Static and Buckling Studies of a Safety Ladder by SolidWorks Simulation

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Abstract

Simulation results of static and buckling analyses of a safety ladder conducted by SolidWorks simulation software are presented in this paper. At first, a four-step safety ladder was created. 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 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 static analysis, four sets of simulations were carried out with a 200lbs. load on each step separately. Results reveal that similar patterns of stress, strain, and displacement distributions are developed for all four ladder steps. The maximum stress was developed on the places where the pins are attached to the wood, and the maximum strain and defamation take place at the middle part of the steps. For buckling analysis, the simulation was carried out with the same amount of load, but only on the top step of the ladder. A buckling factor of safety of 26.38 was obtained, which indicates that the ladder is likely to withstand a load up to 26.38 times larger than what is applied, i.e. it will start buckling with a load of 5267 lbs. (critical load). A comparison with the static analysis, which yielded a stress factor of safety of 1.08, indicates that the ladder would yield before it would buckle.

Keywords: Statics Analysis, Buckling, Stress, Strain, Factor of Safety (FS)

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1. Introduction

Safety ladders, also known as step ladders, are one of the commonly used tools for household tasks as well as in various industries. 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 [4].Therefore, safe use of this type of ladder a key factor to provide to an injury-free work environment.

Safety ladders are columnar structures. These columnar structures should be designed so that they do not break due to stress developed by the applied load and can safely support their intended loading without buckling [3]. To prevent failure due to the load applied on a safety ladder, it is important to have a better understanding of its resultant stress, strain, critical load for buckling, etc. caused by the load. Static and buckling analyses of such structures, a very common approach in different engineering applications, can provide us with this information.

The objectives of this study were to provide a better understanding of (a) structural stress/deformation and (b) buckling analysis of a safety ladder by performing SolidWorks simulation. The buckling analysis would allow us to determine its critical load of buckling (the maximum amount of force the column can hold before it starts to buckle), and to visualize its buckled shape. Another objective was to compare the static and buckling analyses results.

2. Analysis software

As mentioned, both static and buckling analyses were conducted by SolidWorks Simulation. 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 [4].

3. Parts and Assembly

As seen in Figure 1, 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. After creating the three separate Part files [6] according to the dimensions, an assembly file was prepared for SolidWorks simulation. The assembly file is shown in Figure 2.

