – Inner wall (Figure 9): The core samples had about 1 cm plaster, 6 cm of grey concrete and 3 cm of white concrete. Except from the plaster, this was as expected.

Thus, in general, the core samples taken from the three stables were representative for the time of which they originate.

## 3.1 Compressive strength of core samples

The results from the compressive test experiments are given in Figures 5 – 9.

| **Stable A** | Core samples inner wall |
|---|---|
| Inner wall | 155 cm<br> |
|  | Expected composition: 10 mm. plaster, 80 mm. pimpsten/letbeton, 10 mm. beton LC 20-25 / 1600 |
| Compressive strength test |  |
|  | Compressive strength at 155 cm: 5.2 MPa |

*Figure 5: Core sample from 155 cm height in Stable A. Pictures from before and after compressive strength test, the expected layers in the sample in relation to Appendix A, and the compressive strength test measured.*

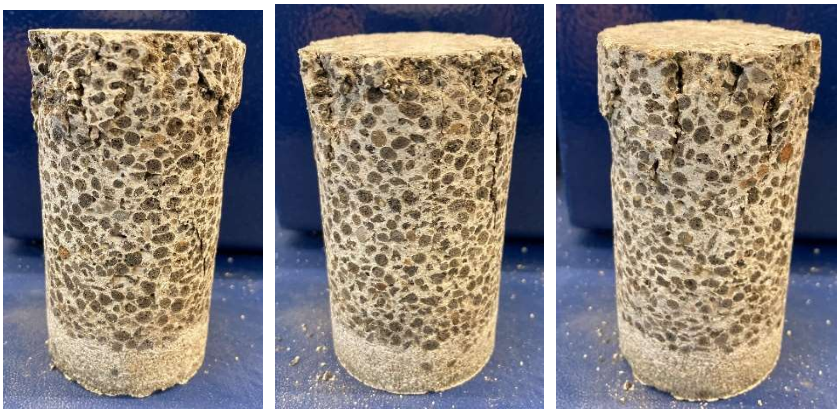
| **Stable B** | Core samples outer wall |
|---|---|
| |  30 cm 90 cm 160 cm |
| | Expected composition: 10 mm. pudslag, letbeton 90 mm. Vådstøbt, LC16/1600, Armering, plastfibre<br>The element were 26 cm thick in total, and consist of 10 cm. inner wall/concrete, 10 cm. mineral insulation and 6 cm. outer wall concrete. |
| Compressive strength test |  |
| | 30 cm: 5.3 MPa<br>90 cm: 6.1 MPa<br>160 cm: 5.0 MPa |

*Figure 6: Core samples from Stable B outer wall. Pictures from before and after compressive strength test, the expected layers in the sample in relation to Appendix A, and the compressive strength test measured.*

| **Stable B** | Core samples inner wall |
|---|---|
| | 30 cm 90 cm 160 cm<br> |
| | 10 mm. puds, 80 mm. pimpsten/letbeton, 10 mm. beton, LC 20-25/1600 |
| Compressive strength test |  |
| | 30 cm: 6.7 MPa<br>90 cm: 8,8 MPa<br>160 cm: 12,4 MPa |

*Figure 7: Core samples from Stable B inner wall. Pictures from before and after compressive strength test, the expected layers in the sample in relation to Appendix A, and the compressive strength test measured.*

| **Stable C** | Core samples outer walls |
|---|---|
| Outer Wall | 30 cm <br>90 cm <br>160 cm  |
| | 10 mm. pudslag, 90 mm. Traditionel vådstøbt beton som bagmur LC25/2400 Armering Y6 / 200 mm. |
| Compressive strength test |  |
| | 30 cm: 32.8 MPa<br>90 cm: 36.6 MPa<br>160 cm: 32.4 MPa |

*Figure 8: Core samples from Stable C outer wall. Pictures from before and after compressive strength test, the expected layers in the sample in relation to Appendix A, and the compressive strength test measured.*

| **Stable C** | Core samples inner walls |
|---|---|
| | <br>30 cm<br>90 cm<br>160 cm |
| | 20 mm. hvid, 90 mm traditionel vådstøbt beton som bagmur LC25/2400<br>Armering Y6 / 200 mm. |
| |  |
| | 30 cm: 32.1 MPa<br>90 cm: 40.8 MPa<br>160 cm: 41.7 MPa |

*Figure 9: Core samples from Stable B inner wall. Pictures from before and after compressive strength test, the expected layers in the sample in relation to Appendix A, and the compressive strength test measured.*

### 3.1.1 Stable A.

The three core samples from 15, 20 and 91 cm height did not come out in one piece (Figure 2(a)). They all broke in the exact position of the reinforcement. Since the reinforcement was seen to be very corroded, this is most likely causing the issue. When the reinforcement corrodes, it expands in volume, and since there is no room for this expansion, internal forces are created, which subsequently causes cracking.

