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Archival Research, Underwater Optical Surveys, and 3D Modelling: Three Stages for Shaping the Wreck of the Steamship *Bengala* (Isola di Capo Rizzuto, Crotone, Italy)

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Abstract: *Bengala*, a steamer that sank in 1889 near Capo Rizzuto, Italy, was a relatively new vessel for its time, with an unusually short 18-year service life, given that steamers of the period typically operated for 30 to 40 years. Despite its brief history, *SS Bengala* played a significant role in the development of Italy's young merchant navy, undergoing multiple ownership changes and serving various Italian shipping companies. Employed mainly along the route to Southeast Asia, it transported Italian migrants overseas and also participated in troop raids during the Italian military expedition to Eritrea in 1887. Despite its historical significance, no iconographic material has yet been found to depict *SS Bengala*, and archival research conducted in Italy and England has not uncovered any naval plans, photographs, or drawings of the ship. To overcome this gap, the authors employed new technologies and historical information to create a virtual reconstruction. This research combined archival sources with underwater surveys, including a detailed 3D survey by divers and archaeologists. Archival research, including consultation of official documents, provided critical information on the ship's dimensions, superstructure, rigging, materials, and construction methods. The 3D modelling of the ship's external hull, based on precise geometric data from the wreck site, offers a first step towards virtual reconstruction. The modelling is grounded in photogrammetric surveying techniques, ensuring high accuracy in the reconstruction process. The model can be used in augmented reality (AR) applications to enhance underwater exploration, allowing divers to visualise the reconstructed ship in its original environment. Additionally, it supports museum exhibits, interactive visualisations, and educational games, making it a valuable resource for engaging the public with maritime history and archaeology.

Keywords: historic iron ship; maritime archaeology; shipwreck; steam-powered vessel and steamer; underwater heritage; underwater photogrammetry; 3D reconstruction

1. Introduction

The steamer *Bengala* foundered in May 1889 near Capo Rizzuto (Crotone, Italy) after being on duty for only 18 years. It was a fairly recent and technologically advanced vessel, for, at that time, the average service life of a steamer was estimated to be between 30 and 40 years [1] (pp. 286, 422) [2] (pp. 529–530). Yet, the few years in which she was on duty were troubled and full of events, as the steamship was re-flagged four times and renamed three times. From her launch at Sunderland's South Dock, where she was built and named as *SS Mecca*, she first was sold to the Genoese company Lloyd Italiano with the name *SS Livorno*, then to Rubattino & Co. with the name *Bengala*, and, finally, to the Navigazione Generale Italiana [3]. At a time when more than 90% of the Italian fleet was composed of sailing ships and the merchant steam fleet was growing very slowly to adapt to the logic of the large-scale maritime market [4] (p. 200) [5] (pp. 37–38) [6] (pp. 80–81) [7] (p. 332) [8] (pp. 247–255) [9] (pp. 85–86), *SS Bengala* has to be considered as a valuable testimony of the history of the young merchant navy of the Kingdom of Italy (*Regno d'Italia*). The short life of the steamer, with its changes of ownership and the numerous events that she lived through (such as the transport of part of the Italian troops for the military expedition to Eritrea in 1887), is of great importance because it is intimately connected to the historical and commercial parables of some of the most important Italian shipping companies of the time, made up of rapid growths and sudden declines (Figure 1).

