DAMAGE PREDICTIONS IN CONCRETE SILO USING FINITE ELEMENT ANALYSES

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Abstract

The objective of this study is to improve the ultimate internal pressure capacity, the strength, and durability of silos. The first part of this paper is to analyse the mechanical behaviour of reinforced concrete silos during filling using numerical simulation approach. These results are compared with results from analytical approach. The second part of this work concerns the reinforcement of silos by external wrapping of damaged sections using carbon fibre reinforced polymer (CFRP) materials as an alternative repair of the structure. The wheat is modelled by 8 solid elements, the reinforced concrete silos are modelled by shell elements and their nonlinear behaviour is considered by concrete damaged plasticity model. At the silo wall -wheat material interface, the friction is modelled by Coulomb's law and it is chosen in the range of 0.4 – 0.5. The results show that the use of carbon fibre reinforced polymer materials offers a substantial benefit over the damage resistance during filling silos.

Keywords: Concrete silo, Finite element method, Composite, Damage.

1. Introduction

The reinforced concrete silos used for storing different granular materials are subjected to temperature variations and to a number of loading cycles resulting from filling and discharge of the material. This unusual loading conditions and the behaviour of concrete at certain ages may lead to severe damage or even collapse of the silo. These phenomena are observed in several silos, which are built in Algeria between 1960s and 1970s for storing wheat. Theoretical solutions presented in the literature concern the prediction of silo pressure under static and dynamic loadings. Since the works of Janssen (1895) related to the estimation of pressures on silo walls and bottoms. many papers have appeared concerning damage and failures in silo, granular material-structure interactions using finite element models, and the behaviour of silos under earthquake loading. Elghazouli and Rotter (1996) have investigated the wide variation in pressure calculation according to different methods and examined structural damages of reinforced concrete circular silos. They have shown that inadequate crack control causes rapid deterioration in the strength and may often lead to premature structural failures. Silo damage and failures due to explosion and bursting, asymmetrical loads created during filling, or discharging. large and non uniform soil pressure, corrosion of metal silos, design errors, construction errors, and utilization errors are presented by Dogangun et al., (2009) and Carson and Holmes (2003). Nateghi and Yakhchalian(2012) have tried to see the effect of granular material-structure interaction in seismic behaviour of reinforced concrete silos, the results show that considering the effective mass of granular material equal to 80 percent of granular material total mass results in more severe tension damage in silo walls.

However, due to the deterioration of concrete silos, Carbon Fiber Reinforced Polymer (CFRP)is a new kind of composite reinforcement material. In this work, a numerical study of the behaviour of reinforced concrete silo is presented using finite element methods. A method is used to stop damage propagation and structurally reinforce concrete silo by external wrapping of damaged sections using carbon fibre reinforced polymer materials. The obtained results are compared with results from analytical approach

2. Modelling of reinforced concrete silo

In this paper, the silo structure is modelled by the concrete damaged plasticity model, 4 node shell elements are used for modelling the walls and bottom silo. It assumes that the two failure mechanisms are tensile cracking and compressive crushing. Circumferential and meridionalrebars were defined as layers of uniaxial reinforcement in shell elements.

The cylindrical wall was reinforced with two layers of meridional reinforcements of 10 mm diameter, and two layers of circumferential reinforcements of 14 or 16 mm diameter at a vertical spacing varying between 150 mm.

The mechanical properties of rebars, concrete and wheat are presented in Tables 1 and 2. The silo dimensions are presented in Table 3. The wheat is considered as a granular material and represented by 8 node solid elements. The wheat material inside silo was modelled by elastic perfect plastic Ducker Pager model. The only applied load was gravity loads and vertical friction loads under static conditions. Coulomb's friction model is used to describe the interaction between the silo wall and the bulk solid wheat. Since the cohesion sliding resistance between both materials, c is assumed to be zero, the wall friction coefficient (μ=0.45) was the only required parameter needed. Hence, equivalent shear stress, τ is linearly dependent on the wall normal pressure, P (in kPa).

$$\tau = \mu P + c$$

To simulate the contact of the stored material with the wall, a surface-to-surface contact model was used with the penalty method algorithms.The simulations are performed with the commercial software ABAQUS. A sensitivity analysis using increasing numbers of elements has been carried out. For the finally chosen mesh, a good relative convergence accuracy of the damage values was observed.