Lightweight aggregate concrete (LAC) has typically densities in the range of 1200 – 1900 kg/m$^3$ (Fredborg, 2004). The strength is to some extent determined by the density. Some typical specifications for wall elements are LAC6 and LAC15. LAC6 has a density of 1350 kg/m$^3$ and the compressive strength of 6 MPa, whereas LAC15 has the density of 1850 kg/m$^3$ and the compressive strength of 15 MPa (Fredborg, 2004).

The compressive strength of the core sample from 155 cm height was 5.2 MPa. It is seen from Figure 5 that the core sample broke in the depth of about 3-4 cm into the sample in a layer parallel to the surface, i.e. in the matrix of lightweight concrete. Since the compressive strength was 5.2 MPa, i.e. a low strength compared to the typical values. The lightweight concrete might have lost strength in this height in the use period, which is likely considering the broken specimens form the other depths. The density of the four pieces of the broken core specimens from 20 and 91 cm height (Figure 2a) was between 3.6 and 4.2 kg/m$^3$ (average 3.8 kg/m$^3$) which is also low compared to the typical values. The reason may be degradation of the cement phases in the harsh environment during the lifetime of the stable.

### 3.1.2 Stable B

The core samples from the *outer wall* of Stable B had two layers (plaster and lightweight concrete) and it broke in the lightweight concrete. The compressive strengths were at 30 cm height 5.3 MPa, at 90 cm height 6.1 MPa and at 160 cm height 5.0 MPa. The average being 5.5 MPa.

The core samples from the *inner wall* of Stable B, which were composed of three layers, did have the lowest compressive strength in the middle layer of lightweight concrete. The sample from 30 cm height broke mainly in the interphase between plaster and lightweight concrete, whereas the two other core specimens broke in the layer. Due to this, the compressive strength of the three cores reflect the strength of the layer of light way concrete: at 30 cm - 6.7 MPa, at 90 cm - 8,8 MPa and at 160 cm - 12,4 MPa. The average was average 9.3 MPa.

The outer walls in Stable B, which had similar composition as the wall from Stable A, was reinforced with plastic fibres. And the same problem as in Stable A with reinforcement corrosion is hereby avoided. In stables, concrete structures made of fiber-reinforced polymers are less prone to corrosion and are more durable. (Maraveas, 2020)

### 3.1.3 Stable C

The core samples from Stable C did not contain lightweight concrete, which is on the contrary to the core specimens from Stables A and B. The strength is much higher in accordance to the use of sand and gravel aggregates.

The strength of the core samples from the *outer walls* were in 30 cm - 32.8 MPa, in 90 cm - 36.6 MPa and in 160 cm - 32.4 MPa. The average being 33.9 MPa.

The strength of the core samples from the *inner walls* were in 30 cm - 32.1 MPa, in 90 cm – 40.8 MPa and in 160 cm – 41.7 MPa. The average being 38.2 MPa.

## 3.2 Drilling powder samples

Since the investigated walls had different compositions (layers) the basic material in the drilling powder samples were also different. The drilling powder from the wall in

- Stable A. consist of lightweight aggregate concrete.
- Stable B contained plaster and lightweight aggregate concrete (outer wall) and concrete and lightweight concrete aggregate (inner wall).
- Stable C contained plaster and concrete bot from inner and outer walls

Due to the different base of the drilling powder samples the measured pH, conductivity and content of elements cannot be compared directly between the different walls, since the initial and e.g. background content varies. Regardless this, the results for each parameter are shown in the same figures, but they are discussed separately.

### 3.2.1 Aggressive ions

Aggressive ions (aggressive ions $Cl^-$, $SO_4^{2-}$ , $Mg^{2+}$ and $NH_4^-$) and acetic acid would come from the manure (De Belie, et al. 2000). This investigation includes $Cl^-$ and $SO_4^{2-}$.

