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Design criteria for structural design of silage silo walls

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Abstract

The national guidelines for design of silage bunker silo walls are not available today. The present calculation and design is based on previously issued guidelines. These were elaborated to be used in designing silo wall heights of maximum 3 m. There are reasons to believe that these guidelines overestimate the forces and pressures, mainly from silage juice, that are occurring especially for silo walls > 3 m. This could result in over-sizing, material waste and increased investment costs.
The aim of the project is to determine silage physical properties of importance for the horizontal wall pressure and evaluate maximum silage juice level of silos with a wall height of 3 m or more. The data will form a basis for new national design guidelines and a revised Swedish Standard. The ultimate goal is to lower the investment costs for silage bunker silos.
A pressure profile was acquired by means of transducers mounted on a “ladder rack” placed vertically along the inside silo wall. The pressure on the transducers was recorded by a data acquisition system displaying static and total load (pressures imposed by silage matter and compacting tractor).
The silage juice levels were measured by slotted 16 mm steel pipes placed vertically along the silo walls. The level inside the pipe was determined by a measuring stick. Additionally the juice level could be registered in one of the legs of the “ladder rack”.
Silage juice level measurement were carried out during two seasons, all together in 24 silos, while pressure profiles were measured during 10 grass and maize harvests in one season, with approximately 400 pressure profiles at each harvest. The static loads were recorded with no tractor present and total loads as a tractor was passing in front of the transducer racks. The difference between the static and the total load was defined as the dynamic load.
Preliminary results show that the silage juice level can vary considerably between harvests within the farm due to weather conditions and geographic location in Sweden. Mean of peak levels was approximately 40% of the silage height. A direct relation was found between grass silage juice level and silage total solid content. The silage juice level tends to remain stable during the storage but can be radically redistributed between layers within the silo.
Tentative pressure profile results show that the dynamic pressure created by the compacting tractor is largely concentrated to the first half metre below the vehicle when driving 0.1-0.5 m from the silo wall. Pressure measurements after filling the silo show an increase in wall pressure. The pressure profile results are presently under evaluation.

Key words: Silo, wall, silage, pressure, force.

1. Introduction

1.1. Background

The farmer interest in growing feed for cattle is increasing. Locally produced fodder can decrease the amount of transportation and with it the climate footprint. A large part of the fodder used in milk and beef producing units are stored in horizontal silos (bunker silos) as silage, based on grass and maize. A typical bunker silo contains a silo bottom of concrete with walls of locally cast concrete, concrete elements or by wood. The silo wall height has traditionally been 2-3 meter. During the last years it has been more popular to build silo walls of 4 meter. The trend is to make them even higher. The yearly investments in bunker silos in Swedish farming have more the doubled the last 10 years.

1.2. Problem approach

The structural design of the silo walls has been based on the horizontal forces acting from the silage at silo filling and from the silage as it is stored in the silo. Furthermore there are the loads from the compacting tractor as well as the hydro static load from the silage juice. The amount of the silage juice load is directly dependent on to what extent silage juice is going to be developed. This pressure against the silo wall will be the same as the water pressure derived if the same amount of water were present in the silo.
In designing the silo walls and its fitting to the silo concrete bottom, the decided level of silage juice will have a decisive impact on design and material amounts.
Previously design guidelines from the Swedish Board of Agriculture have been used but they are not applicable today (LALT, 1983; SJV, 1995). They were elaborated to be used in designing silo wall height of maximum 3 m. The present calculation and design is based on previously issued guidelines and are used until new guidelines are approved.
According to these guidelines, the silage wall design should take into account the load from silage and a silage juice level that will appear up to 1.5 m below the maximum filling height. The demand to assume this high silage juice level in bunker silo design is based on measurement conducted at silo fillings of bunker silos with 2 meter walls (Kangro, 1986).
It can be questioned how sufficiently wide ranging these measurements have. The effect of this load has less importance at low wall heights. However, at wall heights of 4 meter or more the load surplus effect is substantial. Practical experience reveals that this surplus load of silage juice seems to be overestimated. Neither silage juice effluent amount points in that direction.

