Evaluation Of Multi-shot Firework Articles Using Mortar Recoil Measurements

R. Guilbeault and E. Contestabile
CANMET Complex – Building 12, 555 Booth Street, Ottawa, ON K1A 0G1, Canada

Abstract: *Recoil from fireworks articles often arises as a concern in accident investigations or when fireworks are launched from unconventional locations such as rooftops, or other light building elements such as overhangs, from decks of small bridges or those of barges. In this latter case, the Authority Having Jurisdiction will typically require some assurance that the structure will not be damaged and is sufficiently robust to support the dynamic loads resulting from the function of the firework articles. In this study, it is proposed that such measurements can also be used to evaluate multi-shot devices since; their recoil load history reflects their performance in time and magnitude.*

Various researchers have, over the last decade, devised means to measured recoil loads. Piezoelectric load cells, which have fast response time, have been used and found to satisfactorily track the fireworks recoil loads. This study presents data obtained using an apparatus in the form of a 25-cm diameter platform. Fireworks mortars or articles are placed and functioned on the platform. The signal from the piezoelectric load cell is recorded by a digital storage oscilloscope.

The results indicate that the recoil history can be used to determine inter-shot times, total duration, and relative launch heights of the effects of the multi-shot article. In addition, defective launches and other modes of failure such as in timing can also be easily identified.

Keywords: *multi-shot fireworks, recoil, load cell, RLP, mortar*

Introduction

The Canadian Explosives Research Laboratory (CERL), as part of its mandate, evaluates firework articles intended for sale and use in Canada. Part of the evaluation process is testing the articles' performance. Articles must meet certain minimum performance requirements which are given by the standards outlined in the Family and Display Fireworks Criteria[1] document. Standard test procedures at CERL require articles to be functioned and the performance, in terms of hazards or malfunctions, evaluated. This evaluation is based on visual observations and video records.

The evaluation of multi-shot articles such as Bombardo boards and cakes can become difficult primarily because of the often high number of shots constituting the article. Also, many products have several different effects incorporated into the mix. To facilitate a more comprehensive evaluation of the performance of such articles a load cell device was used to monitor the recoil forces generated when an effect is projected from the article. Such a record can provide quality indicators such as consistency of timing, projection heights and overall function time.

A number of tests were performed on professional class cakes and their recoil assessed with the load cell device. The performance and the recoil force records obtained are presented and discussed. Recommendations as to the usefulness of such a tool for the evaluation of multi-shot firework devices are also made.

Experimental Set-up

A load cell device, henceforth referred to as the Recoil Load Platform (RLP), was constructed specifically for measuring recoil forces generated by firework mortars. The construction is shown in Figure 1. This device was initially used for the evaluation of the recoil loads from large diameter fireworks.[2,3]

The RLP clamps and pre-stresses a piezoelectric force ring transducer so that it can track recoil loads and the associated rebound. The force ring is connected to a signal conditioner which in turn is connected to a digital oscilloscope with a 16-bit input module that provides the gain and high resolution required for the low range of recoil forces produced by these fireworks articles. The calibrated range of the force ring used was 0 to 60 000 lbf. Data were collected at a sampling rate of 5 kHz over a 90 s period.

The fireworks sample was placed on the RLP and functioned without any additional stabilization or support (Figure 2).

Results and Discussion

A total of 15 tests were conducted on six types of articles with the number of shots ranging from 19 to 49. A description of the articles tested is given in Table 1, with two of the samples being shown on the RLP in Figure 2. Note that some of the articles described in Table 1 do not have masses indicated because they were not declared by the manufacturer.

All articles tested were of similar size and had similar tube diameters, however the amount of lift charge per tube varied substantially. These articles varied in base sizes and some overhung the surface area of the RLP. As a result, some of the tubes were not supported directly on the base.

Also, the firing sequence varied according to the design. The mixed effect cakes fired different effects in groups of 7 for a total of 49 shots. This made interpretation of the recoil data more difficult. A video record was needed to correlate the effect-type to the projection height and the recoil force. A typical recoil record is shown in Figure 3.

