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ANALYSIS OF GFRP STRENGTHENED STEEL SILO WITH FINITE ELEMENT METHOD

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Abstract

Due to their unique deformed shape, thin cylindrical metal shell structures such as silos and tanks are subject to elastic–plastic instability failure at their walls caused by high internal pressure and axial compression in the shell structure cause this type of buckling to occur. This is a common situation in a silo where the silo wall is subjected to both the normal pressure of the stored granules and vertical compressive forces caused by friction between the stored granules and the silo wall. This paper presents a novel method of strengthening cylindrical shells by applying a thin layer of fibre-reinforced polymer (FRP) composite, used at the silo body, can effectively eliminate the problem and increase the buckling strength. The strengthened shell is analysed using finite element method (FEM) in this preliminary study. Furthermore, the resistance of FRP materials to corrosion means that they can be used to replace steel and reinforced concrete in situations when they would be exposed to corrosion. FRP therefore has wide application prospects in civil engineering ranging from reinforcing rods and tendons, wraps for seismic retrofit of columns and externally bonded reinforcement for strengthening of walls, beams, and slabs, to all composite bridge decks, and even hybrid and all-composite structural systems.

In this study, a steel silo structure was modeled in the SAP2000 program. First, the existing structure was analyzed. Then, 4 mm thick GFRP (Glass Fiber Reinforced Polymer) was applied to one side of silo walls and analysis was made. The aim of this study is to examine the effect of the GFRP material applied to the walls of steel silo on the period and displacement values of the structure. As a result of the analysis and comparisons made, it was seen that the dominant period of the GFRP applied structure decreased by almost (26%) compared to the existing structure. The study showed that the GFRP material applied to steel silo walls provides a significant improvement in the period value of the structure.

Keywords— Steel silo; GFRP; Modal parameters; FEM; Strengthening.

Introduction

Steel silos are commonly used to store granular solids for long or short periods of time. Granular solids include flour, iron or pellets, coals, cement, crushed rocks, plastic, chemical compounds, sand, and concrete aggregate, among other things. Silos are thin-walled shells in which buckling failure is a major concern that need specific consideration. Since the early twentieth century, scientists have explored the buckling of a thin metal shell (Timoshenko, 1936). The classical phase of those studies refers to the time period between the 1900s and the 1970s, when simple load situations and modest geometric flaws were utilized, prior to the computer era, when finite element analysis and non-linear equilibrium routes became powerful tools. Fibre reinforced polymers are obtained by combining high-strength fibers with a resin matrix, with the fibres providing strength and the resin binding the fibres together. Carbon, aramid, and glass fibres are used. As a result, the strength of FRP might vary based on the type of fibers employed. Glass Fiber Reinforced Polymer (GFRP) for reinforcing Steel Silos has been studied extensively [2], [3], [4], [5], [8, [9], [13]. Steel silos were reinforced with a GFRP layer, and a finite element analysis was used to determine their dynamic behavior. Dynamic parameters were compared between the GFRP amplified state and the state before reinforcement. The differences were revealed by examining all the effective parameters (frequency, mode shape, etc) in the dynamic behaviour before and after the reinforcement. For GFRP materials, proper surface preparation is critical. The most significant issue in the deployment of GFRP in structures is the removal of the cover layer, which involves stripping the material or separating the concrete. In FRP materials, material strength can be adjusted by changing the alignment directions of the fibers in the desired direction. Compared to other strengthening techniques, it has the ability to be applied in places that concrete or steel cannot. In both cases, the mode shapes and the period values of the mode are given separately and compared. Thus, it is aimed to reveal the effect of GFRP reinforced on the modal parameters of steel silos.