The concentration of $SO_4^{2-}$ was very high in the powder samples from Stable A (4500 – 5500 mg/kg) compared to the two other walls (<35 mg/kg). Even taking the different materials of the powder samples into account, the content of $SO_4^{2-}$ in the 30 year old wall (Stable A) shows a high contamination of the wall during the long use phase. Also the $Cl^-$ content was much higher in the wall from Stable A and especially until the height of 61 cm, where it was 1200-3400 mg/kg compared to the less than 90 mg/kg in the two newer Stables B and C. The lowest concentration measured in Stable A was 390 mg/kg.

### 3.2.2 pH and conductivity

Figures 10 and 11 shows the pH and conductivity, respectively, in the different heights of the walls.

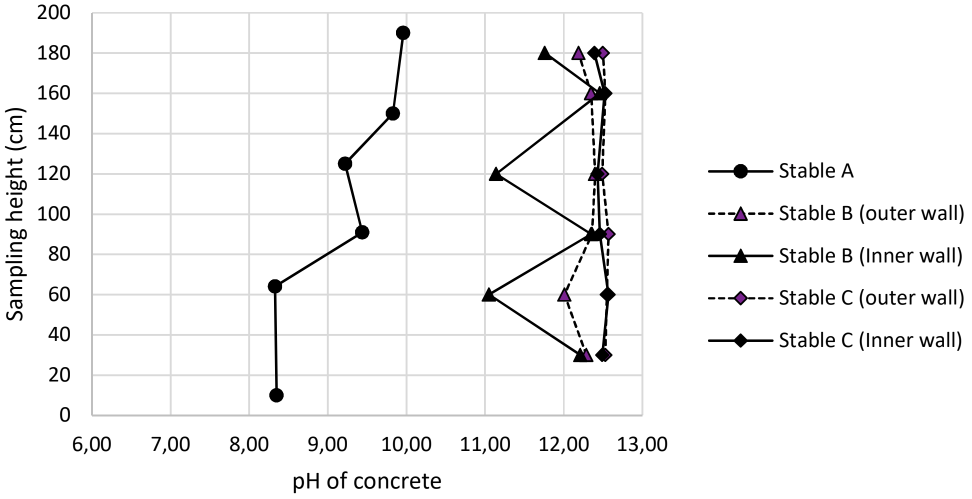


*Figure 10: pH in the drilling powder samples from the investigated walls*

The pH is interesting in relation to protecting the reinforcement steel towards corrosion. The cement in concrete has a high pH, usually around 13-14. At such high pH, the passive layer on the reinforcement steel is intact and the steel is protected towards corrosion (unless $Cl^-$ is present). The passivation effect protecting the steel is lost at around pH 9.5 to 10.5. The pH in the wall from Stable A has a too low pH for the reinforcement steel to be protected (<10, see Figure 10), and this corresponds well to the found corrosion of the reinforcement bars in the core samples (Figure 2a). In the walls from Stables B and C, the pH was high enough to expect passivation of the reinforcement.

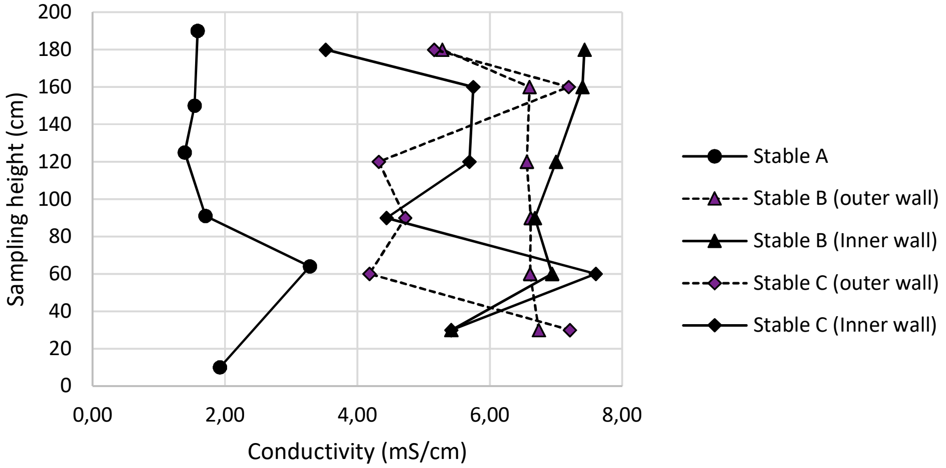


*Figure 11: Conductivity in the drilling powder samples from the investigated walls*

The measured conductivity expresses the content of ions in the drilling powder. In case pH of concrete is it the same level, the conductivity is linked to the soluble salt content. However, the conductivity also depends on pH (at high pH there is a high content of $OH^-$ ions, which result in high conductivity). This means that the low conductivity in the drilling samples from Stable 1 (relative to the other) probably is due to the almost neutral pH rather than a lower ionic content.