The profile displays a distinct record of the recoil force for each shot for this article. The total number of shots, the interval between shots and the total function time can easily be extracted from the record. A detailed view of the load profile of a single shot is shown in Figure 4. Each shot often exhibited a similar pattern with a double peak and subsequent lower magnitude perturbations. These signals can be attributed to materials being projected, decoupling of the multi-shot article from the recoil base and from the response characteristics of the RLP. As seen in Figure 5 these patterns have similar trends.

Figure 2 *Cakes on recoil base.*

The magnitude of the recoil force, the intervals between firings and the duration of each of the 15 articles tested were extracted from the records and

Table 1 *Firework specifications.*

Article identification	Effect	Number of shots	Tube diameter/ mm	Declared mass/g			Duration/s
				Gross	NEQ	Lift/tube	
A	Reports	49	32	N/A	N/A	N/A	N/A
B	Star shell	19	24	1600	180	2.0	N/A
C	Mixed	50	24	N/A	N/A	N/A	N/A
D	Mixed	49	32	7620	1190	5.0	40
E	Mixed	49	32	6180	1100	4.7	N/A
F	Mixed	49	39	11300	1715	9.2	40

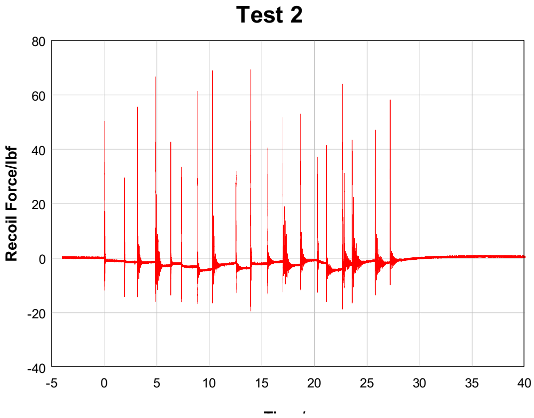

Figure 3 *Typical recoil profile of Article B.*

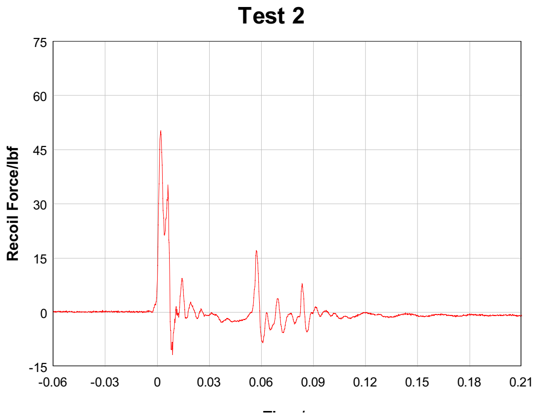

Figure 4 *Expanded view (Shot #1).*

summarized in Table 2.

Recoil forces vary from tube to tube, and they and the corresponding impulses have not been correlated to the projection heights of the pyrotechnic effects. Even groupings of similar effects displayed a wide variation in recoil forces (Figure 6).

The quality of the tube and fit of the components or shells influence the recoil forces recorded. If a shell or component fits very tightly, then there will be a greater pressure built up within the tube. This results in the pyrotechnic effect being ejected with a greater force and this is reflected in a higher recoil force. If the fit is very loose then the tube pressure will be lower resulting in lower projection

Table 2 *Recoil results.*

Test	Article identification	Effect	Number of shots	Recoil characteristics					Duration/s
				Peak force/lbf		Interval/s			
				Min	Max	Min	Max	Avg	
1	A	Report	49	34	72	0.8	2.2	1.31	64
2	B	Star shell	19	29	69	0.9	2.2	1.42	27
3	A	Report	49	25	85	0.6	2.0	1.37	67
4	B	Star shell	19	38	84	0.5	2.4	1.42	27
5	B	Star shell	19	37	90	0.9	2.5	1.37	26
6	B	Star shell	19	28	100	0.9	2.6	1.37	26
7	A	Report	49	10	95	0.8	0.9	1.39	68
8	A	Report	49	16	97	0.9	3.1	1.39	68
9	A	Report	49	36	145	0.8	2.0	1.24	61
10	A	Report	49	13	110	0.8	1.6	1.45	71
11	C	Multiple effects	50	67	>100	0.3	30	1.44	72
12	C	Multiple effects	50	67	211	0.1	2.1	0.92	46
13	D	Multiple effects	49	23	277	0.4	13.8	1.00	49
14	E	Multiple effects	49	48	212	0.3	1.8	0.94	46
15	F	Multiple effects	49	255	>420	0.8	1.2	0.16	8

