Further Testing of NFPA Safety Shelters
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Introduction

Before describing this work it should be mentioned that the purpose was not to find fault with the requirement of the National Fire Protection Association (NFPA) in its Code for the Display of Fireworks for a safety shelter on manned electrically fired displays on barges. Rather, it is to determine the level of protection actually provided by a shelter meeting the minimum NFPA requirement as it is most often applied, to share that information with the industry, and to offer suggestions to those that might wish a higher level of protection.

Probably the most extreme test of NFPA’s required barge safety shelter construction is the direct impact of an aerial shell fired from the minimum distance allowed. To begin this investigation, last fall some initial testing was conducted and the results were reported. In summary, when a typical 3-inch shell was fired directly at the plywood (i.e., perpendicular to its front surface) from a distance of 8 feet, the 3-inch shell was found to be capable of penetrating ¾-inch AC exterior plywood backed with 2×4 dimensional lumber on 2-foot centers. Following this somewhat surprising result, thought was given to relatively easy and inexpensive ways that the shelter’s resistance to shell penetration might be improved. During further trials, it was eventually found that relatively simple and inexpensive modifications could be made that provided substantially improved penetration resistance, ranging to at least 6-inch shells. Descriptions of many of the trials and their results are presented below.

Further Penetration Trials

A summary of the preliminary test results is presented in Table 1 and is discussed below. However, it must be acknowledged that often only a single test was conducted of each configuration. Thus the results cannot be taken as representing what would happen every time had repeat firings and a variety of other aerial shells been used.

An early attempt to improve penetration resistance was simply to use two thicknesses of ¾-inch plywood in contact with each other, without gluing or securing the two pieces of plywood together as a unit. This arrangement successfully protected from a direct impact of a 3-inch shell, but a 4-inch shell was able to penetrate the double-thickness of plywood. Figure 1 is a series of high frame-rate video images (spanning approximately 0.015 second) of the impact of a 4-inch shell into two sheets of 3/4-inch plywood, plus a still photograph (bottom) of the hole through the plywood sheets.

Figure 1. A series of four image (spanning approximately 0.015 second) of the impact of a 4-inch shell into two sheets of 3/4-inch plywood, plus a still photograph (bottom) of the hole through the plywood sheets.
In subsequent testing, it was found that if an aerial shell impacted a single sheet of plywood at an approximate 45° angle, a similar level of protection was achieved as when using two sheets of ¾-inch plywood with an impact angle of 90°. Specifically, it was found that a single sheet of ¾-inch plywood at a 45° angle to the trajectory of the impacting aerial shell survived the impact of a 3-inch shell; however, a 4-inch shell could still penetrate that single-thickness of plywood at a 45° angle. Two possible shelter configurations that present a front wall at an approximate 45° angle to the mortar area are shown in Figure 2. One has a front shelter wall appearing somewhat like the bow of a ship; the other is a sloping front shelter wall.

By combining the use of both a double-thickness of ¾-inch plywood (loose contact with no separation between the sheets) and a 45° impact angle, it was found that a further increase in
penetration resistance was achieved. This combination was successful in stopping a 4-inch aerial shell, but allowed the penetration of a 5-inch shell.

Another attempt to improve penetration resistance at 90° was to allow a 3-inch gap between two sheets of ¾-inch plywood and to secure the two sheets together as a single unit. The rational for this trial was the hope that the impacting aerial shell would be sufficiently damaged in the process of penetrating the first layer of plywood that the shell (and fragments from the first layer of plywood) would be sufficiently spread-out that they would not be able to penetrate the second layer of plywood. This improved performance was found to be the case for a 4-inch shell, which did penetrate the first sheet of plywood; however, that shell left the second sheet of plywood intact. When this approach was tried again with a 5-inch aerial shell, the impacting shell fully penetrated both sheets of plywood.

It would have been interesting to have tested the combination of a double-thickness of plywood (with a 3-inch gap) and an impact angle of 45°. Unfortunately, this was not considered at the time of the testing, and no further testing is planned at this time.