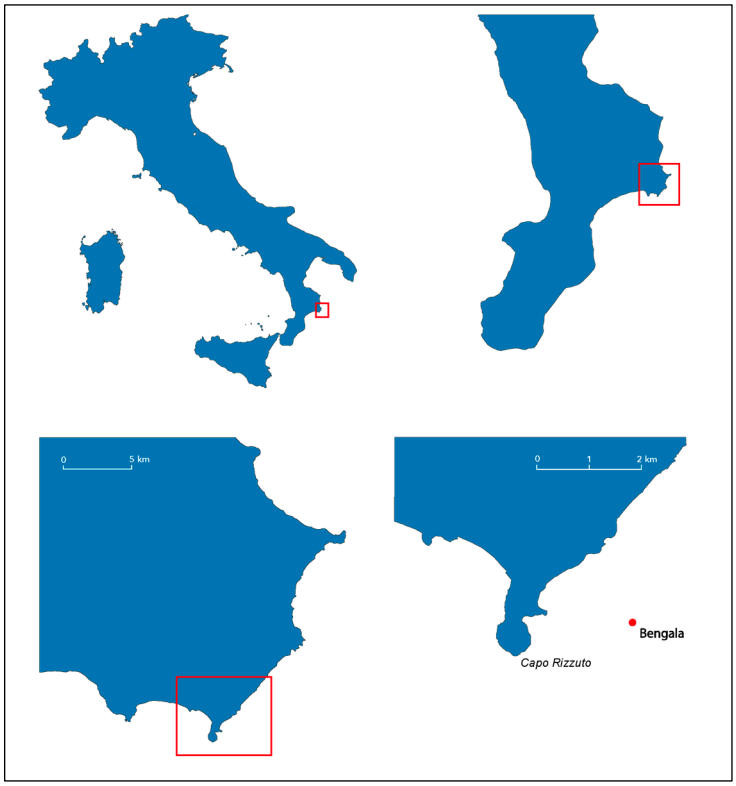


Figure 1. Wreck location on maps (elab. S.M.).

Despite the undoubted historical interest of this steamer, we did not find any iconographic material that would allow one to define its looks and its features. Archival research

was mainly undertaken in Italy and England and so far did not yield any naval plan, photograph, painting, or drawing depicting the steamer. In the hope that further research might fill this gap, we have attempted to put a face on the steamer by means of new technologies combined with the fair amount of available historical information.

Archival research—not entirely concluded, but already described by the authors in this journal in 2020 [3]—has been complemented by underwater surveys and findings. A complex and detailed three-dimensional survey conducted by divers and a comprehensive set of direct observations of the site made by archaeologists have created an initial documentary base of notable quality. In fact, optical surveys with centimetre-level accuracy stand as a very flexible instrument, capable not only of providing a whole set of data for the protection of the submerged site (for example, the state of preservation of iron structures inevitably subject to disintegration) [10,11], but also allowing for the acquisition of elements that are fundamental for the reconstruction of the ship and of the processes acting on the wreck in the post-depositional stage [12,13].

For the purposes of this work, geometric parameters resulting from underwater surveys are the 'single source of truth' for virtual reconstruction. As demonstrated by a consolidated methodology applied to underwater surveys on wrecks [14–17], 3D modelling can be very accurate due to the constraints given by the wreck remains, which, although sometimes randomly scattered on the seabed, have been carefully analysed, interpreted, and digitally reconstructed by means of photogrammetric surveying. Therefore, 3D modelling is the last step of a process in which nothing has been left to chance: the few lost elements that cannot be reconstructed—neither on the archaeological nor on the historical documentary level—have been hypothesised on the basis of the naval technology of the iron steamers of the time.

The outcome of this research, namely the 3D reconstruction of the external structure of the hull, should not be considered as a conclusive result in itself. Several case studies (see, for example, [18,19]) have demonstrated how a 3D reconstruction could become a means of enhancement and promotion if connected to augmented exploration systems or virtual reality devices aimed to offer semi-immersive and immersive experiences.

2. Materials and Methods

2.1. Historical Background

Ordered by R. Milbanke Hudson Junior at the shipyards of Messrs Iliff, Mounsey, and Co. at Sunderland's South Dock, Yard No. 48, the iron steamer *Mecca* was launched on 6 May 1871 [20] (p. 4) [21] (p. 365) and registered on 7 July 1871 with the official number 62626 in the *Register of Shipping* of the HM Customs and Excise registers for the Port of Sunderland [9] (pp. 893–895).

SS Mecca was a "hybrid" vessel. It was set up to be a freighter and a carrier for passenger transport at the same time, as she was equipped with a mixed propulsion with steam and sails. In the year of her launch, *SS Mecca* moved first to Liverpool, where it received the A1 class in red [3] (p. 896) [20] (p. 4), and then, under the command of Captain F.B. Denton, made only one journey to Calcutta in July 1871. During the return journey, the steamer did not go back to England, but she landed first in Leghorn and then, in December of the same year, in Genoa [3] (pp. 896–897 with references).

