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A Tool to Design the Concrete Constructions of Horizontal Silos

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Abstract
A tool is developed in order to plan and design concrete structures for horizontal silos. A mathematical model was developed. Subsequently, the tool is developed by integrating the mathematical model into an electronic spark map. The spark map (decision tree) specifies the horizontal silo dimensions according to the planned storage volume, computes the required amounts of construction materials to build the horizontal silo, and calculates the capital investment and the fixed, variable, and total costs. On the other hand, the mathematical model of the spark map requires some input data. According to these data, the spark map will make calculations and show the output data automatically. Data of 4 horizontal silos were used to carry out the model validation. The differences between actual and calculated values were determined, and the standard deviations were calculated. The coefficients of variation were 3.4%, 5.5%, 5%, 7%, and 4.5% for amounts of concrete, gravels, cement, sand, and iron rods, respectively.

***Key words and phrases*:** concrete structures, mathematical modeling, silage structures, cement based materials, horizontal silos, forage storage, spark mapping, costs calculation

1. Introduction and Preliminaries

Bartali (1999) stated that reinforced concrete is obtained by adequately mixing in specific proportions aggregates (gravel and sand), cement, and water. Lindley and Whitaker (1996) elucidated that water:cement ratio is 0.53 l/kg and cement:sand:gravel mass ratio is 1:2.2:3.7 for floors, driveways, structural beams, and columns; however, they added that horizontal silos are built of concrete, provide storage at considerably lower costs, and are adaptable to self feeding. Holmes et al. (2003) developed forage storage design and management tools. Miller and Marter (2003) stated that the engineering design for proper feed-off rate, gives the highest quality feed, lowest losses, and the lowest operational costs. Zhang and Britton (2003) have developed a model for predicting dynamic pressures during discharge in bulk solids storage bins.

The objective of this study is to develop a tool to design horizontal silos, to compute the required amounts of construction materials, and to calculate the costs.

The tool was developed by integrating a mathematical model into an electronic spark map. The mathematical model was developed using the plans, designs, parameters, variables, and constant values of concrete structures of horizontal silos available in the references. Subsequently, MS-Excel is used to develop the electronic spark map of the mathematical model, and to show the results of the input settings automatically.

The validation of the mathematical model was carried out using data of 4 concrete horizontal silos. The relative differences between actual values and calculated values were determined for concrete volume, gravels volume, cement mass, sand volume, and iron rods mass, and then the averages of relative differences were computed. Afterwards, the standard deviations (σ) and the coefficients of variation (COV) were determined.

2. Main results

The electronic spark map (Figure 2.1.), of designing concrete structures for horizontal silos, specifies the dimensions of concrete horizontal silo (Figure 2.2.) according to the required storage volume. Consequently, the electronic spark map calculates the required amounts of concrete volume, gravels volume, cement mass, sand volume, and iron rods mass to build the horizontal silo. However, the spark map requires some input data (Table 2). According to these data, the electronic spark map will compute the output data (Table 3) by using the mathematical model (Table 1). Subsequently, the spark map will calculate the capital investment and the fixed, variable, and total costs of constructing the concrete horizontal silo.

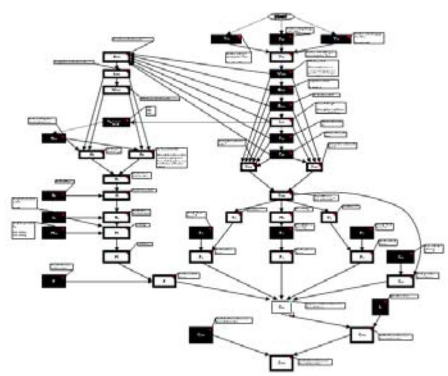

Fig.2.1. Electronic Spark Map

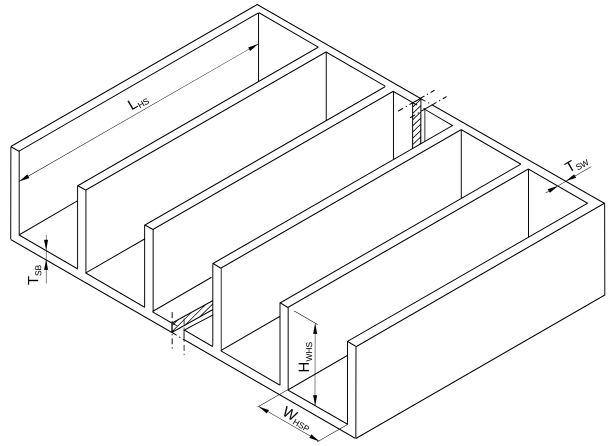

Fig.2.2. Horizontal Silo

The statistical analysis of the model validation elucidated that COV were 3.4% (σ = 0.03), 5.5% (σ = 0.04), 5.2% (σ = 0.01), 7.3% (σ = 0.07), and 4.3% (σ = 0.04) for amounts of concrete (Figure 2.3.), gravels (Figure 2.4.), cement (Figure 2.5.), sand (Figure 2.6.), and iron rods (Figure 2.7.), respectively.