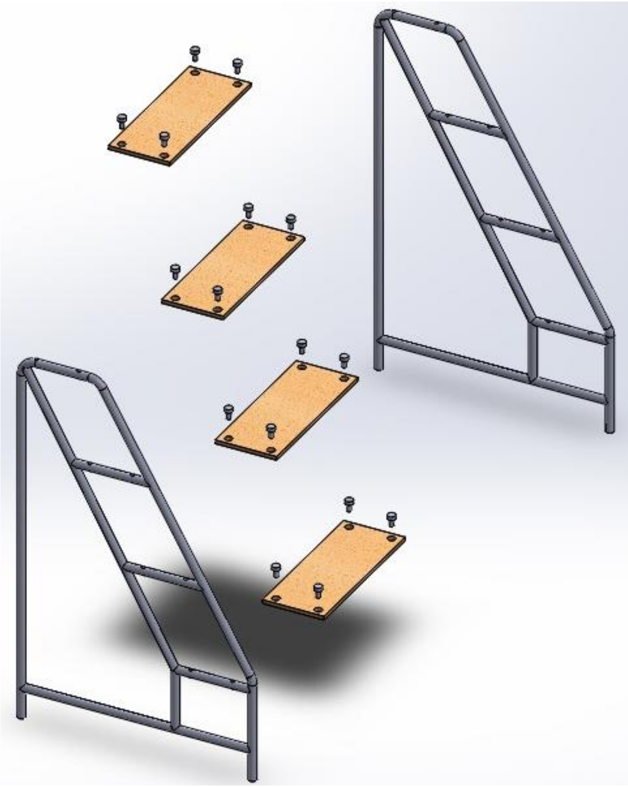

Figure 1: Exploded view of the safety ladder

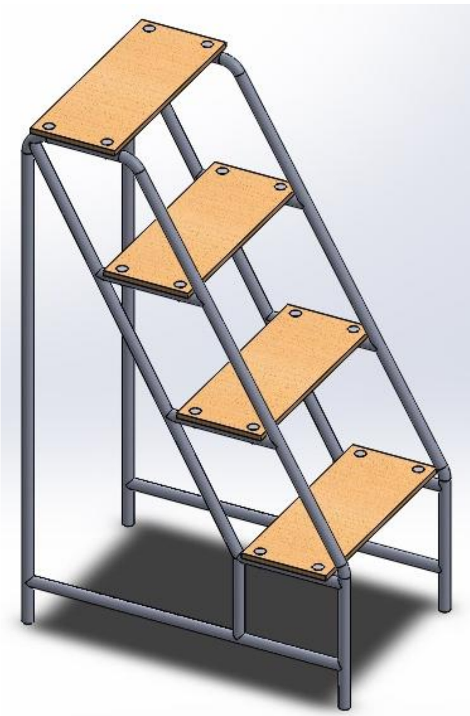

Figure 2: Assembled view of the safety ladder

The frames have a height of 48 inch with 1 inch circular cross section. The steps are apart by 12 inch. The pins are 1.5-inch-long with 0.5-inch diameter on the lower side and 1-inch diameter on the upper side. The steps have the dimension of 20-inch length, 8-inch width, and 0.5-inch height. It should be noted that the dimensions were arbitrary chosen by the authors; they were not replicated from any existing model of ladder assembly.

4. Simulation Details

For SolidWorks simulation, 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.

For static analysis [1], four sets of simulations were carried out. For each simulation, a 200 lbs. load was applied on the top face of one step, with no loads on the other three steps. The simulations produced stress, strain, and displacement data.

For buckling analysis [2], the load was applied only on the top step to analyze the buckling effect on the side frames. The simulation yielded a value of buckling factor 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 [3].

5. Results

5.1 <u>Static Simulation</u>

As mentioned in the previous section, four sets of stress, strain, and deformation plots were produced. Each set represents the simulation results for the same load on each of the four steps of the ladder.

Results show the similar trends of stress, strain, and deformation distributions for all four steps. As a sample set of results, the Von Mises stress, strain, and displacement plots [1] for the top step are shown in Figures 3, 4, and 5, respectively. These figures show the maximum stress is developed on the places where the pins are attached to the wood. As expected, the maximum strain and defamation take place at the middle part of the step, which is similar to the behavior of the simply supported beams. It should be noted that the deformations of parts shown in these two figures are not their actual deformations. The deformation scale in these figures is 56. This was done intentionally for a better visualization of stress, strain, and deformations of the ladder assembly. The stress factor of safety for the top stop was found as 1.08.