I. Description Of Glass Fiber Reinforced Polymer

Glass fiber fabrics are still the most commonly used reinforcement in the field of composite materials today. They are generally the least cost-effective reinforcements and the easiest to process. In combination with resin, they produce composite parts with excellent strength, low weight and outstanding appearance. All fiberglass fabrics are woven by fiber orientation, and each fabric has its own unique weight, strength, and weave characteristics, that should be considered before beginning a project. Fiberglass is a lightweight composite material used in a variety of applications. Although it is not as strong and stiff as carbon fiber, it is less brittle and its raw materials are significantly cheaper. It has a higher strength and weight than many metals, and can easily be molded into more complex designs. Fiberglass is used in planes, boats, and vehicles, among other things. Glass fiber fabrics, prepregs, and spools are all available. We may supply large quantities of product to industry or small quantities for prototypes. The exterior surfaces of concrete structures, arches, vaults, and domes are wrapped with GFRP textiles (fig. 1) in the proper direction and width to increase their carrying capacity and ductility under existing loads. Preparation of the surface before application of all dust and free of material to remove the material between the GFRP fabric and the structure that would effect the adherence of any dust particles should be done with caution [6], [7], [12] The most important advantage of GFRP fabrics is that it gives a much more rigidity than conventional methods with a few
millimeters of material reinforced to the structure. [6],[7].

The material to be used for the planned reinforcement is shown in Figure 1. The thickness of the GFRP fabric to be used is designed as 4 mm. The parameters of the material are specified separately under "Mechanical properties of the GFRP material".

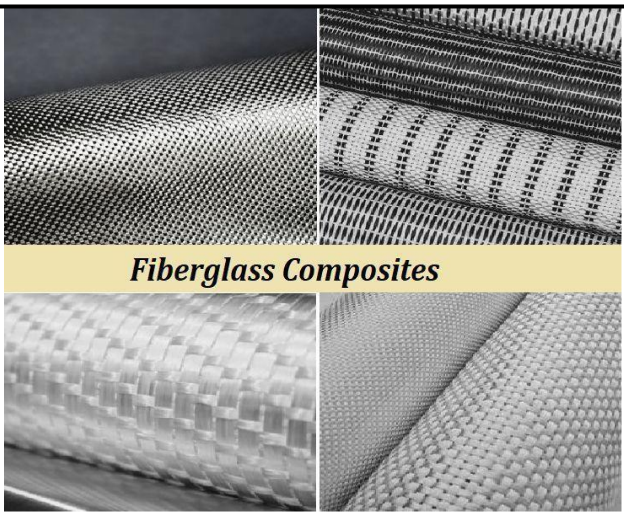

Fig. 1. GFRP Fabric

Fig. 2.

II. MECHANICAL PROPERTIES OF USED MATERIALS

A. The mechanical properties of the steel material were entered into SAP2000 program as follow;

- Mass and Weight of the Material:
  1- Unit Volume Weight = 7849.047 kgf/m3,
  2- Unit Volume Mass = 7851.72 kgf/m3.
- Mechanical Properties of the Material:
  1- Elasticity Module:
  E1 = $2.1*10^5$ kgf/mm2
  2- Poisson Ratio:
  U12 = 0.3

B. The mechanical properties of the GFRP material were entered into SAP2000 program as follow;

- Mass and Weight of the Material:
  1- Unit Volume Weight = 1900.65 kgf/m3,
  2- Unit Volume Mass = 1938.12 kgf/m3.
- Mechanical Properties of the Material:
  1- Elasticity Module:
  E1 = 4078.86 kgf/mm2
  E2 = 4078.86 kgf/mm2
  E3 = 815.77 kgf/mm2.
  2- Poisson Ratio:
  U12 = 0.25
  U13 = 0.25
  U23 = 0.25.

III. METHOD AND RESULTS

A. Authors and Affiliations(TNR- 10, Italic,Bold)

First, the characteristics of the steel silo and the properties of the GFRP material were entered into the SAP2000 program. In this study, the GFRP material is applied to the entire surface. This closes all the thin cracks on the surface. The diameter of the steel silo is 4 meters, while the height of the steel silo is 12 meters. The type of steel used is St52. The steel thickness of the silo is 0.005 m. In this paper, the analysis were made using the finite element method for the current state and the state after reinforcement, respectively. The studies have been examined under separate titles and the data obtained have been presented. In both cases, the mode shapes and the period values of the mode are given separately and compared.

Steel silo and GFRP's wall thicknesses used in this reasearch article are given in Table 1.

