Design of an Outdoor Solar Eclipse Viewing Structure

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Abstract. A solar eclipse occurs when the moon partially or totally obscures the sun from an Earth-based viewer. Due to the relative sizes and positions of the objects involved, the sun and moon appear approximately the same size when viewed from Earth, allowing the moon to completely cover the sun when the timing and alignment are right. The occurrence of a total eclipse at a particular location is rare, only taking place on average every 375 years. Erie, Pennsylvania, experienced this once-in-a-lifetime event during the 2024 solar eclipse of April 8th that swept across the nation from Texas to Maine, passing directly over Erie. The eclipse lasted 2 hours and 28 minutes, and the only safe time to observe the eclipse without a solar filter was during the 3 minutes and 42 seconds of totality from approximately 3:16 to 3:20 PM EST. An eclipse is an event that people want to personally witness and, as such, many people are compelled to stare at the sun during the partial phases of the eclipse. This raises concerns for eye safety, since the sun emits ultraviolet radiation which can, unknowingly to the observer, cause permanent damage to unprotected eyes. Children are especially susceptible, as they are least likely to proactively protect their vision. In this paper, we discuss design and construction challenges encountered while building a large temporary outdoor viewing structure to accommodate multiple people viewing the eclipse at the same time without the need for individual protective eyewear.

INTRODUCTION

Spectators have long been warned against the dangers of looking directly at the sun [1]; the earliest warnings date back at least to ancient Greece [2]. Specifically, the sun's electromagnetic radiation can be harmful. The sun emits electromagnetic radiation in ultraviolet (UV), visible, and infrared (IR) wavelengths. UV radiation is subdivided into three main bands: UVC (100–280 nm wavelength), UVB (280–315 nm), and UVA (315–400 nm). UVC is very nearly totally absorbed in the atmosphere. UVB is also largely absorbed by the atmosphere but is biologically active and can directly damage DNA via sunburn. However, UVB is required to synthesize vitamin D. UVA mostly reaches the ground but is not biologically very active. It can, however, induce significant damage to DNA via indirect pathways such as oxidative stress. A common approach to safely viewing an eclipse is to wear solar eclipse glasses incorporating an eye-safe protective lens material (e.g., aluminized Mylar or black polymer) that effectively blocks UV radiation from reaching the eye. However, since visible light is also drastically attenuated, the user is effectively blind to their surroundings. An outdoor eclipse viewing structure offers similar or better levels of eye protection by incorporating UV-blocking material into its roof, thereby allowing each person underneath to maintain spatial awareness. In this way, spectators can safely view the eclipse while interacting more easily with those around them.

Overall, the student design team balanced several considerations: attenuation of UV radiation, roof inclination angle, structure transportability, structure stability, and cost. Cost and material availability considerations for the roof of the 6 ft × 6 ft viewing structure required that a suitable material be found to function as the black polymer found in modern solar eclipse glasses. After researching this, the team settled on using a polyvinyl chloride (PVC) welding curtain. Similar to solar electromagnetic radiation, gazing at the bright flashes while welding—even while wearing eye protection—can lead to permanent eye damage. Shade 8 welding curtains are commonly used in the construction of semitransparent welding screens used to create a physical barrier between welder and nonwelder. Importantly, the welding curtains also attenuate and block radiation, including UV [3], emitted from welding equipment.

Eclipse glasses should adhere to the standard set by ISO 12312-2, which specifies safe transmittance levels of UVB and UVA [4]. Accordingly, maximum luminous transmittance (i.e., the ratio of transmitted to incident visible light) is set at 0.0032 percent. Both UVB and UVA transmittance must be no higher than this limit in order to avoid eye damage (e.g., solar retinopathy [1,5] or phototoxic maculopathy [6,7]). This standard translates to a shade 12 welding filter [4]. Note, shade 13 and higher welding filters have also been used but result in increasingly dimmer images [1]. As a result of product availability, the design implemented here used two layers of shade 8 welding screen material, one layer on top of the other, leading to an approximate overall shade protection level of 16 [8].

Another design feature we incorporated was the ability to modify the inclination angle of the roof in order to optimize the view based on external variables, including the ground slope and the sun's position in the sky. With the design, the roof angle can be adjusted on-site and can accommodate a maximum slope of approximately 19 degrees. The student team also considered transportability, since three distinct viewing sites were planned, and stability, since wind conditions are unpredictable. The interface between the legs of the viewing structure and the ground were 3D printed "feet" that were friction-fitted and glued onto the legs and could either be staked or weighted down, depending on the type of ground surface (i.e., soil, turf, or asphalt).