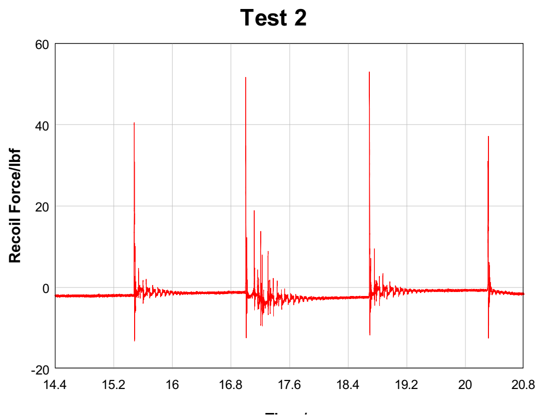

Figure 5. *Sequential shots (Shots #11–14).*

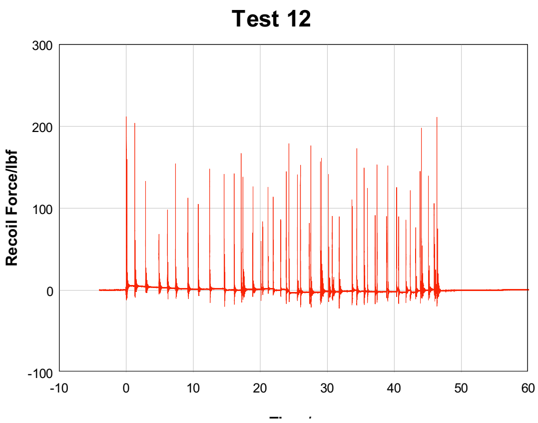

Figure 6. *Complete history of a 50-shot cake (Article C).*

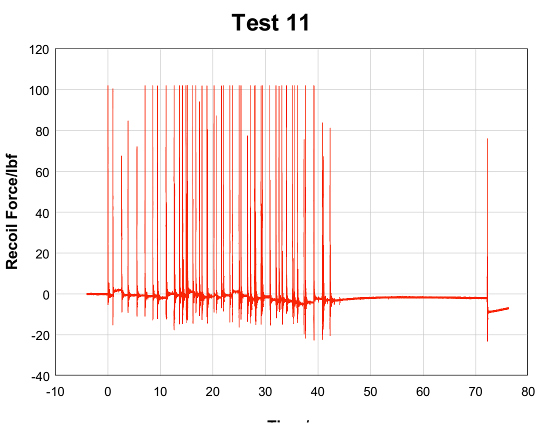

Figure 7. *Long inter-shot delay (end).*

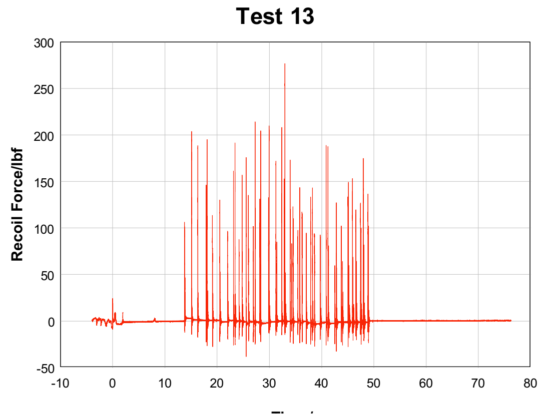

Figure 8. *Long inter-shot delay (beginning).*

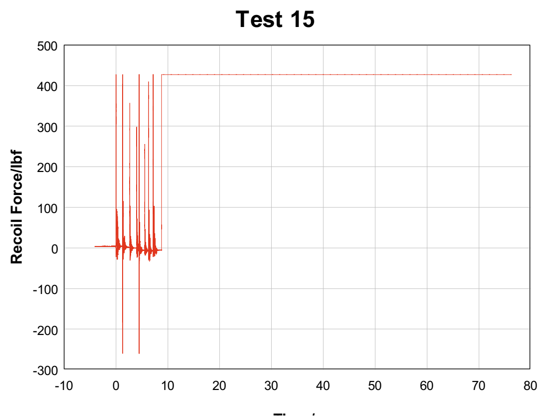

Figure 9. *Malfunction (mass explosion of remaining effects of Sample F).*

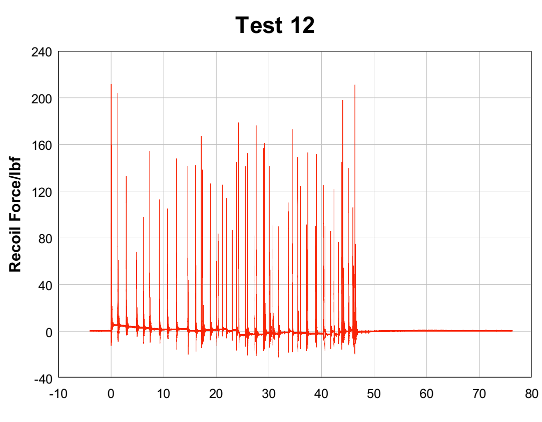

Figure 10. *Rapid firing record.*

heights and recoil forces.

Defects and malfunctions were observed in 3 of the 15 tests. Two articles had extremely long delays between shots and the third ceased functioning after eight shots fired. These malfunctions are shown in Figures 7 to 9.

Figure 7 shows a long delay between the initial group of shots and the last one while Figure 8 shows a long delay before the first and subsequent shots.

The RLP also provided a record (Figure 9) of the malfunction in Test 15 where the 49-shot article stopped functioning just after the eighth shot.

Articles of this type, depending on the design of the delay fusing, may also fire effects in very rapid succession making it difficult for the observer to determine timing. The recoil records provided a method for evaluating this timing. In at least one case several effects fired rapidly. This can be seen upon closer examination of the recoil history of Test 12 shown in Figure 10 and expanded in Figure 11. It is difficult to determine the number of individual shots from the original record. The expanded view clearly shows individual firings at as little as 100 ms apart.

