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Effect of Cross-section on Column Buckling

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Abstract:
In this study, a buckling analysis of a square safety ladder has been conducted by SolidWorks simulation software. In a previous study, a similar buckling analysis was conducted for a circular safety ladder. To analyze the effect of cross-section, the cross-sectional area, load, fixtures, and materials were kept the same in both studies, but the cross section types were different; the previous one was circular and the current one is square. The ladder was created with four steps. The frames on the two sides of the ladder were connected with the steps by pins. After creating the step, frame, and pin as SolidWorks part files, they were assembled to create the 3D square safety ladder model. The material assigned for the two side frames and sixteen pins was Aluminum Alloy and that for the four steps was Balsa Wood. For a 200-lbs load on the top step of the ladder, a buckling factor of safety (BFS) of 23 was obtained, which indicates that the square safety ladder is likely to withstand a load that is up to 23 times as large as what is already applied. A comparison of the BFS for the circular and square columns shows that the buckling of the square column is supposed to take place at much lower load than that for the circular safety ladder.
***Key Word**: Column; Buckling; Safety Ladder, Cross-section, Stress; Strain; Factor of Safety (FS).*

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I. Introduction

The safe use of step ladders, sometimes also known as safety ladders, is a key factor to provide an injury free work environment at our homes and industries, as safety ladders is a commonly used tool for various household and industrial tasks. According to US Department of Labor's Occupational Safety and Health Administration (OSHA), falls from safety ladders are one of the leading causes of occupational injuries and fatalities [1]. There, it is important that these long slender structures, well-known as columns, be designed in such a way so that they do not break due to the stress developed by the applied load. The other type of failure of that these columnar structures may experience, when exposed to an axial comprehensive force, is a lateral deflection or buckling. Columnar structure should safely support their intended loading without buckling [2]. To prevent buckling due to the load applied on a safety ladder, it is also important to have a better understanding of its critical load for buckling. Simulation of buckling of such structures is a very common approach in different engineering applications that can provide us with this information.

The most common safety ladders are circular columnar structures, although some safety ladders are of square cross-section. The objectives of this study is to provide a better understanding of how buckling of columnar structures is affected by their cross-sectional area. The buckling load analysis of a circular safety ladders was conducted in a previous study [3].The focus of this study is to carry out a buckling analysis of a rectangular safety ladder with the same cross-sectional area. Both analyses were conducted by SolidWorks Simulation. The comparison of these two analyses allowed us to determine the critical load of buckling for the safety ladders with two different cross-section types, which in turn determined what column type could withstand higher buckling load.

II. Simulation Software

The buckling analysis of the square safety ladder was conducted by SolidWorks Simulation [4]. This is the same software that was used in the previous study with the circular ladder. SolidWorks is a Windows-based three-dimensional Mechanical CAD (Computer Aided Design) program. This software is currently used by over two million engineers and designers at more than 165,000 companies all over the world [5]. SolidWorks Simulation software, embedded within SolidWorks, is a powerful computational design validation tool that shows engineers how their design will behave as physical objects, and thus helps making decision to improve quality [6].

III. Design of the Square Ladder

The ladder is composed of four steps at different heights to apply loads on those, which are supported by the two frames on both sides. Each of the steps are attached to the frames by a two pair of pins, i.e., one pair on each side. The dimensions of the frames, steps, and the pins are shown Figure 1.