The varying conductivity in the powder samples from the walls in Stables B and C do likely reflect that the plaster layer has slightly different thicknesses and thus the relation between plaster and concrete differs, which most likely influences the conductivity. There are too many influencing variables in relation to the conductivity to make conclusions on the measurements.

### 3.2.3 Concentrations of sulphur and copper

Figures 12, 13 and 14 shows the concentrations of sulphur, copper and zinc, respectively, in the different heights. The high concentration of sulphur in the wall of Stable A supports the finding of a high $SO_4^{2-}$ content (paragraph 3.2.1).

A high sulphate content may cause degradation of the concrete. Sulphate attack on concrete is a well-known decay mechanism where chemical breakdown mechanism where sulphate ions attack components of the cement paste. The compounds responsible for sulphate attack on concrete are water-soluble sulphate-containing salts, i.e. the sulphate ions in paragraph 3.2.1. It combines with the concrete paste, and begins destroying the paste that holds the concrete together. As sulphate dries, new compounds are formed, often called ettringite. These new crystals occupy empty space, and as they continue to form, they cause the paste to crack, further damaging the concrete. The high sulphide content in the wall from Stable A must be considered problematic in relation to reuse, since it shortens the technical lifetime of the wall elements significantly.

Pig manure contain copper and zinc, which has received attention as problematic to spreading the manure at agricultural land (Landbrugsavisen 2015). High concentrations in the walls of these toxic heavy metals could hamper reuse. However, the concentrations of the two heavy metals in the powder samples from the investigated walls are all at a relatively low level, and is not considered problematic in case reuse of the walls is planned.

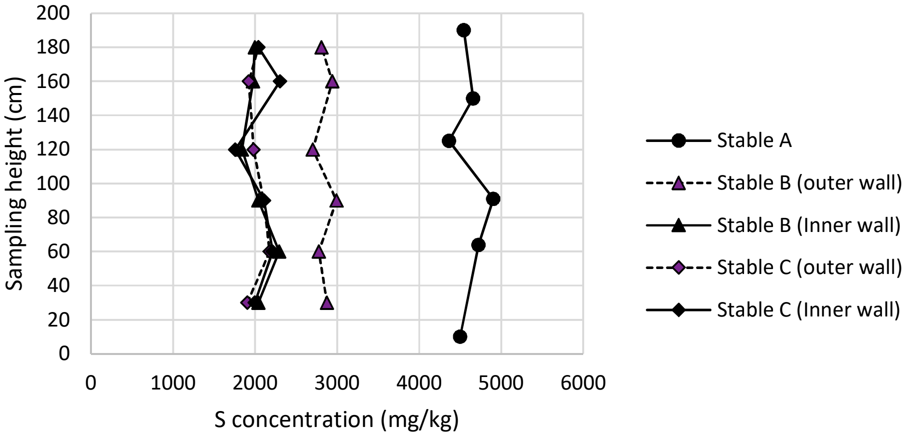


*Figure 12: Sulphur concentration in the drilling powder samples from the investigated walls*

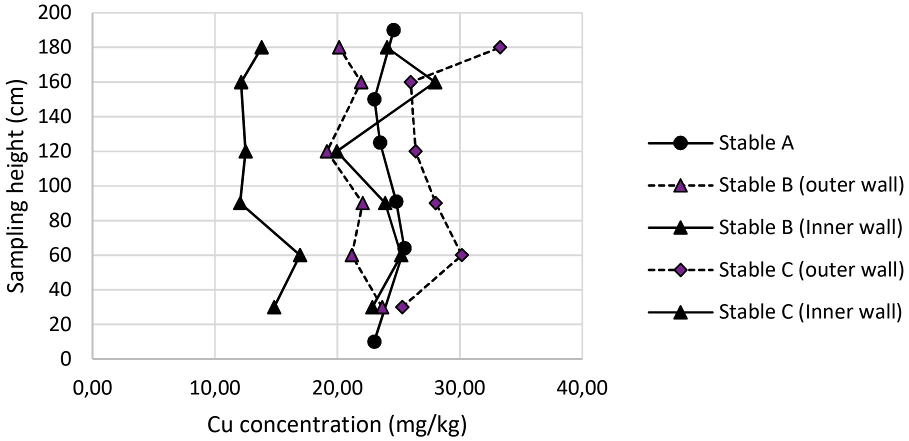


*Figure 13: Copper concentration in the drilling powder samples from the investigated walls*

