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The Gap Rock Lighthouse: construction and typhoon damage

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This paper focuses on the Gap Rock lighthouse, a legendary maritime infrastructure built 130 years ago in the Chinese territory and an early example of joint venture among the Qing Dynasty, the British Empire and the Hong Kong Colonial Government over a course of two decades. Based on 4 years of cross-territorial archival and field research as well as in-depth interviews with descendants of two key stakeholders, the origin of this lasting legacy on the sea is traced, followed by a detailed account of its challenging processes of planning, design and construction, and of the considerable damage to the compound by a severe typhoon in 1893. A qualitative analysis of the key contributing factors of the damage was conducted by taking into consideration the Island's unique topography and the historical records of territorial weather reports. A re-construction of the typhoon impact on the Lighthouse is presented to explain the possible mistakes in its siting and design that eventually caused the severe damage. This serves as a reminder of the significance of a thorough geographical investigation for any infrastructure for all construction professionals in the face of climatic change.

This article is part of the theme issue 'Environmental loading of heritage structures'.

1. Historical background to the construction of the Gap Rock Lighthouse

After the establishment of the Hong Kong Colonial Government (HKCG) in 1841, maritime trade in the region saw considerable growth. In 1851, about 1100 vessels launched a total of 380 000 tonnage into Hong Kong harbour [1]. Ten years later, the figures grew to

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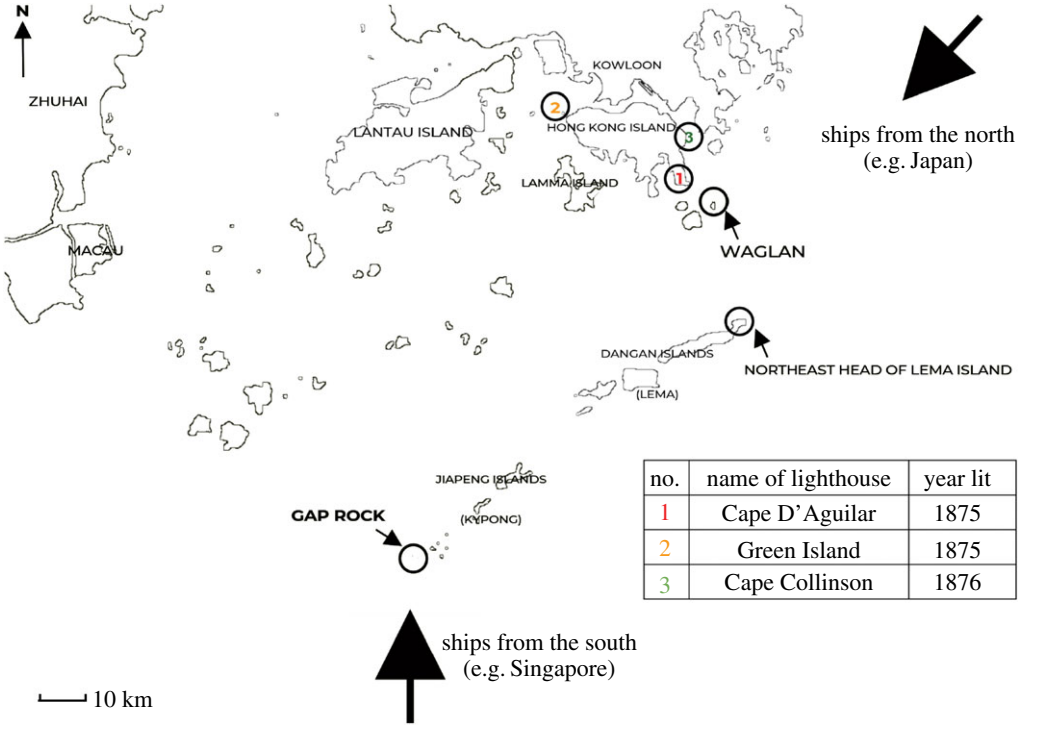

no.	name of lighthouse	year lit
1	Cape D'Aguilar	1875
2	Green Island	1875
3	Cape Collinson	1876

Figure 1. Map of location of historic lighthouses of Hong Kong. *Source*: Drawn by the research team. (Online version in colour.)

over 1200 and 650 000, respectively [2]. The Treaty of Tientsin signed in 1858 stipulated the opening of 11 more ports in China for foreign trade, implying maritime facilities would be required to guide the approaching vessels.

In 1867, Sir Richard MacDonnell, the Governor, having considered the increasing shipping of the colony, had taken steps to implement the erection of lighthouses. Commander Reed, a British naval surveyor in command of H.M.S. *Rifleman*, was instructed to investigate suitable lighthouse locations to cover the port approaches to Hong Kong. The proposed three locations were Waglan Island at the east entrance, northeast head of Lema Island at the west entrance and Gap Rock Island to mark the south approaches (figure 1) [3]. However, no action was pursued since the locations mentioned were all within the territory of China.

In 1869, the Suez Canal was opened and 1 year later 4791 vessels of 2 640 000 tonnage [2] entered Hong Kong, signalling that the sea trade was booming. In 1872, the Hong Kong General Chamber of Commerce (HKGCC) proposed to HKCG that lighthouses be built in order to guide the vessels and prevent wreckages [4]. In 1873, Robert Hart, the Inspector General of the Chinese Imperial Maritime Customs Service (IMCS), responded by explaining the low priority of erecting the Gap Rock and Waglan lighthouses due to anticipated little tonnage dues [5]. He suggested HKCG to pay the cost of constructing the two lighthouses, and China would maintain their operation. Without reaching any agreement and to avoid further delay, HKCG decided to build three lighthouses within Hong Kong waters. The Cape D'Aguilar lighthouse and Green Island Lighthouse were completed in 1875, and Cape Colinson Lighthouse was lit in 1876 (figure 1) [6].

