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Cover Page Footnote

Archaeological research at the Poudriere de l'Esplanade was conducted by Parks Canada, Quebec Region as part of the building's restoration and development project. The author wishes to thank archaeologist Anne Desgagne for her assistance in conducting the research as well as Pierre Beaudet for his encouragement and comments during the writing of this article.

THUNDER AND POWDER: MAY THEY NEVER MEET! LIGHTNING CONDUCTORS AT THE ESPLANADE POWDER MAGAZINE, QUEBEC CITY

Pierre Drouin

Archaeological excavations carried out at the Esplanade powder magazine in Québec City have revealed the remains of three successive lightning conductor systems. These 19th-century remains are closely examined in the light of contemporary literature and compared with the military instructions concerning the subject. Their presence highlights the efforts made by military engineers of the time to safeguard contents, buildings, and people from the hazards inherent to the storage of explosive materials in powder magazines.

Des fouilles archéologiques effectuées à la poudrière de l'Esplanade dans la ville de Québec ont permis la découverte des restes de trois systèmes de paratonnerres utilisés successivement à cet emplacement au cours du 19^e siècle. Ces vestiges sont étudiés à la lumière de la littérature scientifique contemporaine et confrontés aux directives des ingénieurs militaires. Ces découvertes font ressortir les efforts des ingénieurs militaires de l'époque pour protéger la population et les équipements militaires des dangers inhérents à l'entreposage des matières explosives dans les poudrières.

Introduction

*And through it, at our feet, conducted without violence,
The captive thunder comes to die in silence.*

Jean Antoine Roucher, 1779 in Figuier [1870]: 575

The recent restoration of the Esplanade powder magazine (FIG. 1) for its use as a visitor center for the Fortification of Québec City National Historic Site provided Canadian Parks Service archaeologists with an opportunity to investigate the design, lay-out, and occupation of the building through time. Archaeological investigations were carried out in the fall of 1990. The site is located between the Saint-Louis and Ursulines bastions, on the western front of the mid-18th-century fortification wall of the city.

Research results relating to the presence of a drainage system as well as to a shifting room where cartridges were filled with gunpowder are discussed in a Canadian Parks Service Research Bulletin (Drouin 1993), while this article focuses on the remains of three successively used lightning conductor systems. These testify to the efforts of the British military engineers to improve the protection of their buildings against lightning, particularly during

the period when the Esplanade magazine was used for the storage of gunpowder, from about 1816 to 1871.

The Powder Magazine

The Esplanade powder magazine first appears on a plan showing the fortifications of Québec in 1816. However, we know that its construction was well underway, if not completed, in 1815 as a document calls for "laying floors in the powder magazine lately erected on the Esplanade and cutting and dressing stone for coping the wall inclosing the same" (National Archives of Canada [hereafter NAC], MG 11 Q, Vol. 139: 66). A massive and low structure surrounded by a protective wall, it is described in 1819 as a regular bomb-proof edifice with a tin roof, measuring 52 feet in length, 22 feet in width, and 12 feet in height, and with a dividing wall in the center (NAC, RG 8, Vol. 407, 1820: 12, in Naftel 1969: 205; Desloges 1976: 126-128).

Its capacity is estimated at 632 barrels of powder, not counting cartridges. Between 1852 and 1871, the year in which ownership of the powder magazine was transferred to the

Figure 1. The Esplanade powder magazine in 1946. (Photograph reproduced courtesy of Québec Department of Cultural Affairs, Gérard Morisset collection.)

Canadian government, the quantity of powder actually stored varied from 67 barrels in 1855 to 630 in 1867. However, 1855 aside, there appears never to have been a single year in which fewer than 314 barrels were stored (NAC, RG 8, Series 1, Vol. 1635).

The magazine was originally used for two purposes, the storage of powder and its shifting from barrels to cartridges. In 1858, however, the latter operation was transferred to a small building erected at the southwest corner of the original structure. Because of the risk of explosions, the proximity of dwellings and the representations of the municipal authorities, and even though they knew that the outer wall acted as a traverse to prevent external damage from powder magazine, the military repeatedly proceeded to improve the protection of the powder magazine against the potentially dangerous forces of lightning.

