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Araştırma Makalesi/Research Article

Design and Testing of a Laboratory Scale Deflection Apparatus

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Abstract

Agricultural structures play an important role in the quality and quantity of products that are either produced or stored within a structure. Main characteristic of an agricultural structure is that it is generally smaller and lighter than other industrial structures. Hence, they require smaller scale and capacity laboratory equipment when conducting studies on structural behaviors of such structures. In this study, a deflection apparatus was designed and tested to determine if it is suitable for use in greenhouse mechanics studies. Design procedures, materials used in the design and performance of the system was discussed. Theoretically calculated deflections were compared by measured deflections obtained from the developed system. The results showed that calculated and measured deflections yielded stronger relationship with an R^2 value of 0.99. It should also be noticed that the cost of the system (5480 TL, $ 1000) makes it ideal for related studies.
Keywords: Agricultural structures, greenhouses, strength of materials, deflection, beams

Laboratuvar Ölçekli Tasarlanan Bir Eğme Deney Setinin Test Edilmesi

Öz

Tarımsal yapılar, bir yapı içerisinde üretilen veya depolanan ürünlerin kalitesi ve miktarında önemli rol oynar. Tarımsal yapının temel özelliği, diğer endüstriyel yapılardan genellikle daha küçük ve daha hafif olmasıdır. Bu nedenle, bu tür yapıların yapısal davranışları üzerinde çalışmalar yapılırken daha küçük ölçekli ve kapasiteli laboratuvar ekipmanlarına ihtiyaç duyulmaktadır. Bu çalışmada, sera mekaniği çalışmalarında kullanılması amacıyla bir eğme deney seti tasarlanmış ve test edilmiştir. Araştırmada, tasarım prosedürleri, sistemin tasarımında kullanılan malzemeler ve performansı tartışılmıştır. Teorik olarak hesaplanan sarkı miktarları, geliştirilen sistem kullanılarak ölçülen sarkı miktarları ile karşılaştırılmıştır. Sonuçlar, hesaplanan ve ölçülen sarkı miktarlarının, 0.99 'luk bir R^2 değeri ile güçlü bir ilişki sağladığını göstermiştir. Ayrıca sistemin, maliyeti gereği (5480 TL, 1000 $) benzer çalışmalar için uygun olduğu göz önünde bulundurulmalıdır.
Anahtar Kelimeler: Tarımsal yapılar, seralar, malzeme mukavemeti, sarkı, kirişler

Introduction

Understanding of strength of materials is one of the most important knowledge required for agricultural engineers. Examination of structural materials under different load conditions is critical to compare experimental and theoretical values (Kareem, 2012). It is also important to test alternative structural materials to be used in agricultural structures and their behavioral characteristics. Therefore, strength of material is also called mechanics of materials.

The structures constructed for agricultural purposes have some different features than the other structures. The fact that crop production depends on growing periods is a limiting factor. Production outside the growing season is possible in greenhouses (Yıldırım et al., 2015). Light frame systems covered by a light-translucent covering material are installed on the production sites enables sunlight required for photosynthesis pass into the structure, and to regulate the indoor environmental conditions independently from the outdoor environment. The most widely used type of greenhouses which can be constructed from various building materials in accordance with the production purpose are the ones with pipe profile plastic covering. The low cost of construction and the ease of installation have made the use of such greenhouses widespread. Frame systems provide economical solutions for most of the agricultural production and storage structures (Lindley and Whitaker, 1996). It is known that plastic covered greenhouses, which have rapidly become widespread in the last 50 years, have low resistance to wind load (Hoxey and Richardson, 1984). Bending tests and mathematical models carried out under