Next the penetration resistance of a single sheet of ¾-inch plywood combined with a piece of thin (24 gauge, 0.024 in.) sheet metal (galvanized heating duct material) on its front surface was tested. In the first trial of sheet metal plus plywood, a 5-inch aerial shell did not penetrate when fired at a 90° angle to the test panel. However, the damage was sufficient that it seemed likely that a 6-inch shell might penetrate a panel of this type, and a test with a 6-inch shell was not performed. Instead, the angle was changed to 45° prior to a trial with a 6-inch shell. In this trial, the 6-inch shell did not penetrate the test panel. To gain some increased confidence in the result of this successful trial, three additional 6-inch shells were fired into the same test panel. An attempt was made to have the three additional shells impact the panel at slightly different points. However, two of those additional shells impacted the panel within approximately one foot of the first shell. Despite this, none of the three additional

Figure 2. Illustrations of two basic configurations presenting a front wall at an approximate 45° degree angle to mortars that might become repositioned in the discharge area.

Figure 3. A series of four images (spanning 0.006 second) of a 6-inch aerial shell impacting a sheet metal augmented test panel at a 45° angle, plus two still photographs of the test panel after having been struck by one (left) and four (right) 6-inch shells.
shells penetrated the test panel. The upper part of Figure 3 is a series of four images (spanning 0.006 second) from the first of four impact trials. In the upper-left image, the shell (traveling to the left) is about to impact the test panel at a 45° angle. In the upper-right image, the shell has struck the panel and has already significantly collapsed. In the middle-left image, the shell has nearly completely collapsed. In the middle-right image, the collapsed shell has begun to slide upward along the test panel. (Typically in these tests the contents of the shell do visibly ignite but not until they are out of the field of view of the camera.) The lower left still photograph was taken after the impact of the first of the four 6-inch shells had impacted the test panel. The lower right still photograph documents the result of all four 6-inch shell impacts on the panel. By the end of the testing, the plywood backing the sheet metal had been significantly damaged from the four impacts; however, none of the shells or their contents had torn the sheet metal or penetrated the test panel.

Another Safety Strategy

While not tested, it would seem that the layout of mortars in front of a safety shelter has the potential to provide an improved level of protection to occupants of a safety shelter. If the smaller mortars are placed closest to the shelter, it would seem likely that any repositioned larger mortars (those more distant than the smaller mortars) are somewhat unlikely to be able to directly strike the front wall of the shelter. This is illustrated in Figure 4, where it is suggested that any repositioned mortars beyond the first row of racks are likely to either pass over the safety shelter or will first impact those mortars closer to the shelter thus reducing (or eliminating) their potential to penetrate the front wall of the safety shelter. (In addition, the mere fact that the larger mortars are at a greater distance from the shelter, results in a reduced probability that a shell fired from one of those larger repositioned mortars would strike the shelter, because the shelter becomes in effect a smaller target.)

Conclusion

Given the modest increase in cost and weight of a front wall made of ¾-inch plywood augmented with sheet metal (24 gauge galvanized steel) as contrasted with bare ¾-inch plywood, it would seem that this is an approach worth considering to improve the penetration resistance of a safety shelter. Further, if the front wall of the shelter is at a 45° angle to the likely trajectory of an impacting aerial shell and if the layout of mortars is chosen to provide some additional protection, it seems likely that the firing crew inside the shelter will have a relatively high degree of safety from direct shell impacts. An example of such a simple safety shelter design (erected as a demonstration) is shown in Figure 5.

Figure 5. An example of a safety shelter design with a sloping sheet-metal covered front wall.

In conclusion regarding this testing, it must be acknowledged that:

- The amount of testing performed in this brief study was very limited.
- There may be other problems and consequences not fully considered by the authors.
- Reinforcing the front wall of the shelter offers essentially no added protection from falling dud shells.
• There certainly may be other reasonably simple configurations that provide equal or greater penetration resistance.

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References

1) Code for Fireworks Display, NFPA-1123, 2006, paragraphs 4.2.3, 4.3.2 and 4.4.1.