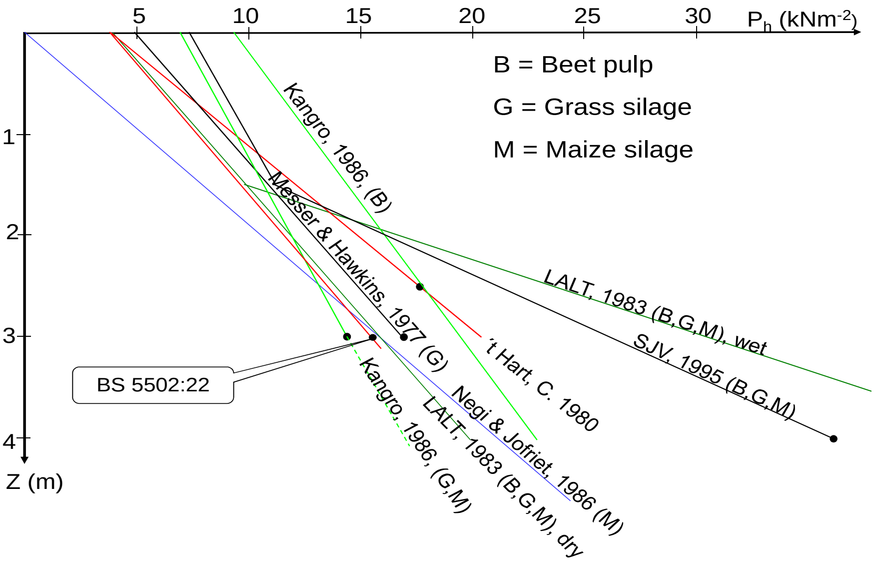


Figure 1. Different guidelines for silo wall design, where the vertical axis (z) indicates the distance below the silage surface and the horizontal axis (P_h) the horizontal silo wall pressure that has been measured or is given in different guidelines.

Comparing design guidelines and scientific publications in a wider perspective (Gruyaert et al., 2007; SJV, 1995; Kangro, 1986; LALT, 1983; Martens, 1993; Negi & Jofriet, 1986; Nilsson, 1982; Van Nuffel et al., 2008) also show that the Swedish guidelines are based on extremely high silo wall loads. Furthermore it could be anticipated that the order of magnitude of the design loads are not the same, as we have other types of silage and heavier compacting tractors.
The result of the pilot study is summarised in Fig. 1. It can be concluded that the Swedish guidelines (SJV, 1995) provides higher silo wall load compared to foreign recommendations at silo wall heights of more than approx. 2 meter. For a silo all of 4 meter the design load is approx. doubled compared to what is recommended by other sources.
Presently there is an ongoing revision of the Swedish bunker silo standard, for which a new base of information is required.
There are reasons to believe that the old guidelines overestimate the forces and pressures, mainly from silage juice, that are occurring especially for silo walls of 3 m or more. This could result in oversizing, material waste and increased investment costs.