Such a compromise solution was not able to satisfy the maritime requirements. In the 1880s, with the increase in numbers of vessels and tonnage entering the port, the question of erecting the Gap Rock Lighthouse was re-opened. Its urgent necessity was justified by force of circumstance. On the one side, the southernmost lighthouse along the China coast was Breaker Point built in 1880 [7]. On the other, the Fort Guia built by the Macao Colonial Government in 1865 (figure 2) was far away from Hong Kong, thus unable to guide the vessels approaching Hong Kong harbour.

Figure 2. Location of Gap Rock and nearby lighthouses. *Source*: Drawn by the research team.

In March 1886, Captain J.P. MaClear of H.M.S. *Flying Fish* suggested to Captain R.M. Rumsey, the Acting Harbour Master, that the lighthouse at Cape D'Aguilar served well for vessels from the north but not for those from the south. Thus, a lighthouse on Gap Rock would be well situated for steamers, particularly from Singapore. He further reminded him that the cost of the steamers' delay and the insurance compensation from the loss of one trans-ocean vessel would end up being comparable to the expense of building a lighthouse [8].

With the same concern, HKGCC stated that the majority of the representatives of the Ocean Steam-ship Companies and the privately owned steamers and sailing vessels, arriving from the South, were willing to acquiesce in the payment of 1 cent per tonnage Extra Light Dues for 3 years or more, as a contribution to the cost of the lighthouse construction [9].

In September 1886, Hart reiterated the interest to erect and maintain the lighthouse at Gap Rock if the colony could arrange to meet the construction cost. He made three proposals regarding the different proportion of cost paid by HKCG with corresponding completion dates [10]. With a visit made in September by Commodore Morant (the Senior Naval Officer), J.M. Price (the Surveyor General), H.G. Thomsett (the Harbour Master) and Assistant Harbour Master, Gap Rock was considered the best location for such a purpose [11].

At the Legislative Council Meeting on 1 October 1886, a query was raised on the progress of the proposed Lighthouse. The Officer Administering the government replied that the subject was under consideration [12]. In November of the same year, HKCG wrote to the Secretary of State for the Colonies iterating HKGCC's decision on the necessity to erect the Lighthouse [11]. Unfortunately, funding was not available in 1887 due to many public works being constructed and so the Colonial Office suggested that the project be considered 1 year later [10,13].

In January 1888, the Governor of Hong Kong wrote to Sir John Walsham, the British Embassy Minister in Peking, with three proposals for the erection of a lighthouse at Gap Rock [14]. Firstly, HKCG would build the lighthouse and maintain it with a nominal annual rent payment for the lease from China to Hong Kong. Secondly, HKCG would build the lighthouse and hand it over to China for maintenance purposes but permitting Hong Kong to make use of it. Thirdly, HKCG offered $80 000 to the Chinese Government for building the lighthouse, and the Colonial Government committed to handle further maintenance costs.

On 21 May 1888, the Qing Imperial Government agreed the construction of the lighthouse subject to certain conditions [15]. On the next day, the British Foreign Minister in Peking replied to HKCG that the Chinese Foreign Office had authorized the construction of the lighthouse on the Island, but with an arrangement differing from Hong Kong's previous three proposals [16]. The Chinese Foreign Office instructed IMCS to build the Lighthouse and it would further delegate to the Kowloon Customs for actual implementation.

Finally, the plan was unveiled in June 1888 through the Commissioner of Customs for Kowloon and District, and the arrangement delivered to the Colonial Secretary of Hong Kong was as follows [16]:

- The Island is not to be used for any other purpose and remains Chinese territory.
- The construction and maintenance of the Lighthouse would be under the control of HKCG, acting in concert with the Kowloon Commissioner of Chinese Customs.
- The Kowloon Customs would contribute a sum of $7500 towards construction, and $750 per annum towards maintenance. HKCG would provide the remainder of both costs.
- The Island would remain within the Chinese dominion and be open as before for visits by Chinese territorial officials; and the Lighthouse would be subject to the inspection by officials of Chinese Customs.
- If Hong Kong is required by China to discontinue the maintenance of the light, the Kowloon Customs would maintain the continuous exhibition of the light.

The Qing Government's contribution to the cost of the construction and the annual maintenance reflected China's desire to have a hand in the project and would wish to have it on record that the island was Chinese territory. It also indicated that the Chinese Government strongly objected to cease or lease territory to a foreign power [15].

Having accepted the terms [17] and considered the difficulty in landing on the Island, HKCG delivered the materials for construction in 1890. During and after construction of the lighthouse, the island had been affected by many typhoons. In April 1892, the light of the lighthouse was lit. Eighteen months later, a very severe tropical storm hit the Island, causing substantial damage to the Lighthouse and other facilities. HKCG re-examined the safety of the compound and concluded that the lighthouse had been erected in the wrong part of the Island.

2. Research methodology

This paper investigates the original design and construction of the lighthouse, and presents qualitatively all the main factors which caused the substantial damage to the lighthouse by the typhoon. Studying such a lighthouse of over one and a quarter century old requires various methods to collect the data, and to trace the personnel and their descendants. The data collection process began from 2014 in a multilingual and cross-territorial environment, including arduous archival research, adventurous field trips as well as in-depth interviews conducted in Hong Kong, Guangzhou and London with descendants of personnel who were involved in the planning, design, construction and operation of the lighthouse. Firstly, data collection and content analysis were carried out in libraries and the Public Records Office in Hong Kong, and archives were traced simultaneously from libraries in London. Documents related to establishment of the lighthouse, including its design, construction, damage and maintenance, were obtained from various local sources such as official reports and local newspapers, and relevant local government departments. The Marine Department, the Hong Kong Observatory and Antiquities and Monuments Office were visited as well.