Of Lightning Conductors

The discovery of the lightning conductor is attributed to Benjamin Franklin. It is thanks to the experiments he himself had proposed that, in May, 1752, the first tests leading to the use of lightning conductors were performed (Ahrweiler 1965: 37–58). A number of his con-

temporaries, however, in particular Nollet and Romas in France, claimed part of the credit for the discovery. By 1760 the use of lightning conductors had become accepted in the American colonies. However, it was not until the early 1780s that their use spread to France and the rest of continental Europe. Britain followed suit only in 1786. This time lag stemmed, in the case of France, from the controversy among scientists over the role played by lightning conductors while, in Britain, it resulted from royal opposition tied to the state of war between the mother country and its American colonies and Benjamin Franklin's involvement in that conflict (Figuier [1870]: 556–567).

The principle of lightning conductors, as described in the mid-18th century, is based on the existence of positive and negative electrical charges in the air. When the opposition between the two forces becomes too great, there is an electrical discharge. Howard J. Critchfield summarizes as follows the relationship among lightning, thunder, and electrical storms:

While thunder and lightning are associated with the typical thunderstorm and are often the most dramatic manifestations, they are in no way responsible for the development of the storm. Lightning results from the discharge of static electricity which is formed as drops of water are broken apart violently in rapid air currents. The dis-

charge may take place from cloud to cloud horizontally, between different levels in the cloud, or from the base of the cloud to the ground. In the latter case, the "strike" can be fatal to persons and animals and it is especially dangerous as a cause of fires . . . Thunder is the explosive sound created as the air expands suddenly with the great heat of the lightning discharge and then cools and contracts rapidly . . . (Critchfield 1966: 124–125)

Since electricity tends to seek out bodies of least resistance in order to penetrate the ground, the key is to provide the electrical charge with the most appropriate route. Installing a pointed metal rod—preferably of copper—at a point higher than the surrounding area, and a wire made of the same material connecting the rod to the ground, gives electricity the path of least resistance that it seeks naturally (TAB. 1) and protects buildings and people from the major damage that lightning can inflict. This principle has been referred to as the power of points (Snow Harris 1875: 184–188; Figuier [1870]: 514–519).

In 1870 the same phenomenon was described as follows:

Everyone knows today that the physical mechanism of the lightning conductor is based on electrification by influence. When, for example, there is a positively-charged thundercloud in the air, it acts by influence, that is at a distance, on any bodies that are on the ground within its radius of activity. It repels positive fluid and attracts negative fluid, which accumulates on bodies at ground level, in greater quantity the higher the bodies. The bodies that stand highest in the atmosphere are thus the most heavily charged and the most exposed to receiving the electrical discharge. But if in other areas lightning conductors have been erected, namely pointed metal rods connected with the ground, the negative fluid attracted from the ground by the influence of the cloud flows into the atmosphere and neutralizes the positive fluid, within the cloud itself.

It may occur however that the mass of electricity contained in the thundercloud is so large that the conductor of the lightning rod remains insufficient to draw from the ground the quantity of opposite fluid necessary to neutralize the free fluid of the cloud. The result is lightning; but since electricity always follows the best conductor, the lightning rod receives the discharge, because of its perfect conductivity, and the building is spared. (Figuier [1870]: 566) [Translation]

The adoption of lightning conductors did not mean that research into electrical phenomena, and particularly on the relationships between electrical storms and electricity, ceased. In Britain, Sir William Snow Harris continued his research on storms and persuaded the Royal

Navy to equip its ships with lightning conductors that could ensure their protection. This was achieved by rendering the masts themselves "perfectly conducting, by incorporating with the spars, capacious plates of copper: all the large metallic masses in the hull [were] tied, as it were, into a general conducting chain, communicating with the great conducting channels in the masts, and with the sea" (Snow Harris 1850a: 9; see also 1847b: 6–8). Between 1830 and 1847, the use of lightning conductors on Royal Navy vessels did indeed reduce considerably the cost of damage caused to the fleet (Snow Harris 1850b). France also noted the disastrous effects of lightning on its navy and on public buildings, this even though both ships and buildings were equipped with lightning conductors. They were most probably poorly installed. In the "Comptes Rendus" for June 1839, we find an account of damage by lightning to l'Hôtel des Invalides at Paris, in which case the lightning-conductor of twisted wire ropes was knocked into pieces (Arago in Snow Harris 1847b: 5). In 1823, lightning having caused widespread destruction, the Minister of the Interior asked the Paris Academy of Science to draw up a guide for the construction of lightning conductors that would be erected in most of the country's districts. Gay-Lussac, a French physicist, was assigned this task and, that same year, published his *Instruction pratique*, which would serve as a reference work for close to thirty years until it was revised by M. Pouillet in 1854 (Figuier [1870]: 576).