Table 1. Mechanical properties of rebars and concrete

Mechanical properties	Rebars	Concrete	CFRP
Young's modulus (MPa)	200000	20800	50000
Poisson's ratio	0.3	0.175	0,3
Density (Kg/m3)	7850	2500	0,3
Tensile Strength	620		
Compressive strength		25 MPa	

Table 2. Mechanical properties of wheat

Mechanical properties	Wheat
Young's modulus (MPa)	5.1
Poisson's ratio	0.32
Density (Kg/m3)	900
Dilatancy angle (°)	17°.6
Internal friction angle (°)	21°
Grain - wall friction coefficient	0.4

Table 3, Dimensions of the silo

Height (m)	30
Internal diameter (m)	6
wall thickness (m)	0.18
Meridional reinforcement	2 layers of Φ 10 (wall and hopper)
Circumferential reinforcement	2 layers of Φ 14 (wall) Φ 16 (hopper)

The uniaxial tension and compression stress-strain curves of concrete and the uniaxial tension and compression damage variables are shown in figure 1. It assumes that the main two failure mechanisms are tensile cracking and compressive crushing of the concrete material. The degradation of the elastic stiffness is characterized by two damage variables, d_t and d_c, which are assumed to be functions of the plastic strains (Fig. 2). The damage variables can take values from zero, representing the undamaged material, to one, which represents total loss of strength.