The target interviewees included retired lighthouse keepers and descendants of lighthouse keepers in Hong Kong. After searching for almost 2 years, two descendants of the key personnel involved in the Lighthouse were identified. Interviews were held in London in the summer of 2017 with descendants of the Engineer-in-chief of IMCS and the first Senior Keeper of the Lighthouse, to understand the work and life in the historic lighthouses. Exchange of information has since taken place with them.

The first of these descendants is Mrs Felicity Somers Eve, who is the great granddaughter of David Marr Henderson, the Engineer-in-Chief (1869–1898) of IMCS. Throughout his 29 years of work, Mr Henderson was the chief architect for the design, construction and maintenance of a network of 34 lighthouses in China, including the Gap Rock lighthouse now under the jurisdiction of Zhuhai City, in the Guangdong Province of China. Only in recent years has Mrs Somers Eve discovered Mr Henderson's archives, including the precious lighthouse drawings and photos taken during his appointment in China.

The second descendant, Mrs Heather Williams, is the great granddaughter of Mr Charles Edwin Nicholas, the first Senior Keeper of the Gap Rock Lighthouse since commencement of the light in 1892. In 1916, Mr Nicholas retired as Principal Lighthouse Keeper after taking charge of all lighthouses in Hong Kong [18]. As the fourth-generation descendant, Mrs Williams has been keeping Charles' archives and in particular a notebook that recorded in detail his life and work as a keeper in Hong Kong. During the interview, she presented the notebook, several photos and other archives to the research team in London in 2017.

The interviews provided not only the access to invaluable archives kept by the descendants, but also the channel to confirm, enrich and supplement the information kept in the official institutions.

In order to understand the difficulties faced by the lighthouse personnel, study visits to the lighthouse were made. From 2014, one visit was conducted each year for three consecutive years. The last one was accompanied by senior officials from Guangzhou Division of Aids to Navigation, South China Sea Maritime Security Centre, China. By doing so, the authors were able to understand the topography of the Island, confirm the significant details of the lighthouse compound and understand the key contributing factors that had led to the severe damage to the lighthouse.

3. Gap Rock Island: geography and topography

While Gap Rock was proposed in 1867 as one of the three places for building lighthouses, a review of its suitability was undertaken as late as 1886. On 27 September, a cruise around the islets to the south of Hong Kong was made by senior government officials with an aim of selecting the best location for a new lighthouse [11].

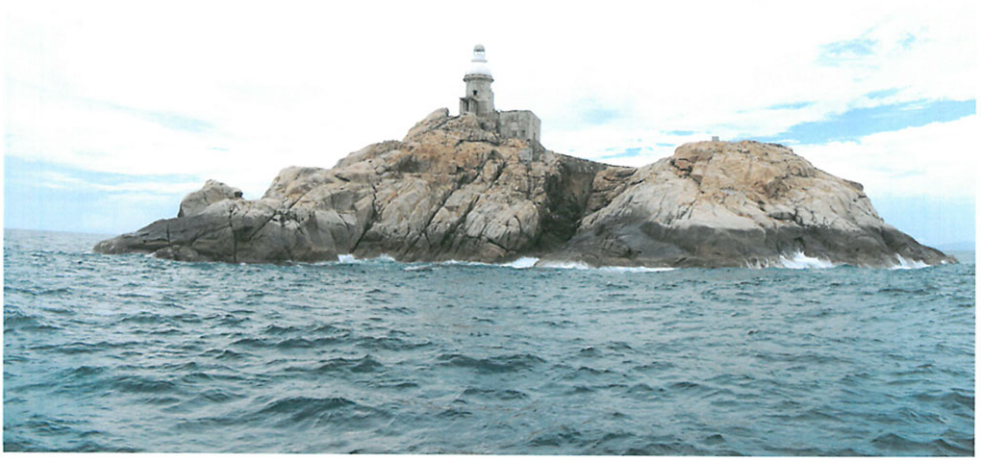

Figure 3. Gap Rock and the lighthouse (note the gap between the two portions of the Island). *Source*: Photo taken by the research team in 2014. (Online version in colour.)

After the trip, the senior naval officer regarded the Gap Rock Island as the best position for a lighthouse [19]. The Harbour Master also considered the Island was the most appropriate site for a lighthouse to fulfil the task of guiding ships from the south, and concluded that the project would meet the colony's lighthouse requirements [20]. However, in his recommendation, he highlighted that the island was small and that there would be difficulty in landing and in communication. Therefore, the erection and upkeep of the lighthouse would be costly. Similarly, the Surveyor General opined the island was the best site, but because the island was steep and almost precipitous nearly on all sides, access would be possible only in fair weather [21]. Nevertheless, the island was re-confirmed by the team as the best location for a new lighthouse in guiding the ships approaching Hong Kong from the south or southwest.

However, the construction issues were considered during the visit which was held on a calm day, with fair weather and ordinary sea waves. Yet, the scenario involving adverse weather and, in particular, the combined effect of the topography of the island and the impact of a severe typhoon was not fully investigated.

Gap Rock is a tiny island of about 12 000 m^2 at the southwestern extremity of Dangan (Lema) Islands and Jiapeng (Kypong) Islands, 50 km from the southwest of Hong Kong (figure 1). The barren rocky island was named so because of the existence of a gap between its two portions (figures 3 and 4).

In his article entitled 'The Gap Rock—some early history' [22], Gibbs mentioned his visits to the island in 1891, April 1894 and August 1894. The last two trips were dedicated to surveying the island with the following records (figure 5).

Invited by HKCG to inspect the lighthouse compound in 1895, Messrs Coode Son and Matthews [23] described the island in detail in their report submitted to the Hong Kong Government.