TABLE I. THICKNESS OF STEEL SILO AND GFRP LAYERS

Material Name	Thickness (mm)
Steel Silo	5
GFRP	4

B. Results and Discussion

In this section, the analysis was made using the finite element method for the current state and the state after reinforcement, respectively. The studies have been examined under separate titles and the data obtained have been presented. In both cases, the mode shapes and the period values of the mode are given separately and compared.

1) Analysis of Steel Silo without GFRP:

The 3D finite element model of the Steel silo was created with the SAP2000 program. Steel silo's finite element model without GFRP results are given in fig. 2

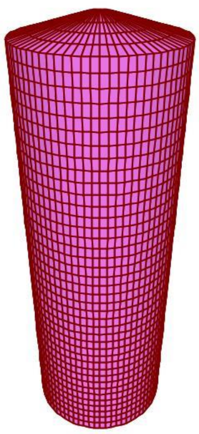

Fig. 3. Steel Silo Finite Element Model without GFRP

Modal analysis results before applying GFRP to the steel silo are given in Table 2 and respectively mode shapes given fig. 3.

TABLE II. PERIODS OF STEEL SILO WITHOUT GFRP

MODE NO.	PERIOD (S)
1	0.0996
2	0.0899
3	0.0836
4	0.0643
5	0.0639

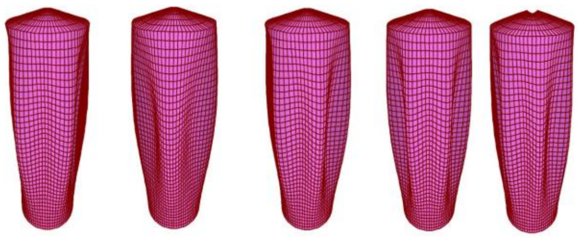

Fig. 4. Respectively Mode Shapes of Steel silo without GFRP

2) Analysis of Steel Silo with GFRP:

The finite element model of the steel silo shown in Figure 4 is the reinforced situation; GFRP reinforced. In this study, the GFRP fabric technique is used as the reinforcement method. The thickness of the GFRP fabric is 4 mm. The GFRP fabric is applied to the entire outer surface. SAP2000 program was used to determine the analysis data

Modal analysis results after applying GFRP to the steel silo are given in Table 3 and respectively mode shapes given fig. 4.

TABLE III. PERIODS OF STEEL SILO WITHOUT GFRP

MODE NO.	PERIOD (S)
1	0.0837
2	0.0803
3	0.0619
4	0.0592
5	0.0493

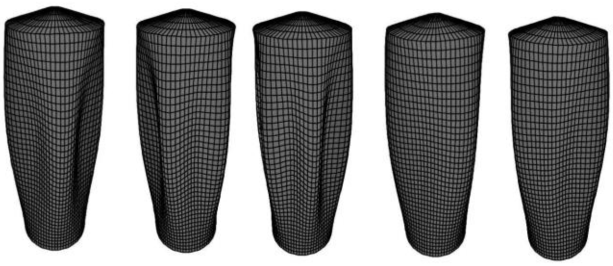

Fig. 5. Respectively Mode Shapes of Steel silo with GFRP

3) COMPARISON OF ANALYSIS RESULT;

TABLE IV. COMPARISON PERIODS BEFORE APPLYING GFRP MODEL AND WITH GFRP MODEL

Mode no.	Diffrence (s)	Diffrence (%)
1-1	-0,0159	15,96%
2-2	-0,0096	10,67%
3-3	-0,0217	25,95%
4-4	-0,0051	7,93%
5-5	-0,0146	22,84%

When the mode shapes are examined, the modal shapes are similar in both cases. There was no discernible difference between them. However, when analyzed as animation, it was seen that large displacements were replaced by torsions.

IV. CONCLUSIONS

In this study, as a result of the reinforcement made by wrapping 4 mm thick GFRP fabric into the 5 mm thick Steel Silo structure, the percentage changes in the parameters of the structure are listed as below.