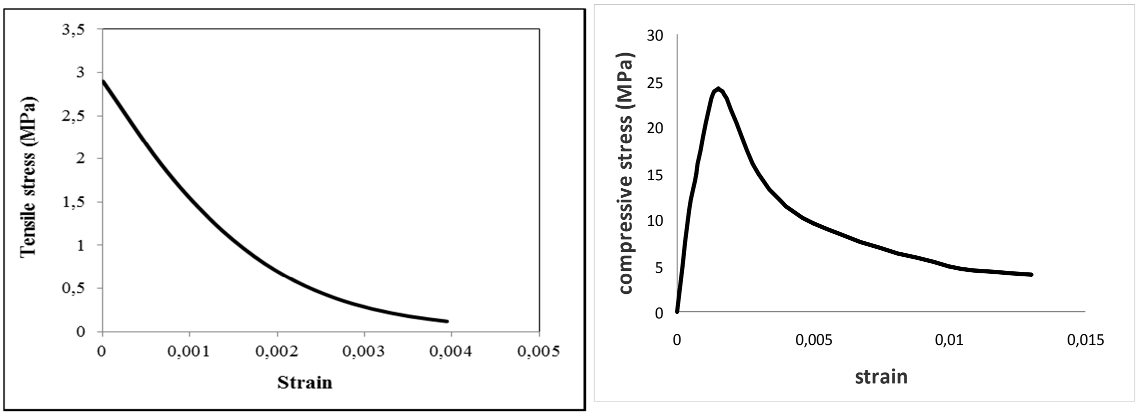

Fig. 1. Uniaxial tension and compression stress-strain curves

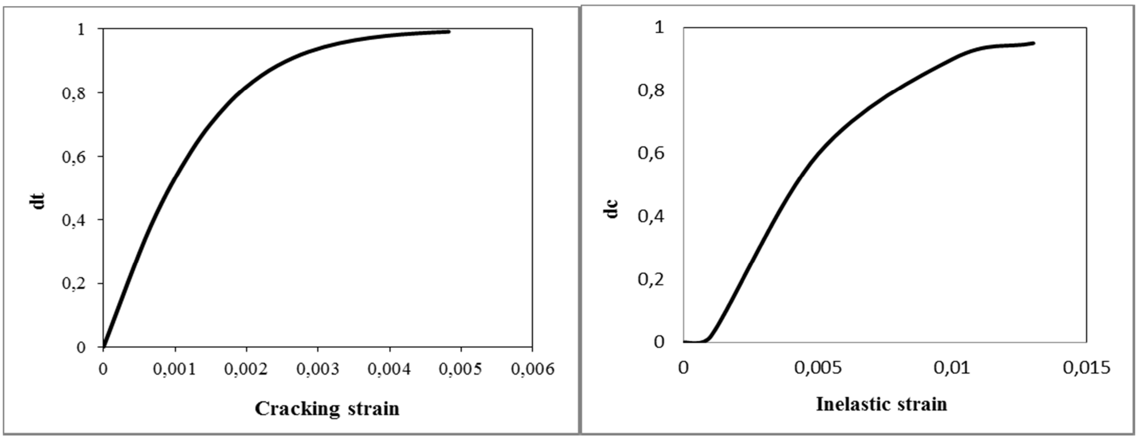

Fig. 2. Uniaxial tension and compression damage

3. Numerical results

The numerical results of pressure distributions in silo shells as a function of the height of the silo during filling are shown in Figure 3. Pressures are calculated taking into account the physical and mechanical properties of stored materials, silo structures and the friction between stored material and the wall.These results are compared with those obtained by Reimbert (1987) and the Eurocode 1 part 4 (EC1-4). It can be observed that the numerical results of horizontal pressures show a good agreement with those obtained by traditional theories and international standards. The maximum pressure at the hopper – silo joint have significant influence on the crack initiation.

Figure 4 shows the result of the horizontal pressure of concrete silo with and without CFRP material. It can be seen that the maximum value of horizontal pressure is 94 kPa without CFRP and much less with CFRP whose value is 62 kPa; this corresponds to a decrease of about 34 % of horizontal pressure. This means that the CFRP material has a significant effect on the performances of reinforced concrete silo and a real impact on lifetime.

Figure 5 shows the variation of the damage value according to the ratio of volume grain to total volume of reinforced concrete silo with and without CFRP material. As shown in this figure, the damage propagation significantly increases as the volume of granular material increases in the case of concrete silo without CFRP. Note that, from 35% filling rate the damage value increases exponentially. In the second case, it should be noted that the presence of CFRP significantly delays the damage initiation which is observed from 60 % filling of granular material.