> The Island consists of two main portions running 134 m in North-east and South-west direction. About midway there is a gap on either side of the centre, the inner ends of which converge until at the connecting ridge between the southern and northern portions is only about 3 m in width.
>
> The southern portion with the axis extends 146 m in the North-west and South-east direction, consists of a mass rising to 29 m above the mean sea level, flanked on the south-east side by a spur of 67 m in length. The North-east face of this spur is almost vertical for a

Figure 4. Aerial photo of the Gap Rock lighthouse showing the gap and the causeway. *Source*: Photo taken by the research team in 2016. (Online version in colour.)

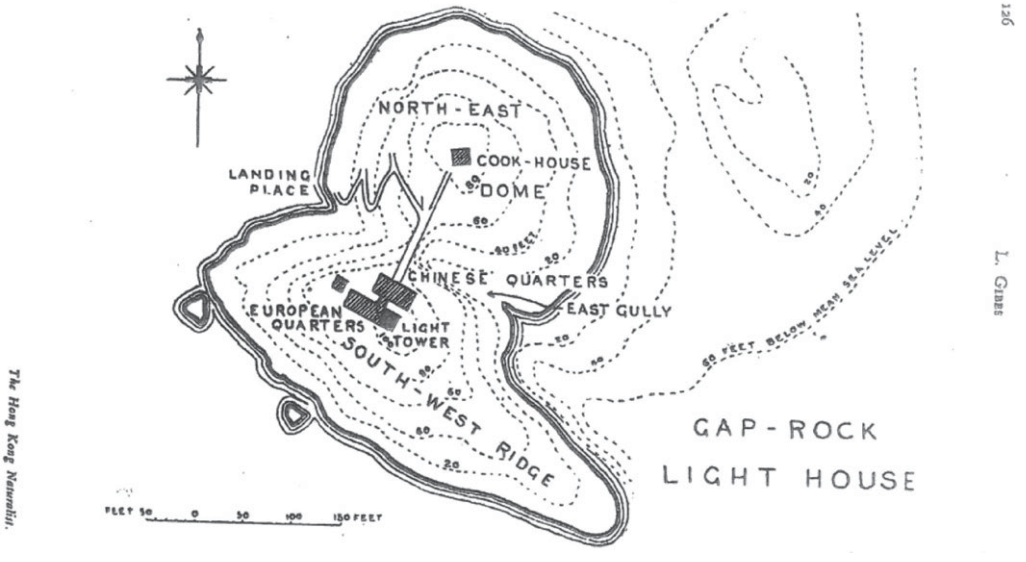

Figure 5. The contours surveyed by Gibbs [22]. *Source*: L.G. Gibbs' paper 'The Gap Rock—some early history'.

height of 11 m, whilst the adjacent face of the gap rises 23 m, in a horizontal width of 15 m. The configuration of the eastern gap and spur of the Island that any sea waves from North-east to South-east would concentrate into a funnel shaped cavity, thereby intensifying the abnormally severe waves which are associated with the occurrence of typhoons.

The northern portion is circular and is 85 m in diameter at its base. It rises to 23 m above mean sea level where there is a flat area of 30 m by 24 m. At the northern end of the plateau there is a small section rises to a further height of 3 m.

Figure 6. The Light Tower. *Source*: British Library, with permission. (Online version in colour.)

> The gap on the western face between the two sections is less exposed than that on the eastern side and is of a much more favourable shape. The landing place has been rightly fixed on this sheltered western face. (figures 3 and 4)

Gibbs observed from his first visit in 1891 a tuft of grass as the only green thing on the island, on the highest part about 30 m above the water. The island is smooth, steep and precipitous in many places [22]. These features described by Gibbs and Matthews were also noted during the three visits by the research team.

4. Design and construction of the Gap Rock lighthouse

Having accepted the terms set by IMCS, HKCG took up the design and construction of the lighthouse [17]. The cost of the construction was initially estimated as £10 000 (about $40 000) in Henderson's report dated 20 June 1872 [9] and $45 000 by Hart in 1873 [5]. Later in 1886, the cost was further increased by the Inspector General to $90 000 [10]. Apparently, the difficulty and problems in construction had by then been considered in detail with solutions included in the revised budget.

An invitation for the tender of the lighthouse construction was gazetted on 7 September 1889 and Mr Tsang Keng, a contractor who took part in many large construction and quarry works in Hong Kong, succeeded in winning the contract [24].

The buildings involved in the project [25] included the tower (figure 6), the European and Chinese Quarters and the Cook House, including a room to accommodate the apparatus for condensing seawater. The lantern contained a revolving light of the first order. The level of the focal plane of the light was 45 m above the mean sea level, and would be visible at a distance of about 20 nautical miles in clear weather conditions [25].

The buildings are made of brickwork and faced with granite blocks (figure 7). The light tower (10 m in height) is flanked by the European quarters that are 12 m long, 5.5 m wide and 9 m tall. The basement consists of a store and a water tank, surmounted by two floors for the accommodation of the keepers. A short passage connects the European Quarters with the building

Figure 7. The Gap Rock lighthouse and the quarters (1893). *Source*: British Library, with permission. (Online version in colour.)

in front (13.3 m long, 6.3 m wide, 6.7 m tall) housing the Chinese Assistant Keepers and the Telegraph Clerk [23].

The prefabrication of the buildings required shipping the construction components to the Island. This turned out to be one of the key challenges, particularly when the weather would not permit landing on the Island. The steam tug *Fame* purchased by the Dock Company was hired for the purpose of conveying workers to and from the island, and transporting materials and provisions (including water) for the workers. Because of its location and exposure, it was found difficult to effect a landing during the Northeast Monsoon. Hence, two derricks were erected, one on the eastern and another on the western side of the island, to facilitate the landing of men and material [25].