At this point, less than a year after her launch, the steamer *Mecca* was purchased by Lloyd Italiano, a shipping company based in Genoa that had been founded a few months earlier (October 1871) [22] (pp. 90–91). With the change of ownership—of which there is a trace in the general register of British ships, i.e., the *Appropriation Books of the Registrar General of Shipping and Seamen* of Cardiff on 2 January 1872 [23]—the steamer was renamed *Livorno*. The new Genoese company was building its fleet and did not limit itself to the sole

purchase of *SS Mecca*, but acquired four other English steamers between 1871 and 1872 [3] (pp. 898–899). Under her new flag, the steamer *SS Livorno* (former *SS Mecca*) sailed mainly to Southeast Asia along the Genoa–Calcutta route, taking advantage of the opening of the Suez Canal since 1872.

Due to a series of financial losses, worsened both by the lack of subsidies from the Kingdom of Italy and by the sinking of two steamers, the *Firenze* and the *Genova*, on 26 September 1876, the Lloyd Italiano company was dissolved and put into liquidation by the Italian Court of Commerce after just six years from its foundation [24] (pp. 146–147). At this point, what remained of the Lloyd Italiano fleet—namely *SS Livorno*, the *Roma*, and the *Torino*, for a total estimated value of ITL 2,150,000—was purchased by R. Rubattino, who was then head of Rubattino & Co., the second most important shipping company in the Kingdom of Italy [25] (p. 187, note 64) [26] (p. 92). With her new owner, the steamer changed its name once again and became *SS Bengala* [27] (p. 11) [22] (p. 91) [3] (p. 901). The new name was likely inspired by the fact that the steamer was mainly used on the West Bengal route, with terminals in Genoa and Calcutta and stopping places in Leghorn, Naples, Catania, Port Said, Aden, Colombo, and Bombay [26] (p. 96, note 1). However, this was not the only route of the steamer under the flag of Rubattino: in fact, it was also assigned to the connection between Genoa and Singapore (and sometimes Batavia) with other ports of call, among which the one in Marseilles stood out for its importance [3] (p. 902).

In September 1881, the two largest shipping companies in the Kingdom of Italy, Rubattino & Co. and Florio, based in Palermo, merged in the "Navigazione Generale Italiana. Flotte riunite Florio e Rubattino" (N.G.I.). With a nominal capital of ITL 50,000,000 and a fleet of 81 steamships—which became 109 in 1885—NGI was considered the second largest shipping company operating in the Mediterranean Sea [25] (pp. 241–251) [28,29] (pp. 33–36). After the merger, *SS Bengala* was sold by Rubattino to Navigazione Generale Italiana [22] (p. 91).

In the years that followed, *SS Bengala* was assigned to the route to Singapore and, in some instances, to New York and Latin America (Buenos Aires, Montevideo, and Rio de Janeiro) for the transportation of the then numerous Italian immigrants [30] (p. 1040) [31] (p. 1406) [32] (p. 1523). Meanwhile, in May 1886, the steamer was transferred from the maritime authority of Genoa to that of Palermo, where, in the following years, it was mainly used along the Marseilles–Genoa–Trieste route, touching numerous minor ports in the Tyrrhenian, Ionian, and Adriatic seas [33] (p. 174). An exception to this route is the journey that she took in 1887 when, after being requisitioned with compensation by the Italian government, it was part of the military convoy heading for Massawa, Eritrea, which left Naples under the command of General A. Asinari di San Lorenzo [34] (pp. 101, 103).