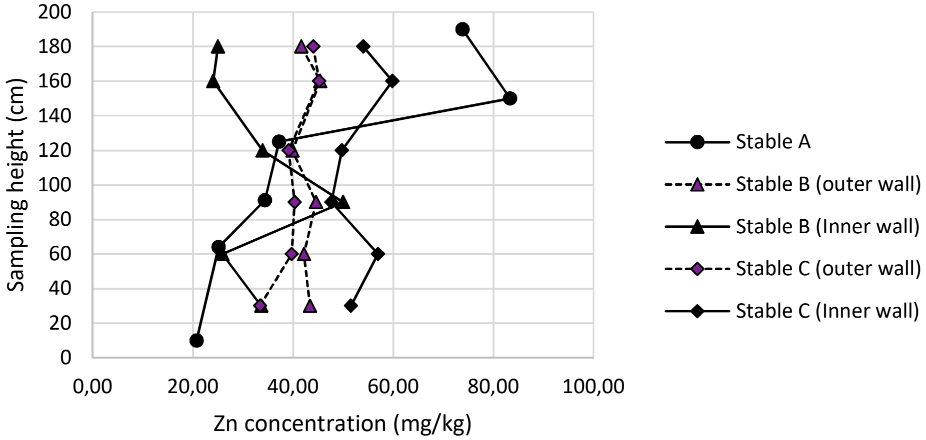


*Figure 14: Zinc concentration in the drilling powder samples from the investigated walls*

# 4. Conclusions

The tree investigated stables represents different compositions of concrete wall elements in pig farms. The compositions (layers) were found representative for the respective periods.

The investigated inner wall of Stable A from about 1992 suffered from reinforcement corrosion due to a low pH in the lightweight aggregate concrete, which it was composed from. This meant that the core samples were broken when they were drilled out from the wall. In addition, the wall had a high sulphur (and sulphate) content which may have induced sulphate attack on the cement paste, or give high risk for it. A low technical lifetime must be expected due to this. Thus reuse of the wall elements from this period cannot be advised, in case the degradation of the investigated wall is representative.

The compositions of the walls from Stable B (2006) and Stable C (2018) were very different. Both inner and outer walls from Stable B contained lightweight aggregate concrete, which was not the case for the walls in Stable C.

No issues with the walls in Stable B were found in relation to reuse. Thus it is suggested to make a more detailed investigation of the stables from this period to explore the reuse potential.

Stable C is only few years old, but since it is made from concrete with +30 MPa the durability must be expected much better that the 30 years old stable A. Reuse could be an option due to the improved composition, and it might be beneficial in such case to think of the option already when building the stable. Design for disassembly could be considered.

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# Appendix A: Betonelementer fra Give Elementefabrik over tid

Note from Kenneth Poulsen – supplied by mail on 15.09.22

### Type 1: Frem til 2004

**Facade bagmur**

- 10 mm. pudslag
- 90 mm. Letbeton/lecabeton (tørbeton)
- LC8 /1400 (Mpa/rumvægt)
- Armering Y5 / 150 mm.

**Skillevægge**

- 10 mm. puds
- 80 mm. pimpsten/letbeton?
- 10 mm. beton?
- LC 20-25 / 1600

### Type 2: 2004 til 2016

**Facade bagmur**

- 10 mm. pudslag
- Letbeton 90 mm. Vådstøbt
- LC16/1600
- Armering, plastfibre

**Skillevægge**

- 10 mm. puds
- 80 mm. pimpsten/letbeton?
- 10 mm. beton?
- LC 20-25/1600

### Type 3: 2018 og frem

**Facade bagmur**

- 10 mm. pudslag
- 90 mm. Traditionel vådstøbt beton som bagmur
- LC25/2400
- Armering Y6 / 200 mm.
- Ekstra armering omkring døre og vinduer.

**Skillevægge**

- (20 mm. hvid)
- 90 mm. Traditionel vådstøbt beton som bagmur
- LC25/2400
- Armering Y6 / 200 mm.
- Ekstra armering omkring døre og vinduer.