METHODS AND PROCEDURES

Including initial discussions regarding overall project scope, the complete design process from start to finish took approximately six months and included four main aspects: materials research, modeling, prototyping, and testing. For materials research, the main question was which type of solar filter could be used for the roof of the structure. Creo 3D modeling was used to generate a digital model of the design. As additional features were added, an assembly drawing illustrated how all of the parts fit together. Three-dimensional modeling enabled visualization of subsequent design iterations and their impact on the overall structure. A 1:6 subscale prototype was constructed in order to validate the design. After demonstrating proof of principle, work on a full-scale prototype was initiated. During this process, some modifications were introduced to address issues not seen with the subscale model. For testing, a completed full-scale structure was set up to examine several design features, including the suitability of the solar filter for viewing the sun, the overall rigidity of the structure, and the ease of modifying the roof angle on location.

Primary considerations in selecting solar filter material included suitability, availability, and cost. Early eclipse glasses used aluminized Mylar in the lens openings, a metalized plastic made from biaxially oriented polyethylene terephthalate (PET). Mylar is created from a polyester film composed of stretched polyethylene terephthalate, which has several useful properties, including high tensile strength, chemical and dimensional stability, transparency, reflectivity, gas and fragrance barrier qualities, and electrical insulation. More recently, black polymer has replaced aluminized Mylar. Black polymer is a carbon-infused resin manufactured via extrusion or casting. It absorbs rather than reflects light, resulting in a matte, nearly opaque finish. It offers excellent UV, visible, and IR blocking, and its flexibility and durability make it ideal for eye-safe filters. Although both aluminized Mylar and black polymer meet ISO 12312-2, they are relatively expensive and neither was found in a sheet size suitable for the project. An alternate material possessing similar eye-safety qualities but obtainable in large-format applications was identified by Chou [1]. Welding screens are physical barriers behind which it is safe to view welding. Welding screens are made from polyvinyl chloride infused with UV inhibitors and pigments, producing a flexible, semitransparent film that attenuates UV and IR radiation. For gas welding, these screens are typically constructed of shade 8 darkening material. The term "shade" refers to a standardized industry scale defined by ANSI and DIN standards (e.g., ANSI Z87.1), which indicates the amount of visible light that a filter allows to pass through. Lower shade numbers transmit more light while higher numbers exponentially reduce light intensity. For example, shade 8 transmits approximately 0.045% of visible light, while shade 14 transmits about 0.0004%—comparable to the ISO 12312-2 maximum transmission limit of 0.0032% for safe solar filters. To safely gaze at the sun, a shade 14 welding screen, typically recommended for heavy air carbon arc cutting, plasma arc welding, and carbon arc welding [8], should be placed between the user and the sun [9]. However, a single piece of shade 14 welding screen was not generally available. To circumvent this problem, the team's solution was to layer two sheets of shade 8 material, one on top of the other, to produce a composite shade 16 filter as protection level is approximately additive [8].

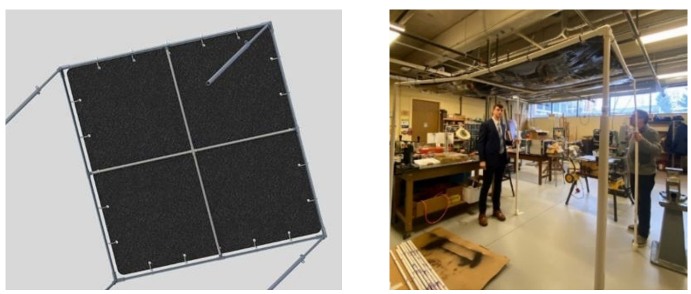
Figure 1(a) shows the overall design of the eclipse viewing structure. The legs were composed of 5-ft-long, 1-in.-diameter (nom.) PVC tubing, and each leg tube housed an inner 4-ft-long, 0.5-in.-diameter (nom.) PVC tube which could slide within the larger outer tube, as shown in Fig. 1(b). A single through hole was drilled into each outer leg tube approximately 1 in. from the top. Subsequently, a series of evenly spaced holes placed 2 in. apart was drilled into the inner leg tube using a mill. To raise and hold the roof at a desired elevation, the holes in the inner and outer PVC tubes were aligned and an eyebolt was passed through and locked in place with a wingnut; see Fig. 1(c). A sloping roof could be implemented by differentially raising two adjacent legs and locking them in place. As designed, a maximum 19-degree roof slope can be implemented while maintaining a 6-ft elevation. The four-member student team cut all PVC tubes for the viewing structure using a PVC pipe cutter.