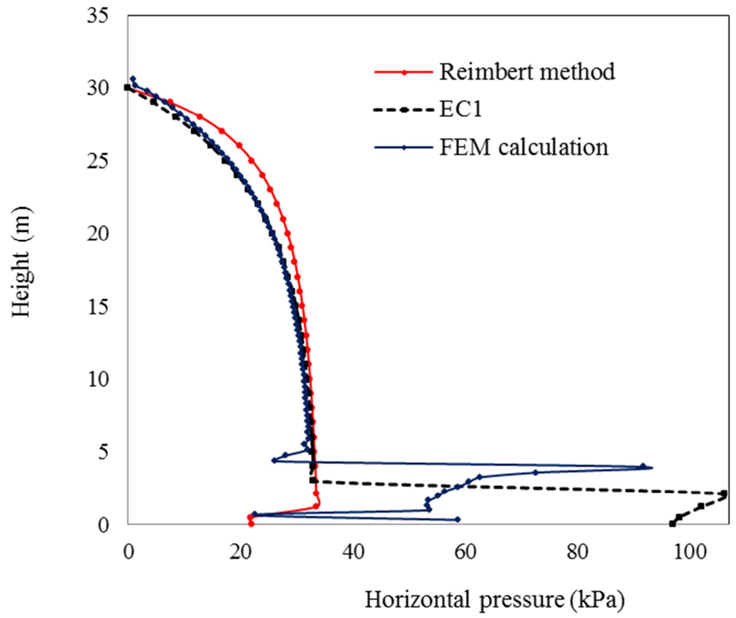

Fig. 3. Distribution of horizontal pressure

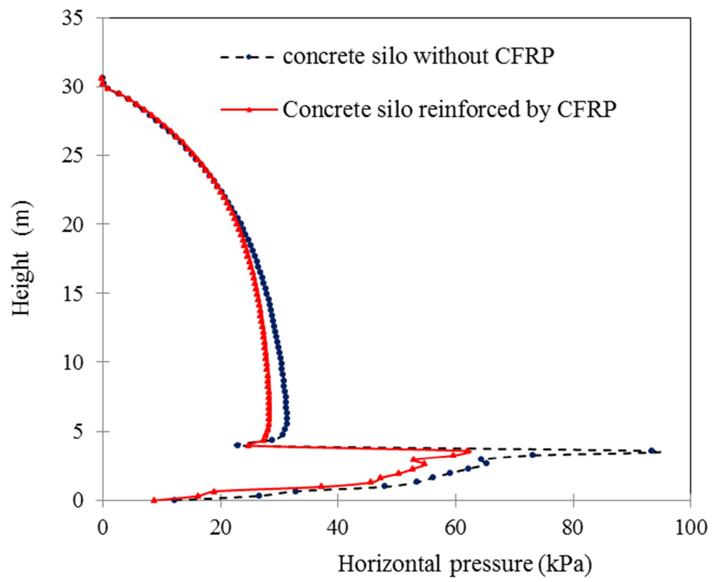

Fig. 4. Effect of use of CFRP

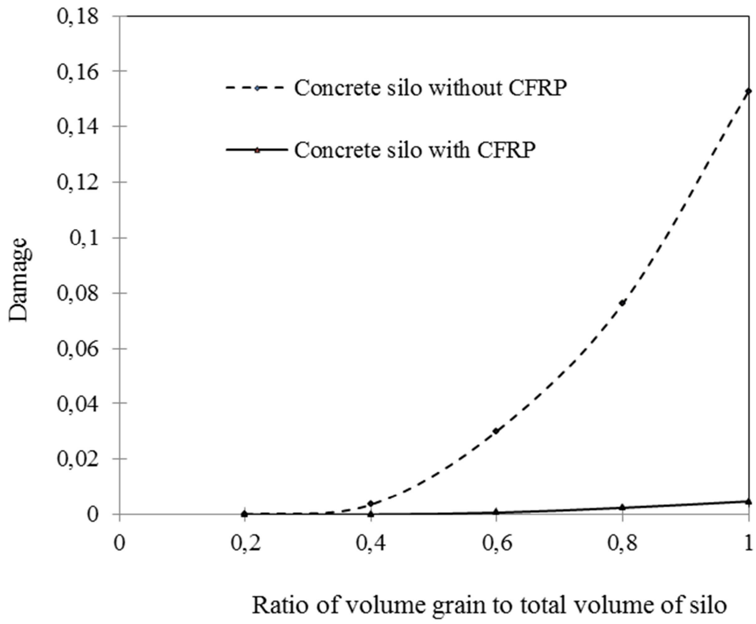

Fig. 5. Predictions of damage initiation

4. Conclusions

In this paper, the effect of fibre carbon reinforcement on the strength and durability of silo has been investigated using finite element method. The finite element simulation is applied to evaluate horizontal pressures with and without composite material in order to predict the evolution of damage during filling process. The study showed that the horizontal pressure increases until it reaches a maximum value at the hopper – silo interface. The numerical results have shown that, the use of CFRP as an alternative repair of silo allows increasing the granular material volume of silo and delaying the onset of damage initiation. However, damage initiation is located near the hopper – silo interface. Note that a similar effect was observed by Nateghi and Yakhchalian (2012) under seismic loading. The CFRP and the reinforced concrete of the silo wall work together to decrease the maximum value of horizontal pressure at this interface and increase the lifetime of concrete silo.

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