Conclusions and Recommendation

The use of a load cell assembled as a Recoil Load Platform (RLP) proved to have value in the evaluation of multi-shot type devices. Evaluation of such devices is sometimes difficult due to their complexity compared to simple fireworks with single effects. The recoil records allow determination of inter-tube firing intervals and durations, and provide proof of malfunctions such as long delay times or duds.

The data obtained from the RLP are useful and should be considered for routine testing, even though it requires additional time for data analysis. It would also be useful to repeat tests using video to track the projection heights so as to correlate them to the recoil force of each shot.

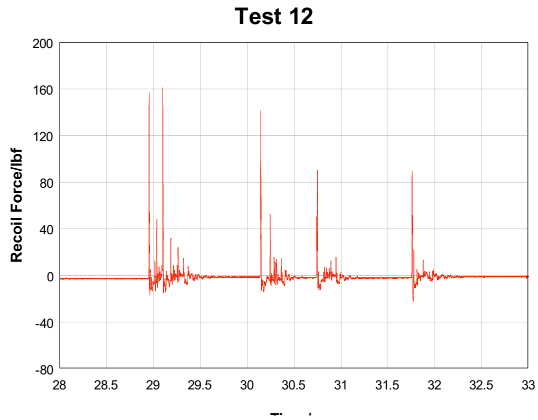

Figure 11. *Expansion of trace record.*

References

1 *Consumer and Display Fireworks Criteria, Authorization, Sampling, Composition, General and Detailed Requirements for 7.2.1 and 7.2.2, Revision 4*, Natural Resources Canada, September 1, 2004.

2 E. Contestabile, R. Guilbeault and D. Wilson, *Loads Resulting from the Recoil of Fireworks Mortars*, 4th International Symposium on Fireworks, Halifax, 1998.

3 K. King, E. Contestabile, K. Hanasaki, R. Guilbeault, A. Rae and J. Collinsworth, *Response of Typical Roof Structures to Recoil Loads from Fireworks Shell Launch*, 9th International Symposium on Fireworks, Berlin, Germany, 2005.