(a) (b) (c)

FIGURE 1. (a) Overall structure; (b) leg detail; (c) eyebolt-wingnut assembly and couplings.

As the inner leg tube slid comfortably within the larger diameter outer tube, a noticeable wobble was present in the leg assembly. To overcome this, two couplings for each leg were designed, 3D printed, and inserted onto the inner PVC tube to bridge the gap. The outer diameter of the coupling sleeve matched the inner diameter of the outer leg tube, thus creating a tight fit and substantially removing the wobble. The couplings (in green) can be seen adjacent to the eyebolt-wingnut assembly in Fig. 1(c). Each coupling was 3D printed with polylactic acid (PLA) filament.

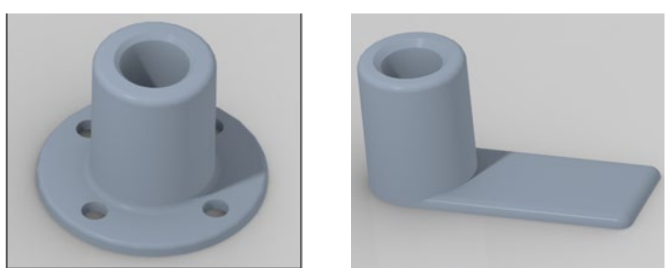
Next, a 6 ft × 6 ft roof frame was constructed from 0.5-in.-diameter (nom.) PVC tubing. Three-way coupling joints were placed at each corner. After the frame was assembled, the welding screen material (two layers per structure) was unwrapped and placed over the open frame. Upon zip-tying the screens to the roof frame at each grommet location, the roof frame bowed inward as tension was applied to limit screen sag. It was ultimately decided to structurally brace the frame at the midpoint (one in each direction) to help prevent the bowing caused by the screen tension; see Fig. 2(a). Placing the brace underneath the welding screen also helped to minimize screen sag in the middle; see Fig. 2(b). Finally, the roof frame was joined to the legs using the three-way corner couplings, friction fit, and glued together.



(a) (b)

FIGURE 2. Double-brace support structure: (a) CAD model; (b) as constructed.

To secure the structure to the ground, feet were designed and installed on each leg. For a grass/soil surface, stakes could be driven through holes in a flanged foot [Fig. 3(a)] to secure it in place. For a turf/asphalt surface, sandbags could be laid across a tabbed foot [Fig. 3(b)] to secure it in place. The feet were friction fit and glued to the leg tubes.



(a) (b)

FIGURE 3. Foot design: (a) flanged; (b) tabbed.

The cost of a viewing structure varied with the method used to fix the structure to the ground. One of the viewing structures was weighed down with sandbags since it was deployed on a multisport turf field, adding $38 in materials. The other two structures were staked to a grass surface, adding $5.

Otherwise, construction costs per structure were as follows: two welding screens (6 ft × 6 ft), \$70; 0.5-in. PVC pipe (50 ft), \$24; 1-in. PVC pipe (20 ft), \$17; PVC connectors (corner, tee, cross tee, eye bolts), \$19; PLA filament, \$10. Bulk purchases included hardware (wing nuts, zip ties, PVC glue) at \$30 and paint at \$33. Hence, the base cost per structure was \$161. The total unit costs were \$166 (staked) and \$199 (sandbagged).

RESULTS

Upon completion, one of the viewing structures was moved outside on a sunny spring day. It was immediately apparent that one could observe a clear image of the sun through the double layer of welding screens; as shown in Fig. 4(a). As built, the team felt that the structure was reasonably stable. However, on the day of the eclipse, several tie-lines were added to reinforce the structure prior to public use [Fig. 4(b)].

(a) (b)

FIGURE 4. (a) Sun viewed through double-layer screen; (b) one of the viewing structures on location in downtown Erie.

CONCLUSION

A student-led project was conceived to design and construct an outdoor viewing structure suitable to witness the April 8, 2024, total solar eclipse without the need for personal solar eclipse glasses. A team composed of mechanical engineering and biomedical engineering students managed, designed, and fabricated three viewing structures over the course of the academic year for use during the eclipse. During the design process, the students researched and found a suitable cost-effective material to use as the roof of the viewing structure. As part of the initial specifications, the design included a variable roof elevation and inclination angle to optimize for the sun's position in the sky. During prototyping, the team encountered and solved several unplanned issues including excessive frame deformation (resulting from screen tensioning) and screen sag. Finally, the student team designed and 3D printed several of the structural components integral to the overall design.

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