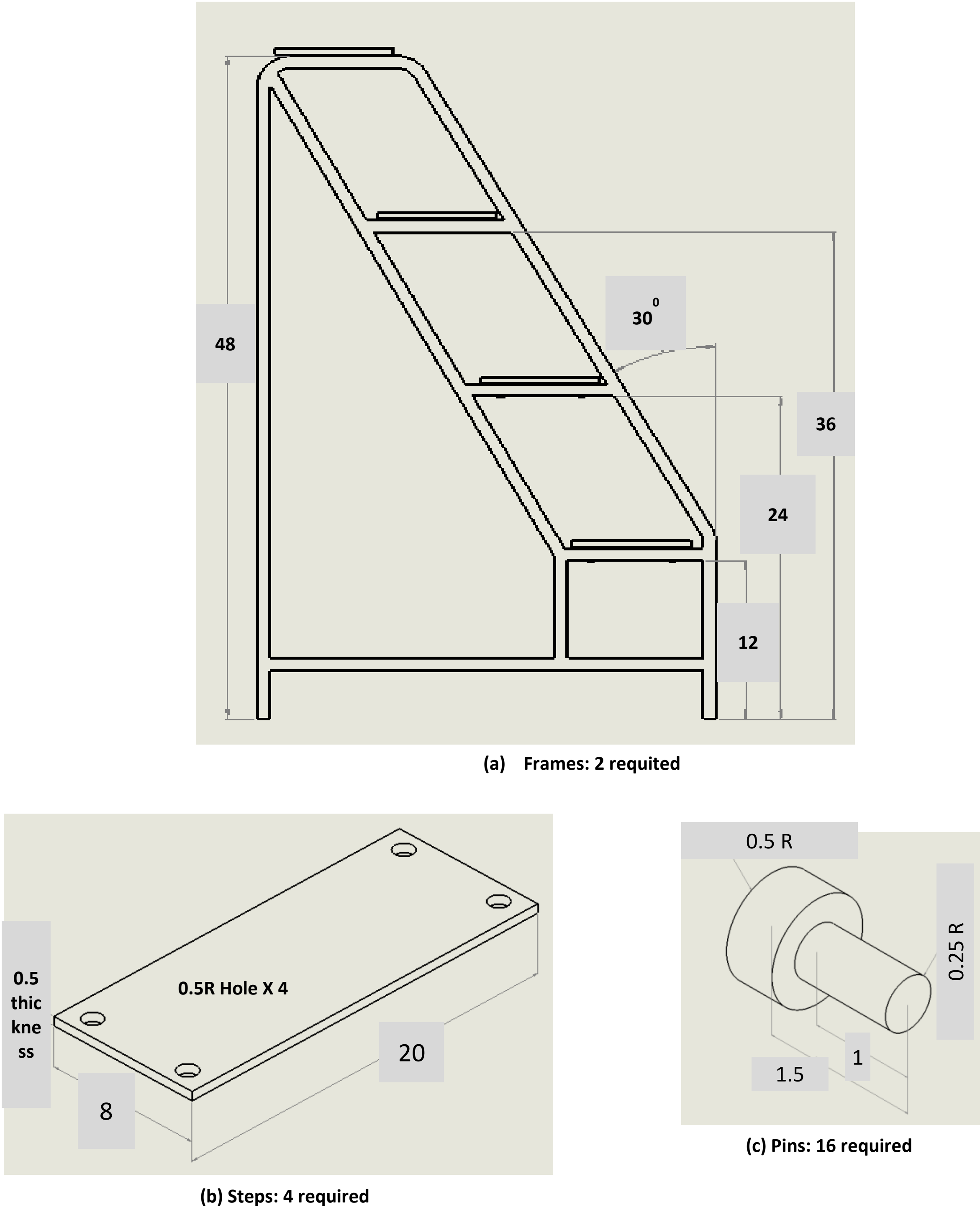

Figure 1: Dimensions of (a) frames, (b) steps, and (c) pins. All dimensions are in inches.

After creating the three separate Part files [7] according to the dimensions, an assembly file was prepared for SolidWorks simulation. The assembly file of the square safety ladder is shown in Figure 2.

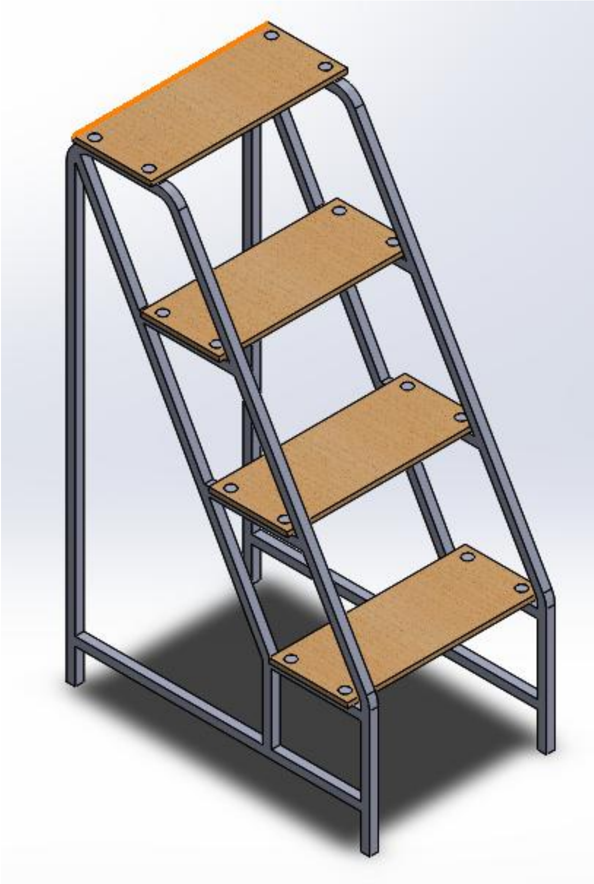

Figure 2: Assembly view of the square safety ladder

In the previous study [3], the circular cross-section of the ladder had a radius of 0.5 in. Hence the cross-section area was 0.786 in^2:

$$Area = \pi(0.5)^2 = 0.786 \text{ in}^2$$

In the present study, the area of the square cross-section of the ladder was kept the same, which means the length of each side, ***a*** of the square safety ladder is 0.886 in:

$$a^2 = 0.786 \text{ in}^2$$
$$a = \sqrt{0.786} = 0.886\text{in}$$

IV. Simulation Parameters

The simulation parameters in the present study were kept the same as the previous one. As mentioned before, the only difference was the type of ladder cross-section, although the cross-sectional area was the same. For the simulation, which was conducted by SolidWorks, the legs of the safety ladder were made fixed to the floor so that they do not move when applying loads. The material assigned to the two side frames and sixteen pins was aluminum 1060alloy and that for the four steps was balsa wood. A200 lbswas applied on the top step to analyze the buckling effect on the side frames. The simulation yielded a buckling safety factor (BSF) value that was used to calculate the critical load. Critical load is the maximum amount of force the column can hold before it starts to buckle. A column can actually support even greater load than its critical load, which will create larger deflections.In engineering design, the critical load is considered as the largest load the column can support [2].