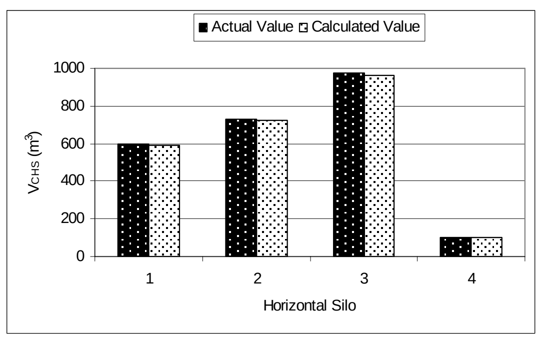

Fig.2.3. Concrete Volume

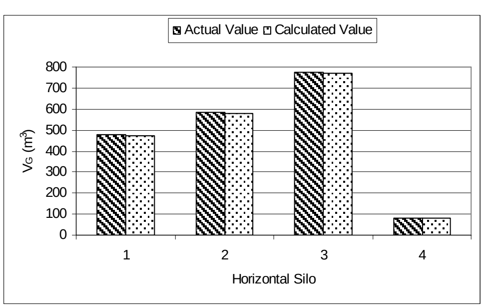

Fig.2.4. Gravels Volume

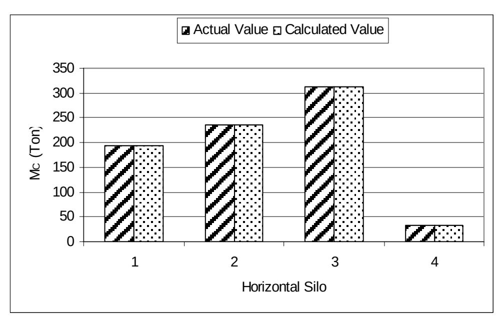

Fig.2.4. Cement Mass

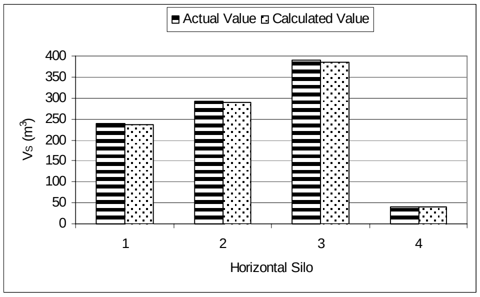

Fig.2.6. Sand Volume

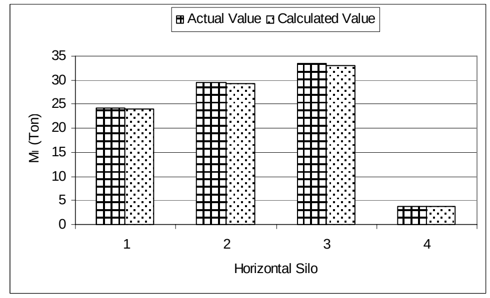

Fig.2.7. Iron Mass

3. Application

Table 1. Mathematical model of concrete structures for horizontal silos

Mathematical Model
$L_{HS} = \dfrac{V_{tHF}}{W_{HSP} \times H_{WHS} \times N_{HSP}}$
$V_{BHS} = N_{HSP} \times L_{HS} \times W_{HSP} \times T_{SB}$
$V_{WHS} = [N_{HSP} \times W_{HSP} \times T_{SW} \times (H_{WHS} + T_{SB})] + [(N_{HSP} + 1) \times (L_{HS} + T_{SW}) \times T_{SW} \times (H_{WHS} + T_{SB})]$
$V_{CHS} = V_{BHS} + V_{WHS}$
$A_{PHS} = (N_{HSP} \times W_{HSP} \times L_{HS}) + [(N_{HSP} + 1) \times (L_{HS} + T_{SW}) \times (H_{WHS} + T_{SB})] + [N_{HSP} \times (H_{WHS} + T_{SB}) \times W_{HSP} \times T_{SW}]$
where $L_{PHS} = \sqrt{A_{PHS}}$ and $2 \le H_{WHS} \le 3$ and $W_{PHS} = L_{PHS}$
$M_C = C \times V_{CHS}$ $V_G = G \times V_{CHS}$ $V_S = S \times V_{CHS}$
Where $C = 325$ and $G = 0.8$ and $S = 0.4$
$N\phi D/m = 6\phi 6/m$ or $N\phi D/m = 6\phi 8/m$
$N_{IL} = [(N_{IML} \times W_{PHS}) + 1] \times 1.05 \times L_{PHS}$
$N_{IW} = [(N_{IML} \times L_{PHS}) + 1] \times 1.05 \times W_{PHS}$
$N_{tIG} = N_{IL} + N_{IW}$
$N_{tI} = N_G \times N_{tIG}$
$N_{tSI} = \dfrac{N_{tI}}{L_{SI}}$
$M_I = N_{tSI} \times M_{IML} \times L_{SI}$ where M_I in kg
$N_{IL} = N_{IW}$ and $L_{SI} = 12$
if $N\phi D/m = 6\phi 6/m$ thus $M_{IML} = 0.666$
if $N\phi D/m = 6\phi 8/m$ thus $M_{IML} = 0.888$
$P_{tC} = P_C \times M_C$ $P_{tG} = P_G \times V_G$ $P_{tS} = P_S \times V_S$
$P_{tI} = P_I \times M_I$ where M_I in Ton
$C_{tEC} = C_{EC} \times V_{CCP}$
$C_{ICH} = P_{tC} + P_{tG} + P_{tS} + P_{tI} + C_{tEC}$
$C_{FCH} = \dfrac{C_{ICH}}{t_P}$ Where $t_P = 20$
$C_{TCH} = C_{FCH} + C_{VCH}$