The preliminary operations undertaken were to form convenient approaches from the landing places to the summit of the island and to provide suitable quarters for the workmen. Until 21 March 1890, the size of the workforce was constrained due to a lack of lodgings and supply of water. After the brick quarters were erected and a water cistern had been installed, the number of workers increased to 65. The brick quarters were capable of accommodating 100 workmen with the upper floor used as the apartment for one European foreman. The basement floor of the tower building contained a permanent water tank with a storage capacity of 54 m^3. In forming the site for the foundations of the lighthouse, the keepers' quarters and the permanent water tank, at least 1000 tons (400 m^3) of rock had been blasted [24]. Some of the blasted rock was used for the construction of the causeway linking the tower buildings and the cook house.

Miraculously, the work progress was in line with the expectation, for which all credit was given to the superintendents. It was thought that the heat and glare would seriously affect the health of the workers. However, with the precautions taken for their safety and comfort, the maintenance of good sanitary conditions of workers' lodgings and a regular supply of food and fresh water, no difficulty was encountered in recruiting the workmen. The number of workers on the island varied from 50 to 95. Contrary to all expectation, no accident or other unusual incident was reported during construction [24].

On 1 September 1890, the foundation stone laying ceremony [26] (figure 8) was officiated by Sir Francis Fleming (1842–1922), the Officer Administering the Hong Kong Government. Senior officials including the Surveyor General and the Harbour Master went to the site on the *Fame*.

Figure 8. The Foundation Stone laid on 1 September 1890. *Source*: Photo taken by the research team in 2015. (Online version in colour.)

In his speech, Sir Francis thanked Sir John Walsham, the British Foreign Minister in Peking, Sir Robert Hart, and the Chinese Foreign Office for their respective contribution. He hoped that the weather would permit the construction be completed earlier than the planned schedule. The spectators cheered and the *Fame* joined the demonstration by giving three blasts of her whistle concluding the ceremony [26].

The construction was completed and the light was lit on 1 April 1892. The total construction cost including the cost of improvements after the typhoon in 1893 and the maintenance cost until the first half of 1896 was $315 935. The additional dues collected during this period were $358 621 [27]. The excess in revenue of $42 684 within such a short period of time after construction had led to the successful appeal from the ship owners for the removal of the additional dues.

5. Interruptions of service

While the light was illuminated for the first time on 1 April 1892, the European lightkeepers who were selected by Trinity House arrived and assumed their duty on 13 June 1892 [18,28]. Charles Nicholas, the first senior lightkeeper, marked his appointment as 'transferred from Trinity Service to Hong Kong Government on 23 April 1892' in his notebook.

At the start, the staff establishment included a senior lightkeeper and two assistant lightkeepers from the UK, three Chinese assistant keepers and three workers. One telegraph clerk was employed for 2 years and later the post was replaced by two watchmen [18] (figure 9).

Communication was carried out fortnightly with the island for the purpose of changing the keepers and supplying their stores. The tug *Pilot Fish*, belonging to the Dock Company, was hired for this purpose. Landing on the island on these occasions was not prevented by the weather though sometimes it was reached with difficulty [28].

It is obvious that such a tiny Island could be subject to immense impact by the adverse weather and such an experience was recorded even during construction. On 16 October 1891, when the lighthouse was under construction, a heavy sea struck the island and hit the water tank at 21 m

Figure 9. Charles Nicholas (front row, centre) and his colleagues at Gap Rock after 1892. *Source*: Courtesy of Mrs Heather Williams. (Online version in colour.)

above the mean sea level. The weight of the wave broke the cover of the tank and contaminated the fresh water inside [28].

From the morning of 2 October 1893 until the next morning, an exceptionally strong typhoon hit the island and caused severe damage to the lantern room and the light. At the peak of the typhoon, rain kept on pouring through the broken glazing into the service room, which was one floor below the lantern room. No light was displayed on 2 October and two oil lamps were rigged temporarily. A couple of days later, the flashes were exhibited with approximate regularity [23].

After the incident, HKCG paid for all the repairs and installed the necessary replacements. The new lens was ordered from the UK and the light was restored to its original condition of efficiency in May 1894 [29]. With the reinstatement of the light and strengthening of the windows of the quarters, an issue was raised: whether the lighthouse would be a safe place to work, and whether a major alteration would be needed [30]. Before providing the answers, it was necessary to keep a record of the lighthouse compound, and Mr L. Gibbs was asked to survey the island [22].

In August 1894, the engineers of Trinity House in the UK reported [23] that the lighthouse was built in the wrong place. It should have been built on the domed northeastern part originally occupied by the cook house. This was disconcerting and further advice was needed. At that time, Coode Son and Matthews were building the Colombo Breakwater in Sri Lanka and Mr William Matthews was requested to visit the island and inspect the lighthouse. It was found that the buildings offered great resistance to the sea, but they were inadequate in such an exceptionally exposed position when subject to extreme weather conditions. The report also concluded that the lighthouse should have been erected at the north end of the island which was well protected. As such, the most likely scenario is that only broken water could have surrounded the buildings without much harm. Also, the filling of the gully on the east side, and the removal of the causeway at the end of the gully would have the effect of easing the sea over the island [23].

Mr Matthews left Colombo and arrived in Hong Kong in January 1895. Accompanied by the Director of Public Works and the Harbour Master, he visited the island on 3 January. In his report [23], he also proposed to build a new cylindrical tower, of 4.3 m internal diameter brickwork faced with granite, on the northern portion of the island. The one-storey quarters for three European keepers with a large tank underneath would be located on the lee side of the tower. The existing

tower and the block of the buildings butting thereon should be removed to the level of the ground floor in order to eliminate any obstruction to free exhibition of the new light. A second landing place, furnished with a derrick, should be erected to the southward of the existing landing place as difficulty and dangers were always encountered when landing on and departure from the island. The estimated cost of the construction work was $139 000.