Lightning Conductors and Powder Magazines

With the exception of the navy, British regulations governing the method for installing lightning conductors by the armed forces appear to date from after December 1827. It was in that month that, at the request of the Inspector General of Fortifications, the army's Corps of Engineers joined with the members of the Royal Society to define minimum standards of protection against lightning for public buildings. Three months later, after the committee had tabled its report, the members of the Board of Ordnance concluded that powder magazines (because of their low and generally sheltered position) were, without a doubt, the public buildings least likely to be struck by lightning.

Table 1. Order of variation of conducting and non-conducting materials.

CONDUCTORS	INSULATORS
<i>Most Perfect</i>	
All known metals	Animal fur and hair
Well-burned charcoal	Dry gases, including the atmosphere
Plumbago	Fine steam of high elasticity
Burning gaseous matter, as flame	Glass and all vitrefactions
Smoke	Diamond, Transparent gems
Concentrated acids	Talc
	Amber
	All resins and resinous bodies
	Brimstone
	Shellac
<i>Less perfect</i>	
Dilute acids	Ice at 0° Farenheit
Saline fluids	Dried vegetable substances
Living animals	Dried animal substances
Living vegetables	Parchment, Leather, Feathers
Wood in its ordinary state	Baked wood
Snow and ice	Oils and fatty substances
	Bituminous matter
	Silk
<i>Imperfect</i>	
Aqueous vapor	
Common earth and stone	
Dry chalk and lime	
Marble and porcelain	
Paper	
Alkaline matter	

Source: Snow Harris 1847a: 7.

Nevertheless, the members felt that their very function and the extent of the damage that they could cause in the event of an accident called for the greatest prudence and, consequently, that the buildings should be equipped with lightning conductors (Public Record Office, War Office 55 [hereafter PRO, WO], Vol. 885: 139–144).

Grounding Pits: The First Esplanade System

The first lightning conductor system put in place at the Esplanade powder magazine included two grounding pits dug into the rock at either end of the building (FIGS. 2, 3). Historical documents do not specifically mention its installation. However, the system probably predates the first instructions issued by the Board of Ordnance in 1828. This is supported by a document dated 1824 where it is said: “In reply to your letter of this date relative putting up conductors to all Government Buildings in Québec, as directed in your former

letter of 11th June last, . . . it will probably be about two months before the whole of the conductors can be affixed to the various buildings the order comprehends” (NAC, RG 8, Series I, Vol. 419, 1824: 131–132). Further, the two pits are located much closer to the Esplanade building than it is generally recommended in one of the 1828 Board of Ordnance instructions:

insulated conductors at the distance of 10 or 12 feet from the wall of a building are preferable to those which are attached to the building itself, the former must of course be secured by fixing them to masts or poles of sufficient height, that two such conductors placed at the ends of a Powder magazine will generally be sufficient for its protection, unless the building should be of more than usual length, in which case it may be proper to add two others, also insulated, one in front and one in rear, towards the center. (PRO, WO 55, Vol. 885: 139–141)

The use of lightning conductors predating these first instructions is not surprising since Franklin’s works had been largely discussed even at this early date. A 1798 encyclopedia published in Philadelphia also provided recommendations for protecting powder magazines (Dobson 1798).

Figure 2. First lightning conductor system at the Esplanade powder magazine. (Drawing by Louis Lavoie 91-39G-3.)

Figure 3. Grounding pit at north end of powder magazine. (Photograph by Pierre Drouin, 39G-90R4X-13.)

This first system appears to have been in use until the early 1840s, as shown on several period drawings (FIGS. 4–7) and discussed in documents relating to its replacement. If the position of the pits was not modified in 1828 to conform to Board of Ordnance instructions, it probably results from the system's general acceptance under the new directive.

A Second System: The Lightning Conductor Tank

A plan dated December 2, 1850, tells us about the second lightning conducting system used at the Esplanade powder magazine. Most likely put in place after 1840, it consisted of two lightning rods placed at either end of the building, both connected with the water tank. The rods were wired to a brick masonry tank, the top of which was 2 ft 6 in (76 cm) below ground level. It was positioned on the east side of the building, between the outer wall and the magazine (FIG. 8).

Excavations in the eastern sector of the site revealed the well preserved remains of the brick conductor tank (FIGS. 9, 10). Circular in shape, it had an exterior diameter of 1.45 m.

The interior face was covered with a coating, probably to make it more watertight. The tank, 0.92 m deep, was closed at the top by a sandstone slab 1.35 m square and 0.14 m thick, and made in two parts. At the center of the slab was a hole measuring 0.41 m square closed by a moveable piece of wood. Two iron rods, 0.02 m in diameter, ran through the west wall, lengthwise, and led into the tank. These rods probably served to connect the tank with the conductor wires attached to the outside wall of the powder magazine. We know of only one other example of a similar conductor tank, namely that found at the Saint-Jean Bastion at Artillery Park in Québec City (Tanguay 1976: 6; Charbonneau, Desloges, and Lafrance 1982: 223).