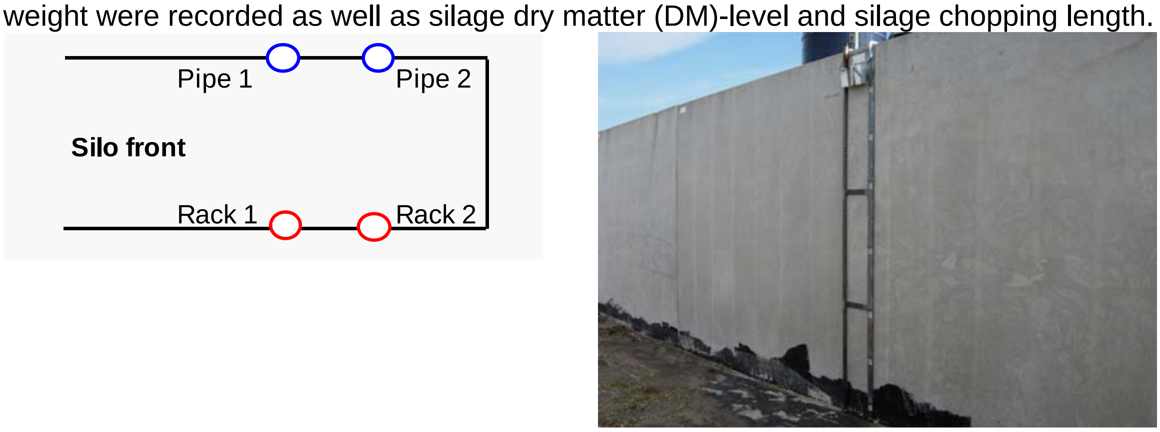
1.3. Aim and objectives

The objectives were to provide data support for guidelines on designing bunker silo walls and to obtain a safe product of storage economical for farmers.
The aim of the project was to determine silage physical properties of importance for the horizontal wall pressure and evaluate maximum silage juice level of silos with a wall height of 3 m or more. The data should form a basis for new national design guidelines and a revised Swedish Standard. The ultimate goal was to lower the investment costs for silage bunker silos. The hypothesis was that the present Swedish silo design guidelines overestimate the loads on silo walls from the silage and silage juice.

2. Material and methods

2.1. Experimental design

The experimental part was carried out at commercial farms. The hydraulic pressure was determined by vertically placed steel pipes (silage juice level) and a measuring rack (horizontal pressure and silage juice level), Fig. 2. The measurements were made during silage filling and during a period of 2 months afterwards. By combining silage juice level and silage wall pressure measurements during a longer period of time after the silo filling, the changes in silo wall pressure over time could be observed. The measurements were conducted in 10 bunker silos with a silo wall height of 3 m or more. The silage was grass and maize silage.
In the investigation the following parameters were of priority. To give an explanation of horizontal pressure and silage juice level the compacting method and the compacting vehicle weight were recorded as well as silage dry matter (DM)-level and silage chopping length.



a) b)

Figure 2. Placement of measuring points in silo for silage juice and measuring racks.

2.2. Silo wall pressure measuring system

A measuring system, DataLink type NOS. DLK 900, Biometricts Ltd, UK, was used for measuring the horizontal silo wall pressure. It consisted of two connected measuring racks, with 4 load sensors on each rack, from the silo bottom to the silo top along the silo wall. The load sensors (TEKSCAN FSR A401) were sealed in plastic, had a thickness of less than 1 mm, glued and mounted water tight to the measuring rack at 1.0 meter intervals.

2.3. The measurements performance

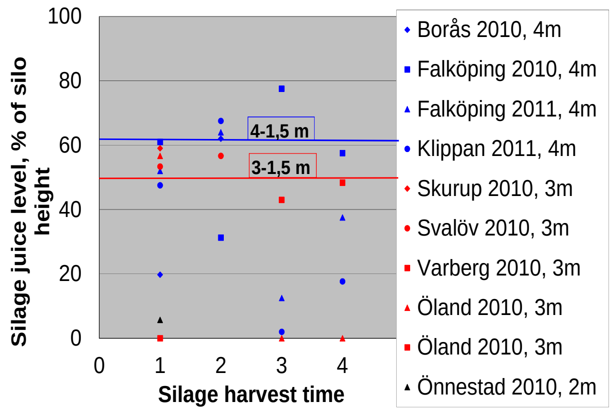
The silage juice levels were measured by slotted 16 mm steel pipes placed vertically along the silo walls. The level inside the pipe was determined by a measuring stick reading. The silo wall pressure measurements were carried out on farms in south western part of Sweden. The measurements were conducted at 1:st to 4:th harvest of silage, where the major part was grass silage and some maize silage. Different climate conditions were covered through a geographic distribution of the farms.

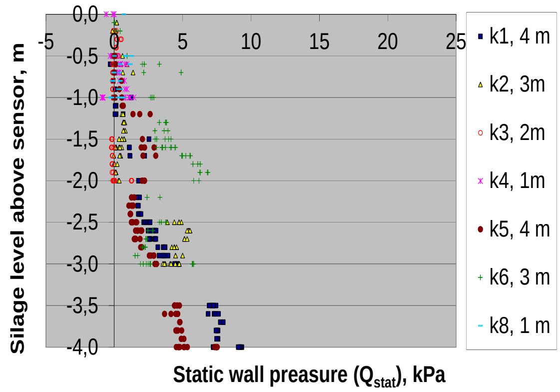
With the vertically mounted sensors the static pressure towards the silo wall was recorded at different levels in the silo during the filling as well as after filling. The dynamic load down through the silage mass from the passing compacting tractor was recorded with replications in every sensor during the filling.
The silage was filled and compacted into the silo in layers of approx 0.25 m at a time spread over half of the silo surface. The compaction was done by driving track by track over the surface 2-4 times for each layer. A measurement series was executed for each layer of filling. During each measurement series hundreds of static load values were recorded as well as peak values from the compacting tractor at different distances from the silo wall and at different silage height above the load sensors resulting in silo wall pressure profiles, which contained sensor placement, silage height and wall distance for static and dynamic loads.