Sir William Robinson, the Governor, referred the rebuilding plan to HKGCC. A committee of the chamber advised that it should be referred to the engineer in charge of the Chinese lighthouses. However, that engineer declined the job and the lighthouse was not rebuilt [23]. The idea of filling the eastern gap to ease the run of the sea therein had not materialized due to the difficulty in forming the toe on a slippery surface and in such an exposed position. The cost of such a slope including the formation of the toe could exceed the execution of the proposed work [23].

From 4 October until 5 October 1894, the rock was again hit by another typhoon. The sea was washing up to the buildings, the derrick was carried away and other damage was sustained [29]. However, the degree of damage was not comparable to that of the typhoon in 1893.

In 1906, one of the biggest typhoons reached Hong Kong and the windows failed to withstand the force, meaning that changing them became the only option. The submarine telegraph cable and the wireless cable tower were also damaged and changes were made accordingly [31].

During the Japanese occupation of the island in the late 1930s and the Chinese civil war in the 1940s, the lighthouse suffered severe damage from heavy bomdardment and intense gunfire [32]. The portion of the building above the water tank had been blasted off and the tank became exposed. The conditions of the lighthouse compound were observed and verified by the research team during the visits to the island.

As Gap Rock was included in the international network of weather reporting stations, HKCG attempted to restore the light soon after the Second World War [33]. In 1946, the Acting Inspector of Lights together with a senior officer of the Public Works Department inspected the lighthouse and estimated the necessary repair works [34]. HKCG insisted that agreement from China to repair the lighthouse should be obtained before work could start on site [35].

In 1947, the British Foreign Minister in Nanking, China, received the news from the Chinese Foreign Office that the lighthouse should be repaired but that works would be handled in a similar manner as it had been throughout the pre-war period. HKCG then ordered the light and related accessories from Sweden at a cost of $0.45 million. At one time, HKCG even considered offering the equipment and spare parts free of charge to China in order to speed up the commencement of the repair work [36]. However, the Ministry of Foreign Affairs replied on 12 April 1947 that 'the Lighthouse at Gap Rock is situated at an important position that its re-establishment seems to be necessary and that the matter will be dealt with by the Chinese Government themselves' [37].

In June 1986, after idling for more than four decades, some major repair and reinstatement work on the island was carried out by the Chinese Government [38]. A small reinforced concrete structure was erected for the installation of solar panels. The lantern room was reinstated and an automated light was installed. All window openings were blocked by bricks. On the northern portion, the original cook house was taken down and turned into a helipad. In 2011, the lighthouse was declared a heritage structure by the local authority of China. In 2017, the South China Navigation Security Centre in Guangzhou planned to reinstate and renovate the whole lighthouse compound, but the proposal has yet to be endorsed by the Central Government of China.

6. The typhoon and resulting damage in October 1893

(a) Description of the typhoon

Details of the 1893 typhoon that caused damage to the lighthouse are described next, as reported by the Hong Kong Observatory [39]:

1 October

10.18 The terrific typhoon passed over Bolinao in the Philippines early this morning and is now moving Northwest ward in the China Sea. The Black South Cone is hoisted indicating that the centre of a typhoon to the South is less than 480 km away from the colony [40]
10.40 The barometer reading is falling. The North wind is increasingly strong. The sea is rough and the weather is becoming bad
10.50 The vessels leaving the port except for the West ward would run at great risk
16.00 The gun fired one round—a strong gale of wind is expected to blow in the locality

2 October

6.00 The gun fired two rounds and a typhoon is expected in the locality
6.15 Typhoon is expected from Northeast to Southeast in Hong Kong

3 October

8.30 The Black Ball is hoisted, indicating a typhoon is approaching to the West of the colony

4 October

7.20 The Red Ball is hoisted, and the typhoon centre is more than 480 km away from the colony
11.10 The Red Ball is taken down

The Director of Hong Kong Observatory wrote about the typhoon in a letter dated 20 October 1893, to the Colonial Secretary [41]:

> Gap Rock was lying very near the track of worst typhoon that have been felt in the colony.
> The typhoon was one of exceptional severity at Gap Rock.
> It was blowing with very strong typhoon force shortly after noon on the 2nd October 1893, and lasted until midnight.
> The disaster was greatly intensified by the unusual great length of time the blow lasted.
> Reasons of the damage to the lighthouse:
> — Exposed position
> — Conformation of the sea bottom
> — Shape of the rock caused the sea to be much worse
> Damage done to the Lighthouse was due mainly to the sea and the wind. Lighthouses built by IMCS are not situated at such exposed position as the Gap Rock.

Though no direct measurement of wind intensity was taken on the island, the 5-day means of wind intensity observed in Hong Kong gives an impression of how strong the typhoon was when it clashed with the Island [42]. The maximum 5-day means of wind velocity each year observed in Hong Kong during the period of 28 September–2 October in year 1893 was 38.6 mph (Year 1893 Report of the Director of Hong Kong Observatory) and is the highest between 1885 and 1907, as shown in figure 10.

The maximum wind speed recorded on 2 October 1893 at the observatory was 81 mph which was confirmed lately by their staff. This does not give the exact magnitude of wind blowing at Gap Rock, 50 km away, yet its severity can be seen from figure 11 which shows the distribution of maximum wind speed from 1885 until 1907 [42].