A reduction in the periods is clearly visible when the steel silo is reinforced with GFRP. Especially when analyzing the dominant period, a decrease of almost 26.00 percent can be observed. It is also known that the reduction of the periods leads the structure out of the resonance range and increases the stiffness.

With GFRP, modal shapes with more balanced displacements in 3 directions are seen instead of large displacements in one direction. It is predicted that the effect of strengthening with GFRP will increase further as the thickness of the GFRP increases. In this study, only the simplest application with a thickness of 4 mm, i.e. a single layer application, was used. This revealed the most fundamental effects. In view of all these findings, GFRP reinforcement can be used to strengthen steel silos.

References

1. Kasimzade, A.A., & Tuhta S. (2012). Analytical, numerical and experimental examination of reinforced composites beams covered with carbon fiber reinforced plastic, Journal of Theoretical and Applied Mechanics, vol. 42, pp. 55- 70.
2. Tuhta. S., Gunday. F., & Warayth M. O. (2021). The Effect of GFRP Steel Silo on Modal Parameters Using Finite Element Method. 8(7), 41-46
3. Kasimzade, A.A., & Tuhta, S. (2017) OMA of model steel structure retrofitted with GFRP using earthquake simulator, Earthquakes and Structures, vol. 12, pp. 689-697.
4. Kasimzade, A.A., & Tuhta, S. (2005) Finite Element, Analytical, Experimental Investigation of Reinforced Concrete Beams Strengthened with GFRP and Related Structure Analysis Problem's Solutions, AACEU, Scientific Works No 0, pp.18-26.
5. Bastianini, F., M. Corradi, A. Borri, & Angelo di Tommaso A. (2005). Retrofit and monitoring of an historical building using ''Smart'' GFRP with embedded fibre optic, Construction and Building Materials.

6. La Mendola, L., M. Accardi, C. Cucchiara, & V. Licata. (2014). Nonlinear FE analysis of out-of plane behaviour of masonry walls with and without GFRP reinforcement, Construction Building Material.
7. Tuhta, S., Günday, F., Aydin, H., & Pehlivan, N. Ç. (2019). Investigation of GFRP Retrofitting Effect on Masonry Dome on Period and Frequency Using Finite Element Method. Presented at the International Disaster and Resilience Congress (idRc 2019), Eskişehir.
8. Tuhta, S., Günday, F., Aydin, H., & Pehlivan, N. Ç. (2019). Investigation of GFRP Retrofitting Effect on Masonry Dome on Stress Using Finite Element Method. Presented at the International Disaster and Resilience Congress (idRc 0219), Eskişehir.
9. Günday, F. (2018). GFRP Retrofitting Effect on the Dynamic Characteristics of Model Steel Structure Using SSI. International Journal of Advance Engineering and Research Development, 5(4), 1160-1173.
10. Tuhta, S., Abrar, O., & Günday, F. (2019). Experimental Study on Behavior of Bench-Scale Steel Structure Retrofitted with CFRP Composites under Ambient Vibration. European Journal of Engineering Research and Science, 4(5), 109–114.
11. Tuhta, S., Günday, F., & Aydin, H. (2019). Dynamic Analysis of Model Steel Structures Retrofitted with GFRP Composites under Microtremor Vibration. International Journal of Trend in Scientific Research and Development, 3(2), 729–733.
12. Tuhta, S., Günday, F., & Alihassan, A. (2020). The Effect of CFRP Reinforced Concrete Chimney on Modal Parameters Using Finite Element Method. International Journal of Innovations in Engineering Research and Technology, 7(2), 1–6.
13. Djermane, M., Zaoui, D., Labbaci, B., & Hammadi, F. (2014). Dynamic buckling of steel tanks under seismic excitation: Numerical evaluation of code provisions. Engineering Structures, 70, 181–196.
14. Chen, J., Rotter, J., & Teng, J. (2005). Strengthening silos and tanks against elephant's foot buckling. Fourth International Conference on Advances in Steel Structures, 459–466.
15. Theory of Elastic Stability. S. Timoshenko. McGraw-Hill Publishing Company, Ltd., 1936. Price 36/-. (1936). The Journal of the Royal Aeronautical Society, 40(312), 903-905.