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laboratory conditions can determine the forces applied by wind and snow loads to greenhouses (Wells and Hoxey, 1980; Hoxey and Richardson, 1983). However, this test, which is applied in real-size models, requires high-cost equipment and intensive labor use (Mathews and Meyer, 1987). Besides, wind tunnel tests that simulating natural conditions also require correction and verification due to insufficient statistical data (Yang et al., 2013). Results obtained by the finite element method (FEM), which is known to provide the most appropriate results by correction and verification methods, differs from the results obtained by direct monitoring (Moriyama et al., 2003). Time-related fatigue in building elements limits the use of mathematical models (Hur and Kwon, 2017). Accordingly, the monitoring of the forces applied by the wind and snow loads to the greenhouses in real conditions will increase the accuracy of the model to be created. On the other hand, the devices that will be fixed on the structure elements and receive data cannot be supplied by the producers due to their high costs. In order to determine the strength properties of frame materials, some tests should be performed in the laboratory. These tests are not only important for material testing but also essential for students to conduct experimental studies in laboratory. However, equipping laboratories with expensive test apparatus is very difficult especially for small universities (Pisačić et al., 2018). For example, the price of an electromechanical test apparatus which can be used in the pressure and tensile tests of the profiles can be up to € 25000 (160,000 TL).

One of the test apparatus that can be used in mechanics laboratories is beam deflection apparatus. This apparatus can be used in a wide range of applications from determination of elastic modulus (E) to deflection studies. An example of beam deflection apparatus is given in Figure 1. It has two tripod legs which act like fixed supports. The deflection is measured with a dial gauge placed at the middle of the material (Pisačić et al., 2018). Kareem (2012) reported that there are also various types of such apparatus produced and used in different countries.

Figure 1. Beam deflection apparatus (Pisačić et al., 2018)

In this study, it was aimed to design a cost-effective test system that can be used to evaluate mechanical properties of structural materials especially used in frame buildings such as greenhouses.

Material and Method

Theoretical approach to calculate the beam deflection

The term deflection is often refers to deformation of a beam from its original unloaded position. The distance between unloaded neutral surface of beam and deformed neutral surface of the beam yields deflection. The neutral surface of the deformed beam is called elastic curve (Figure 2). In the study different loads and corresponding deflection values were calculated. The results were compared to test values.

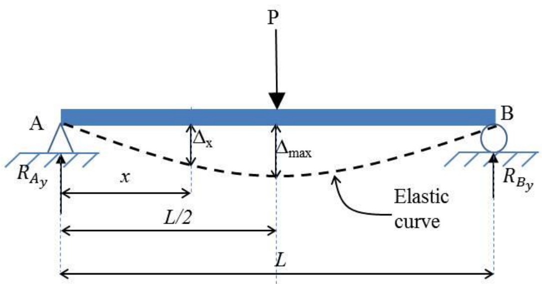

Figure 1. Deflection on simple beam

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Deflection at any point between two supports on a simple beam can be calculated using the following equations (Dupen, 2016).

$$\Delta_x = \frac{Px}{48EI}(3L^2 - 4x^2) \text{ for } x \leq L/2 \quad (1)$$

Where, Δ_x: deflection at a point x meters from support A, P: load (N or kN), x: any point between L and L/2, E: modulus of elasticity of the material from which the beam is fabricated (N/m^2), I: moment of inertia (m^4), L: total length of the beam (m).

The maximum deflection occurs at the midpoint of the beam where the load (P) is applied and x= L/2. Hence if we substitute this value in equation (1), we get following equation (2).