V. Results and Discussions

Buckled shape: The overall buckled shape of the square safety ladder with an application of 200 lbs load on the top step is shown in Figure 3 below. It should be noted that an amplification scale of 3.7 was used in this figure for a better visualization of deformation. As expected, the upper side of the frames undergoes more deformation than the lower side. This deformation created a buckled shape of the frames as the lowers side of the frames are fixed to the floor and the upper side is free.

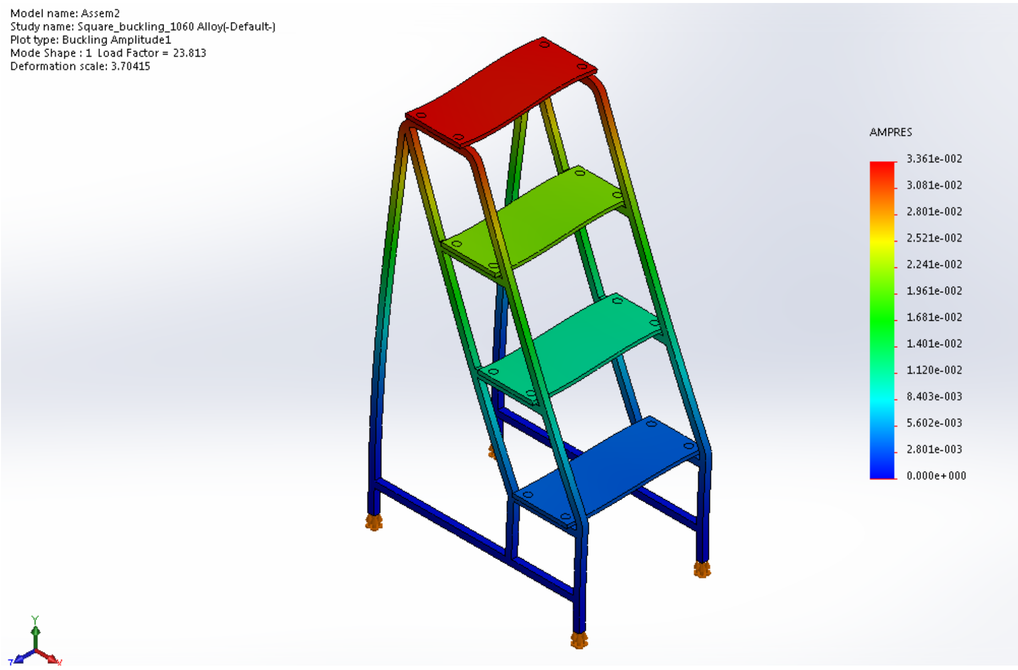

Figure 3: Overall buckled shape and the deformation of the square safety ladder with amplification scale of 3.7.

Buckling factor of safety: The simulation yielded a buckling safety factor of 23. Using this number, the critical load can be calculated using the following equation [2]:

$$Buckling\ factor\ of\ safety\ (BFS) = \frac{Critical\ load}{Applied\ load}$$

$$Critical\ load = Buckling\ factor\ of\ safety\ \times Applied\ load$$

For a Buckling Factor of Safety of 23 and an applied load of 200 lbs, the critical load = 4600 lbs (23 × 200 lbs). This means that for the material (1060 Aluminum Alloy and Balsa Wood) specified, and a load of 200 lbs on the top step of the ladder, it will start buckling with load of 4600 lbs.

Comparison with circular column:A comparison of the BFS for circular (previous study) and square (current study) safety ladders are shown in Table 1. In both cases, the applied load, the cross-sectional area, and materials are the same. This table indicates that the square safety ladder is likely to withstand a load that is up to 23 times as large as what is already applied and its buckling will take place with much lower load than that applied on the circular safety ladder.

Table 1: BFS for circular and square ladders

Circular cross – section	Square cross-section
BFS = 26	BFS = 23

VI. Conclusions and future studies

To analyze the effect of cross-section, a buckling analysis of a square safety ladder has been conducted in this study. The results were compared to those of a similar buckling analysis of a circular safety ladder keeping all the simulation parameters, i.e. cross-sectional area, load, fixtures, and materials the same. In the present study, a buckling factor of safety of 23 was obtained for a 200-lbs load on the top step of the ladder, which indicates that the square safety ladder is likely to withstand a load that is up to 23 times as large as what is already applied. A buckling factor of safety of 26 was obtained in the case of circular safety ladder (the previous study). This means that the buckling of the square column is supposed to take place at much lower load than that for the circular safety ladder.

In future, the authors plan to study the effect of material by using different set of materials for pin, frame, and step for the same model. The authors also want extend their study by conducting and comparing the simulation with hollow structures.

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