As shown from figure 11, the wind speed recorded in 1893 is not the greatest but among the highest ones. The wind velocity recorded for the typhoon in October 1894 was even greater than the one in 1893, yet the damage was not comparable to the one 12 months previously. The wind

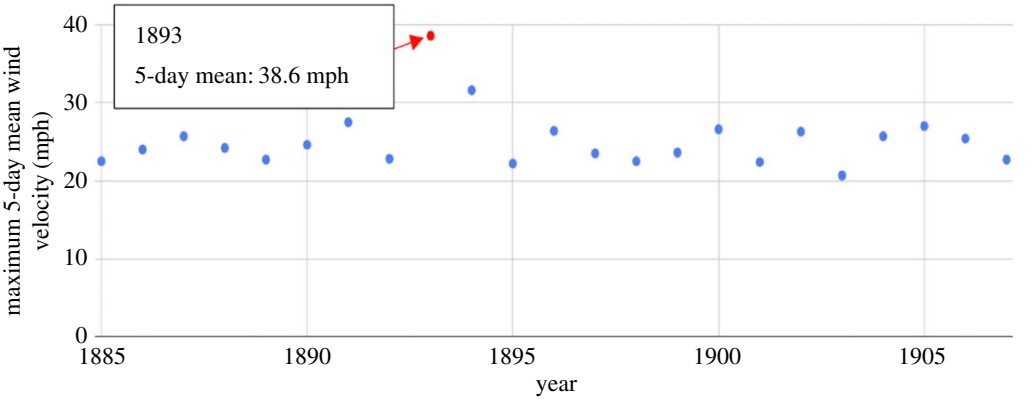

Figure 10. The maximum 5-day mean wind velocities 1885–1907. *Source*: Hong Kong Observatory Annual Report 1885–1907 [42]. (Online version in colour.)

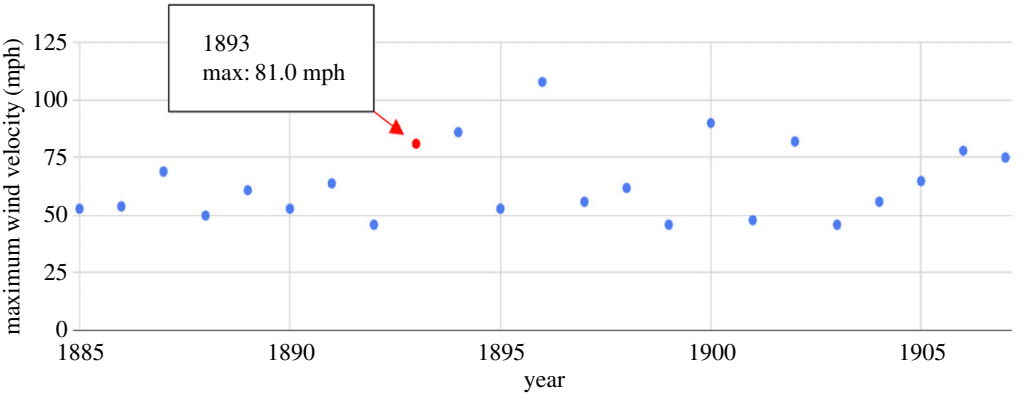

Figure 11. Maximum wind speed recorded at the Hong Kong Observatory or Gap Rock. *Source*: Hong Kong Observatory Annual Report (1885–1907) [42]. (Online version in colour.)

recorded in 1894 was blowing between northeast and southwest, within which the lighthouse compound was better shielded by the southwest ridge.

(b) Description of the damage

Charles Nicholas, the Senior Keeper, was on the island when the typhoon occurred. He recalled that the chief damage was noted at about noon on 2 October 1893 [23]. As four panels of lantern glazing were broken, subsequently a large quantity of water entered the tower. The maximum depth of water in the service room reached about 300 mm with a volume of 3 m^3. Unfortunately, two Chinese assistant lightkeepers and one labourer were trapped inside the service room and unable to open the door. The door was shut partly because of the wind, and partly because of the water and the broken glass against it. In response to the calls of the trapped lighthouse personnel, Charles Nicholas, who had just left the lantern room, broke the door panel in the service room in order to help them.

The two Chinese assistant lightkeepers in the lantern room saw a mass of water, not a solid wave, dashed against the lantern. Later, the lightkeepers carried out a careful search among the debris and found no foreign material was present inside the tower.

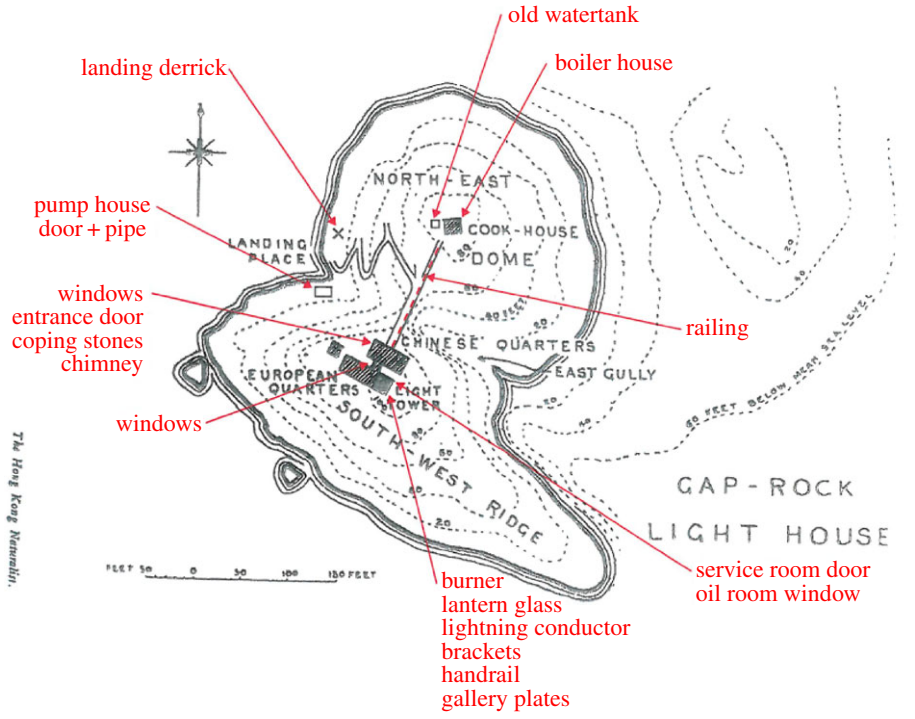

Figure 12. Typhoon damage to the lighthouse compound in October 1893. *Source*: Caption added to the contour map drawn by Gibbs [22]. (Online version in colour.)