$$\Delta_{max} = \frac{PL^3}{48EI} \quad (2)$$

Design of experimental apparatus

Basically, experimental apparatus consists of a base to prevent vibration, shafts to guide vertical movement, a table for loading and stands to support the profile at the ends for the bending test (Figure 3). The 1-square-meter heavy base sheet with 12-mm-thickness holds the test apparatus stationary. Under this sheet, 4 cm thick sheet irons were erected along the 4 sides to act as a foot. In order for the tested profiles to be positioned at the center, the bracelet with an inner diameter of 1 inch was welded on the base. Shafts, 2.5 inches in diameter and posts 2.5 meters in height were placed from the four corners of the base symmetrically. In order to move on these shafts, the loading table was created by cross-fixing the 4 cm moldings. The 1-inch inner diameter bracelet, which is fixed on the lower surface of this table to the middle point, ensures that the tested profile with the bracelet on the base remains in the center. Three-inch pipe pieces, fixed on the 4 corners of the loading table pass over the shafts, ensuring that the table stays stable in the course of vertical movement. The stands designed for the bending test remain in an upright position by cross-welding the 4 cm moldings to the bases of the 2.5-inch-thick and 1-meter-long shafts. To fix the profile to be tested at the ends, these feet were welded on 3 feet of pipe pieces.

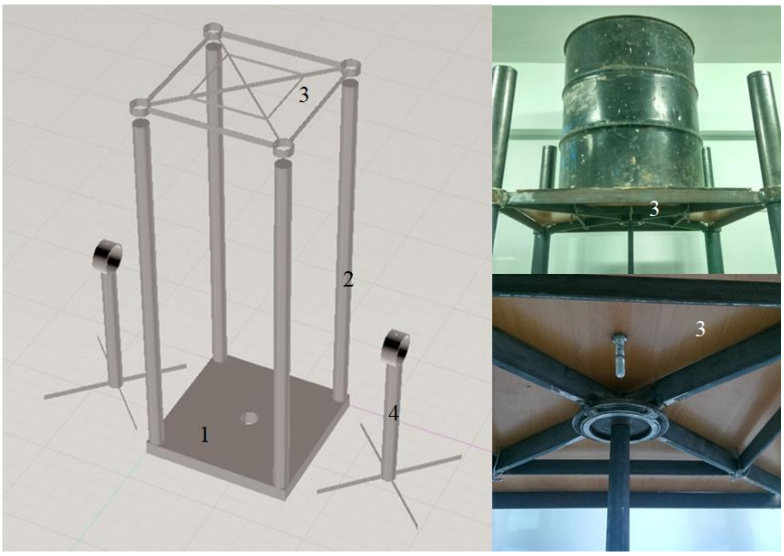

Figure 3. Beam deflection test apparatus (1: base, 2: posts, 3: loading table, 4: stands for beam support)

Results and Discussion

In order to test the apparatus, a 1-inch diameter steel pipe was fixed to the beam stands. The steel pipe was loaded from the mid-point with 0 kg to 140 kg. The load was increased 5 kgs at each

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loading. In order to determine the deflection occurred in the mid-point of the beam, images of the loading phase acquired. The actual Δ_{max} values were measured from the images considering the deviation in elastic curve. The loading up to 40 kgs was applied via adding 5-kg sand bags to the system. From 40 kgs, loading was achieved via adding 5 kg-sand bags in to the barrel located on the loading table. Examples of loadings and deflections obtained in both conditions are given in Figure 4.

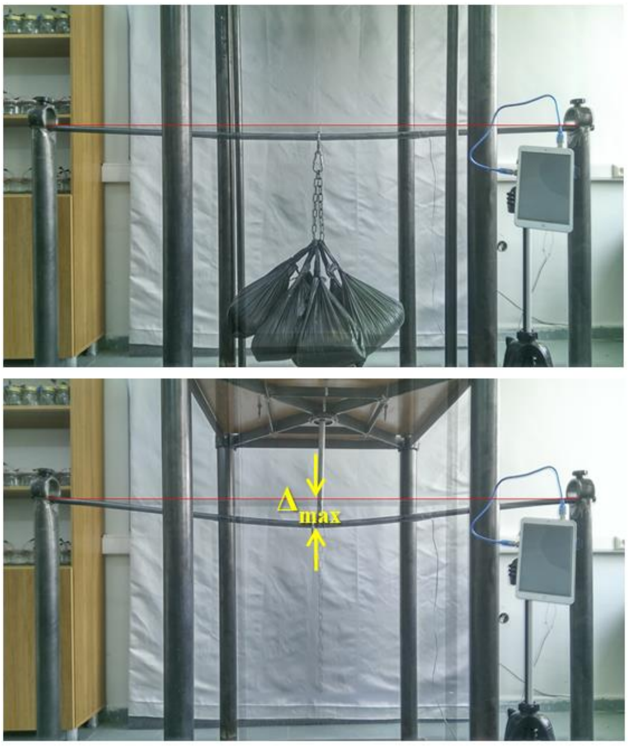
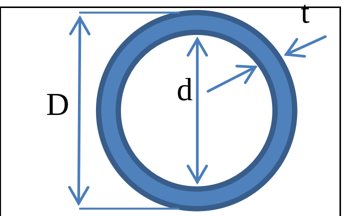