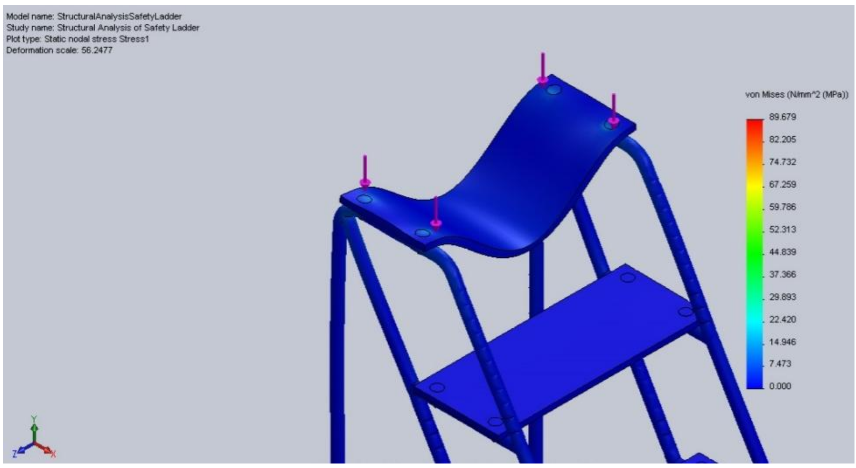

Figure 3: Static analysis: distribution of stress on the top step

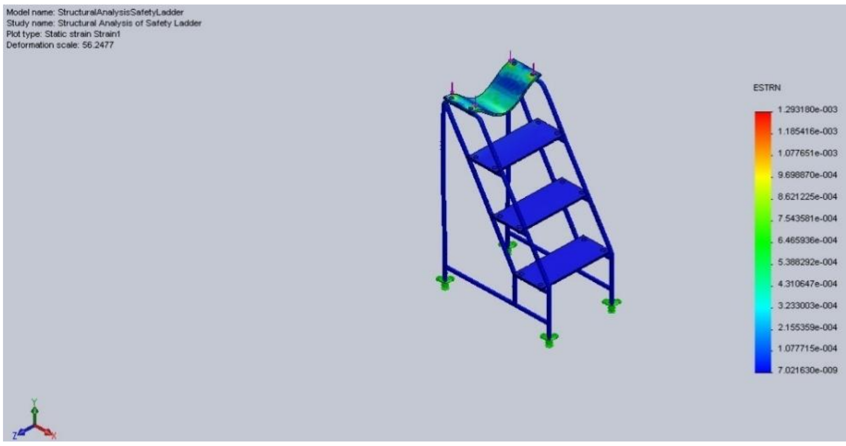

Figure 4: Static analysis: distribution of strain on the top step

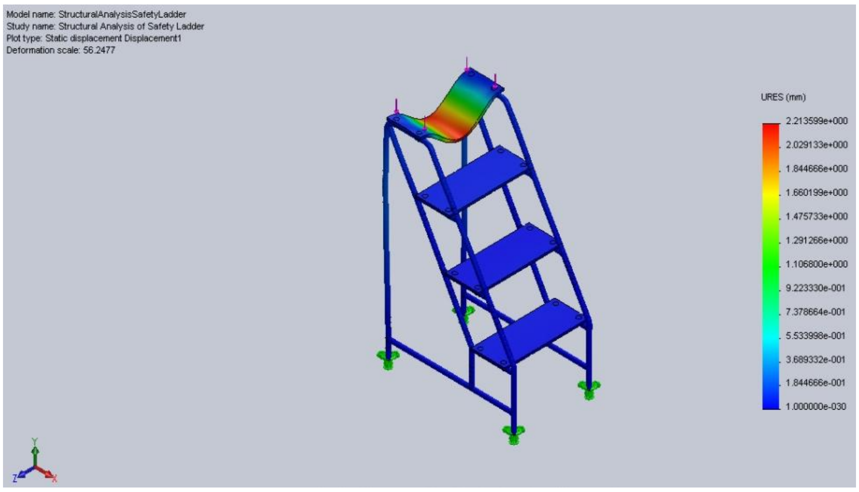

Figure 5: Static analysis: distribution of deformation on the top step

Figure 6: Buckled shape due the application of load on the top step

5.2 Buckling Simulation

Figure 6 shows how the safety ladder would buckle with a 200-lbs load on the top step (deformation scale of 4.15). Since the legs are fixed, the deformation on the upper side is higher.

The simulation yielded a buckling factor of 26.38. Using this number, the critical load can be calculated using the following equation:

$$\text{Buckling Factor of Safety} = \frac{\text{Critical Load}}{\text{Applied Load}}$$

$$\text{Therefore, Critical Load} = \text{Buckling Factor of Safety} \times \text{Applied Load}$$

For a Buckling Factor of Safety of 26.38 and an applied load of 200 lbs., the critical load = 5276 lbs.(26.38 × 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 5267 lbs.

5.3 Comparison between Statics and buckling simulations:

When the stress analysis was performed, it produced a stress factor of safety of 1.08. For the same parameters, the buckling analysis yielded a buckling factor of safety of 26.38. These numbers indicate that the ladder would yield before it would buckle.

6. Conclusions and Future Studies

A safety ladder with specific dimensions and materials has been modelled by SolidWorks simulation and tested for 200 lbs. load using static and buckling analyses.

Statics analysis revealed a similar patterns of stress, strain, and displacement distribution for all four ladder steps. The maximum stress was developed on the places where the pins are attached to the wood, and the maximum strain and defamation take place at the middle part of the steps. For buckling analysis, a buckling factor of safety of 26.38 was obtained, which indicates that the ladder is likely to withstand a load that is up to 26.38 times larger than what is applied, i.e. it will start buckling with a load of 5267 lbs. (critical load). A comparison with the static analysis, which yielded a stress factor of safety of 1.08, indicates that for this specific loading and materials the ladder would yield before it would buckle.

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

7. Acknowledgement

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