We were unable to trace the specific origin of this system. However, in his *Traité élémentaire sur l'électricité*, Gay-Lussac provides the following indications on the subject. A lightning conductor is a metallic rod that rises above a building and descends, without any interruption, into the water of a well or into damp soil. He adds that the conductor is set against the wall, without touching it, and descends along it into the ground. At 50 or 55 centimeters (18 or 20 inches) underground, it bends perpendicular to the wall, extends in this new direction for 4 to 5 meters (12 to 15 feet), and then embeds itself in a well or a hole dug into the ground (Gay-Lussac 1845: 92–104).

The physicist suggested moreover that a trough be dug in the ground to improve the conductor's resistance to rust (cf. also Laboulaye 1847: 2879), and that a strand made of several copper wires be substituted for the metallic rod. We cannot determine, however, the exact type of conductor used at the Esplanade powder magazine.

In the case of the Esplanade example, the presence of two metal rods, one on top of the other, entering the well, causes interpretative problems. We were unable to determine whether the two rods of the conductor were used at the same time or whether they represent two successive uses of the same structure. Gay-Lussac mentions the tendency of metal to corrode underground, hence his recommended solution of enclosing the conductor in a trough filled with ashes to allow it to last (Gay-Lussac 1845: 103–104). This suggestion was not followed at the Esplanade powder magazine, which may mean that the underground part of

Figure 4. The Esplanade powder magazine in 1830, after a watercolor by J. P. Cockburn. (Photograph reproduced courtesy of Royal Ontario Museum, Toronto, J. P. Cockburn Collection.)

Figure 5. The Esplanade powder magazine after a work by Mrs. M. M. Chaplin in 1839. (Photograph reproduced courtesy of National Archives of Canada, negative C-855.)

Figure 6. The Esplanade, Québec. Watercolor by Mrs H. W. Bayfield (ca. 1840). (Photograph reproduced courtesy of National Archives of Canada, negative C-10527.)

Figure 7. The Esplanade powder magazine after a watercolor by P. J. Bainbrigge in 1838. (Photograph reproduced courtesy of National Archives of Canada, negative C-11906.)

Figure 8. Plan of the Esplanade powder magazine showing the lightning conductor system in use and the proposed modifications, 2 December 1850. The tanks' locations at both ends of the building, outside the curtain wall, are yellow on the original. (Photograph reproduced courtesy of National Archives of Canada, negative C-136472.)

the conductor had to be replaced. This hypothesis appears to be borne out by another comment by Gay-Lussac, to the effect that

when two lightning rods are placed on a building, and when they are given a common conductor, which is indeed sufficient, the sections of the conductors that cannot be common shall be merged at a point on the roof equidistant from each rod; and from that point, a metal bar of the same dimension as for a single lightning rod will serve as conductor for both . . . (Gay-Lussac 1845: 120–123) [Translation]

Finally, the same author mentions that the lightning rods must be interconnected in order to act as one. This would seem to support the theory that the two rods entering the tank correspond to two different periods of use.

Snow Harris' Chain System

Efforts to protect the buildings against lightning did not end with the installation of

these two conducting systems. As shown through the above discussed 1850 plan, the engineer of the fortifications of Québec proposed modifications to the system in place. The estimate of the work to be performed specified that the conductor wires in place on the building were to be removed and mounted on poles for greater safety. The request was justified as follows:

the several magazines at Québec which at present are in close connection with the buildings and most of them, pass along the whole extent of the roofs and are moreover not of the prescribed size being only 3/4 inch diameter. As most disastrous effects would be likely to occur in the event of accident happening to either of these magazines, most of which are in the immediate vicinity of barracks fully occupied besides being in a closely built neighbourhood of private houses. It therefore seems imperative that every precaution should be adopted as far as possible to obviate danger, and provision is accordingly made for taking down the present lightning conductors and fixing new ones in the situations shown in the several sketches and agreeably to the orders dated 4th August 1829 and Circular No 150. (PRO, WO 55, Vol. 885: 124)

The proposal, to which the plan was attached, was rejected on the advice of Sir William Snow Harris: the system already in use—rods on the top of the roof connected with a water tank—was deemed safer than the one proposed (PRO, WO 55, Vol. 885: 120). However, the request did lead to a revision of the directives of the Board of Ordnance. As a result, new orders were issued in 1858 (NAC, RG 8, Series I, Vol. 1470: 116–117). The document described knowledge acquired in the field of lightning conductors since the previous instructions issued in 1829 and suggested modifications to be made in order to increase protection from lightning. Priority in replacing existing systems was given to powder magazines.