The damage, listed in table 1 and indicated in figure 12, was recorded by the Director of Hong Kong Public Works Department [43] during the visit to the island with the Harbour Master on 11 October 1893.

7. Factors leading to breaking of the lantern glazing

(a) Process of breaking the lantern glazing

The original lantern glazing was shipped from the UK but without any record relating to the material properties. After the typhoon, portions of glass were found sticking in the frames all around the four broken panels, indicating that the glass though not its fixing to the frame was broken. As the metal framework was still intact, the damage could be a kind of shear failure in the glass. The lantern glass was a flat plate and weaker than the curved one in resisting the impact from the external source such as the dashing mass of water [23]. Based on the available reports, the process of breaking the lantern glass is listed in table 2.

(b) Factors leading to breaking of the lantern glazing

(i) Position

The island is situated at an exposed position and is the furthermost islet to the coast of the Pearl River (figure 1). There are no large islands nearby with hills of sufficient height as barriers to the wind and the sea. The nearest island, also rather small in size, is at least a mile away. The lighthouse, according to Director of Hong Kong Observatory, is located along the common tracks of tropical typhoon visiting South China [41].

Table 1. The damage recorded during the typhoon on 4 October 1893 [43].

estimated elevation above mean sea level (m)	location	description of the damage
4 m	West side of the Island	the landing derrick was carried away
4 m	West side of the Island	a short length of the land wire was displaced
4 m	pump house	the door and a 9 m long pipe were carried away
25 m	causeway	the railing on the eastern side was bent level with the ground
25 m	North of the Island	the old water tank was carried away
23 m	North of the Island	the boiler room and the door were broken
26 m	ground floor of lower building	the window of the telegraph office facing East, the entrance door facing North and the typhoon bar of the entrance door were broken
29 m	upper floor of lower building	the window in the bathroom and the Chinese quarters facing North and East were broken
32 m	roof of lower building	five coping stones and the chimney masonry work were damaged
26 m	upper building	salt water splashing onto the roof drained through the downpipe to the water tank at the basement.
30 m	stairway gangway	two small windows were broken
32 m	oil room	the eastern window was knocked in
35 m	service room	one panel indoor was broken and the room was flooding due to the water entering through the broken lantern glazing
39 m	lantern room	six brackets, three gallery plates and a portion of handrail in the gallery around the lantern were broken; one upper panel of the prism was broken and three bottom panels were slightly damaged; the burner was bent
43 m	lantern	three panes of 12 mm thick on the eastern side of the lantern were broken

Table 2. Process of breaking the lantern glazing.

process	evidence
the wind was from the East when the typhoon was at its height	log book record
a heavy sea wave was directed into the gulley	the funnel action was assisted by the spur and the gap
the sea broke 16 m below the base of the tower	witnessed by two Chinese assistant lightkeepers
the broken mass of water towered up into the air	assisted by the vertical slope of the Island and the vertical wall of the causeway
a portion of the water was carried by the wind force towards the lantern	witnessed by two Chinese assistant lightkeepers

(ii) Topography

The topography of the island and the surrounding sea bed is unique that a combination of the two would lead to the strong seas and wind hitting the lighthouse simultaneously.

Initially, there was no survey of the island until later the contour map drawn by Gibbs [22] (figure 1) indicated that the seabed was steep to the north of the southwest ridge. The sea wave would have been forced to move forward along the ridge face until reaching the east gully. The width of the gully diminishes with its height above the sea, and would serve as a funnel to the seas moving in the easterly direction.

(iii) Building construction

The buildings were made of brick and cladded with granite blocks. They provided the strong resistance to the external environmental loads. However, the windows and doors were initially not installed with iron bars, thus badly damaged by the wind.

(iv) Causeway

The causeway was built to provide a link between the tower buildings and the cook house. It was achieved by filling up a maximum height of about 5 m. This wall structure not just blocked the spilling over of the seas to the west landing place but also forced the seawater to rise vertically in front of the lighthouse buildings. Thus, the post construction landscape should be taken into account in assessing the environmental effect.

(v) Lantern glazing

While the strength of the 12 mm thick plane lantern glazing requires laboratory tests to confirm, the stronger 12 mm thick curved glazing should have been used to resist the environmental forces.

(vi) Typhoon

According to the reports of the Hong Kong Observatory, the typhoon hitting the lighthouse was not just severe but lasted a very long period of time.

8. Conclusion

The Gap Rock is a small remote island in the South China Sea. The island was well named because of the existence of a gap between its two parts.

The Island was chosen as the site for building the lighthouse in order to guide ships coming from the south. Since it is within the territory of China, it took decades to receive the agreement of the Imperial Qing Government to begin its construction.

The lighthouse tower and the ancillary buildings were made of brickwork with granite cladding. The buildings were strong against the environmental loads. However, many doors, windows, fixings and installations were badly damaged by a typhoon in October 1893, 18 months after the light was illuminated.

The severe damage to the lantern glazing was due to the strong seas, being forced into the gully at the east, directed up by the funnel action and deflected vertically by the side wall of the causeway. The mass of water, elevated by the wave, was blasted onto the lantern by the gale. The lantern glazing was a flat plate and proved unable to resist the impact force from the mass of the water. The consultants later found that the lighthouse was erected in the wrong part of the island, and the design was based on a site visit in the fine weather and the consideration of favourable conditions.

This case study serves to remind the present-day construction professionals of the importance of selecting a proper site in fulfilling the specific requirements of a lasting infrastructure, such as a lighthouse on rock, in an era anticipating the frequent impact of adverse weather effect.

Data accessibility. This article has no additional data.

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