Figure 4. Loading and measurement of deflection in test apparatus

In calculation of theoretical deflection Equation 1 was applied using the following parameters (Table 1).

Table 1. Parameters used in the calculation of deflection.

Outside diameter (D)	21.3	mm
Inside diameter (d)	17.3	mm
Thickness (t)	2	mm
Effective length (L_{eff})	1.4	m
Moment of inertia	5.7×10^{-9}	m^4
Modulus of elasticity	2.1×10^{11}	$N\ m^{-2}$



The measured and calculated deflections were plotted to observe if the test apparatus yields reasonable results. The linear relationship between two values and line of equality is given in Figure 5. There is a strong relationship between the actual and theoretical deflections with an R^2 value of almost 0.99. Also, the positions of trend line and line of equality prove the strong and meaningful relationship between two values.

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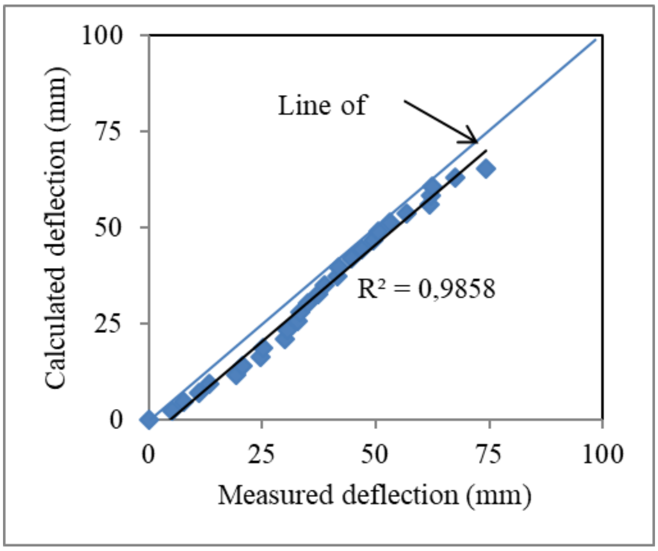

Figure 5. Measured and calculated deflections

Conclusions

Agricultural structures such, especially greenhouses, are generally made of steels in different profiles. Small diameter (2 to 3 inches) pipes are the major structural material for small-scale, and family-owned greenhouse operations. When conducting research on greenhouse mechanics, engineers require the determination of bending properties of different materials under varying loading conditions. However, even though there are industrial-scale state-of-the art equipment are available, they are very costly and most of the time it is not feasible to obtain such technologies.

In this study, it was aimed to design and test the performance of a low-cost deflection apparatus to be used in such studies. The material used in the design was obtained with a reasonable price of 5480 TL ($1000). The results of the study shows that lab-scale deflection apparatus can be used in mechanics laboratories which are conducting mechanics studies on light-weight, small-scale structures.

Note: This manuscript is written for partial fulfillment of the graduation requirements of Graduate School of Natural and Applied Sciences of Çanakkale Onsekiz Mart University. It is produced from the findings of Sefa Aksu's doctoral dissertation entitled "Development of Wind and Snow Load Monitoring System for Plastic Covered Greenhouses".

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