Almost the entire system described in the 1858 directives of the Board of Ordnance was found at the Esplanade powder magazine, on either side of the building (FIG. 11). On the east side, its remains were found on top of the conductor tank belonging to the previous system. Installing the grounding system had involved digging a north-south trench along the major axis of the building and another, running east-west, between the first trench and the point where the conductor entered the ground. Next, the chains were installed, the trenches were filled in with a mixture of ashes and slag and,

ESPLANADE POWDER MAGAZINE
QUEBEC CITY
PHASE 2: THE TANK SYSTEM

Figure 9. The second lightning conductor system at the Esplanade powder magazine in Quebec City: the tank system. (Drawing by Louis Lavoie, 91-39G-6.)

lastly, the tops of the trenches were covered with earth. Near the walls of the powder magazine, the chain ended in a copper plate bearing traces of two rivets that must have been used to connect the wires coming from the roof to the chain.

The design of this system follows in all respects the instructions issued by the Inspector General of Fortifications in 1858, calling for

7.- One or more solid copper rods to project freely into the air, about five feet above the highest points of the building to which the main conductors are applied. The summit of the rod to be pointed, but gold, gild or platinum tops are unnecessary.

8.- The termination of the conductors below to be led into damp or porous soil when the building happens to stand upon it; but when the soil is dry, two or three trenches to be cut, radiating from the foot of the conductor to a depth of 18 inches or two feet, and 30 feet in length, and either the conductor carried along the bottom of the trenches, or old iron chain laid in them, carefully connected with the foot of the conductor. The trenches to be then filled up to one foot in depth with coal ashes, or other carbonaceous substances, and then with earth or gravel.

9.- If it be possible, in regulating the surface drainage, to lead a flow of water during the rain which generally accompanies thunder storms over the sites of the trenches, it will be an additional precaution.

10.- Tanks are useless, except when the water flows freely into them from the surrounding soil, and even then they are superfluous as appendages to the conductors.

Finally, the document indicates that

Existing conductors of iron attached to the buildings, and otherwise fitted in harmony with the above principles, need not be replaced until buildings not provided for are attended to, but water-tight tanks should be replaced by the precautions mentioned in par 8. (NAC, RG8, Series I, Vol. 1470, 1858: 116–117)

The Esplanade powder magazine received its third lightning conductor system in the fall of 1859 (NAC, RG 8, Series I, Vol. 1635, 30th September 1859). Only a few datable sherds of blue died body ware, introduced in the 1840s (George Miller, personal communication, 1993), were found in association with these chain conductors. Collard (1984: 286) also mentions that this ware was produced by the Saint John's Stoneware on the Richelieu River around 1879. If this would have been the case—and there is

Figure 10. The lightning conductor tank at the Esplanade powder magazine. (Photograph by Pierre Drouin, 39G-90R7X-9.)

no way to be sure of that—they might bear witness to possible subsequent repair work. However, this would not seem to be the case from the archaeological evidence.

This seems to have been the last system in use at the Esplanade powder magazine during the English military utilization of the building. The building was transferred to the Canadian Government in 1871 but was never to be used for its original function. From this date onwards, no information is available concerning the presence and design of the building's lightning conductors.

Conclusion

Archaeological remains uncovered at the Esplanade powder magazine constitute tangible evidence of the rapid evolution of lightning conductor systems used to protect buildings on 19th-century British military sites. Three distinct systems were recognized, each related to improvements discussed in contemporary scien-

Figure 11. The third lightning conductor system: Snow Harris' chain system. (Drawing by Louis Lavoie, 91-39G-1.)

tific literature. The comparison of historical and archaeological records underlined the distinction between the development of regulations based on theoretical concepts and their practical application on existing buildings.

Lightning conductor systems are quickly disappearing from our urban landscape. Their *in situ* presentation at the Esplanade powder magazine should help visitors grasp the importance of these ingenious inventions in the prevention of fires, or explosions in the case discussed here.

Acknowledgments

Archaeological research at the Poudrière de l'Esplanade was conducted by Parks Canada, Québec Region as part of the building's restoration and development project. The author wishes to thank archaeologist Anne Desgagné for her assistance in conducting the research as well as Pierre Beaudet for his encouragement and comments during the writing of this article.

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