Table 2. Input data of the spark map

Symbol	Description	Unit
W_{HSP}	Width of Horizontal Silo Pit	m
H_{WHS}	Height of Horizontal Silo Wall	m
N_{HSP}	Number of Horizontal Silo Pits	m
T_{SW}	Thickness of Horizontal Silo Walls	m
T_{SB}	Thickness of Horizontal Silo Base	m
	Type of Iron Rods (NØD/m: 6Ø6/m or 6Ø8/m)	
N_{IML}	Number of Iron Rods per One Meter Length of Concrete	
N_G	Number of Gridirons	
L_{SI}	Length of One Standard Iron Rod	m
M_{IML}	Mass of 1 m Long of Iron Rod	kg/m
P_I	Price of One Ton of Iron Rods	Currency/Ton
P_G	Price of 1 m^3 Gravels	Currency/m^3
P_C	Price of 1 kg Cement	Currency/kg
P_S	Price of 1 m^3 Sand	Currency/m^3
C_{EC}	Employment Costs for 1 m^3 of Concrete	Currency/m^3
C_{VCH}	Variable Costs of Concrete Construction of Horizontal Silo	Currency/Year
t_P	Project Lifetime	Year

Table 3. Output data of the spark map

Symbol	Description	Unit
V_{tHF}	Total Volume of Stored Forage in Horizontal Silo per Year	m^3/Year
L_{HS}	Horizontal Silo Length	m
V_{WHS}	Concrete Volume of Horizontal Silo Walls	m^3
V_{BHS}	Concrete Volume of Horizontal Silo Base	m^3
V_{CHS}	Required Concrete Volume for Horizontal Silo	m^3
V_G	Gravels Volume	m^3
M_C	Cement Mass	kg
V_S	Sand Volume	m^3
A_{PHS}	Area of Concrete Plot of Horizontal Silo	m^2
L_{PHS}	Length of Concrete Plot of Horizontal Silo	m
W_{PHS}	Width of Concrete Plot of Horizontal Silo	m
N_{IL}	Number of Iron Rods in Length	
N_{IW}	Number of Iron Rods in Width	
N_{tIG}	Total Number of Iron Rods in One Gridiron	
N_{tI}	Total Number of Iron Rods	
N_{tSI}	Total Number of Standard Iron Rods	
M_I	Iron Mass	kg
M_I	Iron Mass	Ton
P_{tI}	Total Price of Iron Rods	Currency
P_{tG}	Total Price of Gravels	Currency
P_{tC}	Total Price of Cement	Currency
P_{tS}	Total Price of Sand	Currency
C_{tEC}	Total Employment Costs of Concrete	Currency
C_{ICH}	Capital Investment of Concrete Construction of Horizontal Silo	Currency
C_{FCH}	Fixed Costs of Concrete Construction of Horizontal Silo	Currency/Year
C_{TCH}	Total Costs of Concrete Construction of Horizontal Silo	Currency/Year

The implemented methodology in this study has been implemented by several studies which dealt with other dairy farm facilities [6 through 22].

4. Open Problems

Most mathematical models can be developed as electronic spark maps in order to simplify the use of mathematical models for practical implementation. Consequently, the spark map can be instantly used to make calculations, and to get automatically the results of the input settings. Therefore, the electronic spark map of concrete structures for horizontal silos can be used practically in planning and designing horizontal silos, specifying the dimensions of horizontal silo according to the planned storage volume, computing the amounts of construction materials required to build the horizontal silo, and calculating the costs.

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