The recorded load from the passing compacting tractor was denoted total load (Q_{tot}) and the recorded load with no tractor present the static load (Q_{stat}). The surcharge load from the compacting tractor (Q_{dyn}) was then: $Q_{dyn} = Q_{tot} – Q_{stat}$

3. Results

Silage juice level measurement were carried out during two seasons, all together in 24 silos,





3a) 3b)

Figure 3. a) Maximum silage juice levels during two seasons. Each dot represents the mean value of 6-10 measurements in each silo. Red and blue lines mark the expected maximum silage juice level for 3 m (red) and 4 m (blue) silo wall height respectively according to Kangro (1986).
b) Example of static wall pressure load profile against a 4 m high bunker silo wall at first grass arvest with DM 27% and 591 recorded measuremets from 7 sensors.

while pressure profiles mainly were measured during 10 grass and maize harvests in one season, with approximately 400 pressure profiles at each harvest In five silos the silage juice level increased and was redistributed during the first 3 months after filling. The silage juice level remained at 90 % in the unopened silos.

The average silage juice level was 40% of the silo wall height. The highest level was 78%, recorded in one of 24 silos. The highest design juice level 1.5 m below the silage surface after filling according to Kangro (1986), was exceeded in 4 and 3 cases for 3 and 4 m high silos respectively. A direct relation was found between silage DM content and grass silage juice level, the higher DM the lower silage juice.

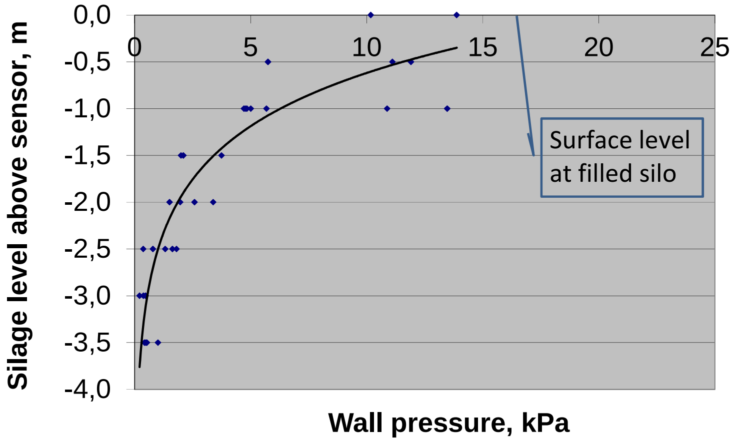


Figure 4. The surcharge load (Qdyn) from compacting tractor (11 ton) compiled from 3 silo measurements. Recorded values with vehicles passing 0.1 m from the silo wall at different heights above sensor location (m) are shown.

Tentative results showing a static wall pressure profile and the surcharge load from packing vehicle are illustrated in Fig 3b and Fig. 4. The static profile is resulting from silage mass and silage juice but no surcharge of silage juice is traceable in the profile at the filling. In this case silage juice level took 3 months to reach the maximum of 50% of the silo height.
The surcharge from the packing vehicle had the greatest impact when driving 0.1 m from the silo wall within the first meter under the vehicle.

4. Discussion

The silage juice level in the bunker silos differed largely over time and depended on several factors like DM, silo pressure and packing at filling, fibre type, silage chopping length and pre drying in field. The DM depends in turn on variety of grass/maize, maturation, fertilize, dew and precipitation (Stewart & McCullough, 1974). A close relation between grass silage juice level and silage DM content have been found in earlier studies (Bastiman, 1976; Sutter, 1955), which also was found in the present study. In this study the different DM levels at filling were a compromise between local weather situation at the time of harvest and the grass/maize maturation.

A high silage juice level remained within the silos during storage which is consistent with O'Donnell (1993) while no drainage system was present in the silos. The design guidelines based on measurement by Kangro (1986) does not seem relevant, while those studies did not cover measurements of silage juice levels after silo filling. On the other hand tentative result of pressure profiles and measurements several months afterwards does not show any traceable surcharge of silage juice in the profile.

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