In May 1889, during a weekly scheduled journey between Trieste and Marseilles for transporting goods and travellers, after having stopped in Taranto and before being able to dock at Catanzaro Marina, the *SS Bengala*, captained by F. Rosasco, foundered near Capo Rizzuto, south of Crotone. On that last voyage, the steamer was carrying various goods, including wine, coffee, sugar, olive oil, flour, and much more. The steamer was not able to avoid a large shoal dotted with rocky shallows while trying to fight against a strong south-westerly wind. The impact caused a large gash in the keel towards the bow, which caused the hull to lean on the starboard side and to sink from the bow sector in a very short time. During the shipwreck, the third engineer and a waiter–cook lost their lives. The other 38 crew members and the few passengers on board survived thanks to the lifeboats and the intervention of the *Mamma Chiara*, a sailing ship based in Taranto that happened to be nearby ([3], with references). The sinking was promptly reported in the 1890 *Lloyd's Register of British and Foreign Shipping* [35] (no. 259), and it was reported by several newspapers (for

some examples, see forward), as well as by the General Director of the Merchant Navy, G. Comandù, in the annual report on the conditions of the Merchant Navy [36] (p. 138).

2.2. The Shipwreck Site and the Remains of the Steamer

The metal remains of the wreck lie between 22.4 and 28.6 m deep, 0.8 nautical miles from the coast in front of Capo Bianco, a little NE of Capo Rizzuto, on a slightly sloping seabed composed of sand and not very prominent calcarenitic rocks. This area is located on a small terrace that occupies the outer edge of a steep and large rocky platform, to which the shoals that caused the sinking of the steamer belong. The hull is oriented along the NW–SE axis and rests with the keel on the bottom, in the same position as it was while navigating [3] (p. 907 ff.).

The current state of preservation of the wreck is largely the result of post-shipwreck events, i.e., the use of explosives for fishing (Figure 2).

Fortunately, this deplorable and illegal technique has been abandoned for decades. The use of explosives was mainly responsible for the collapse of the broadsides, which also led to the consequent collapse of elements of the main deck and the superstructures. On both the starboard and port sides, the broadsides are warped outwards in pieces that follow the morphology of the seabed and sometimes reach considerable lengths, as in the case of the eastern section, which is 34 m long (Figure 2, n. 10). The only area of the wreck where the broadside has collapsed inwards is the port bow area. Always on the left side, both near the amidship line and the stern portion, there are two sections of the broadside that are still preserved in situ to a significant height.

Starting from the SE end, a large section belonging to the stern main deck can be seen lying on the seabed, lacking continuity with the rest of the hull. The well-preserved structure clearly shows the elliptical shape of the transom of which the sheers, some portions of the deck beams, and the longitudinal girders are visible (Figure 2, n. 24).

A short distance away, there is the main piece of the hull, the remains of which seamlessly continue up to the bow. The stern sector is well preserved from the keel to the quarters; at the end, the rudder post is rising almost 8 m from the seabed (Figure 2, n. 25). The dudgeons, the aperture, and the three-bladed propeller are still in place and aligned with the drive shaft. The quarters' structure, densely divided by frames and girders, is clearly visible (Figure 3).

Twelve metres SE from the stern post, near the remains of a collapsed and laid-out condenser, there is the Admiralty stern anchor (Figure 2, n. 5). A little forward, there is the stern winch, torn off and leaning towards the port side, with the mast deck collar from which the wooden main mast protruded onto the main deck (Figure 2, n. 20). The circular mast step of the latter was placed just above the drive shaft and lies a little further on in the N direction (Figure 2, n. 26).

The collapsed piece of the broadside on the port side of the stern sector is 26 m long and is preserved up to the bulwark, with some stanchions of the hand rail still in place on the deck stringer plate (Figure 2, n. 11); at the bottom, hinged to the stringer, there are the bitts with slightly spread shafts and the in-line fairleads (Figure 2, n. 7). On the opposite broadside, there is at least one fixed, circular porthole (Figure 2, n. 22).

Returning to the main piece of the hull, and precisely to the amidship line, on the port side, there are the mechanisms of the steam propulsion: condensers, boilers, steam domes, and the engine with the connecting rods for the service pumps (Figure 2, n. 12–14, 17–19; Figure 4).

Continuing towards the bow, the configuration of hull elements becomes more chaotic and is less well preserved. This clearly indicates that the wreck has suffered the greatest damage in this sector. Nonetheless, even in this portion of the wreck, some elements provide precious information about the technical and structural features of the steamer.

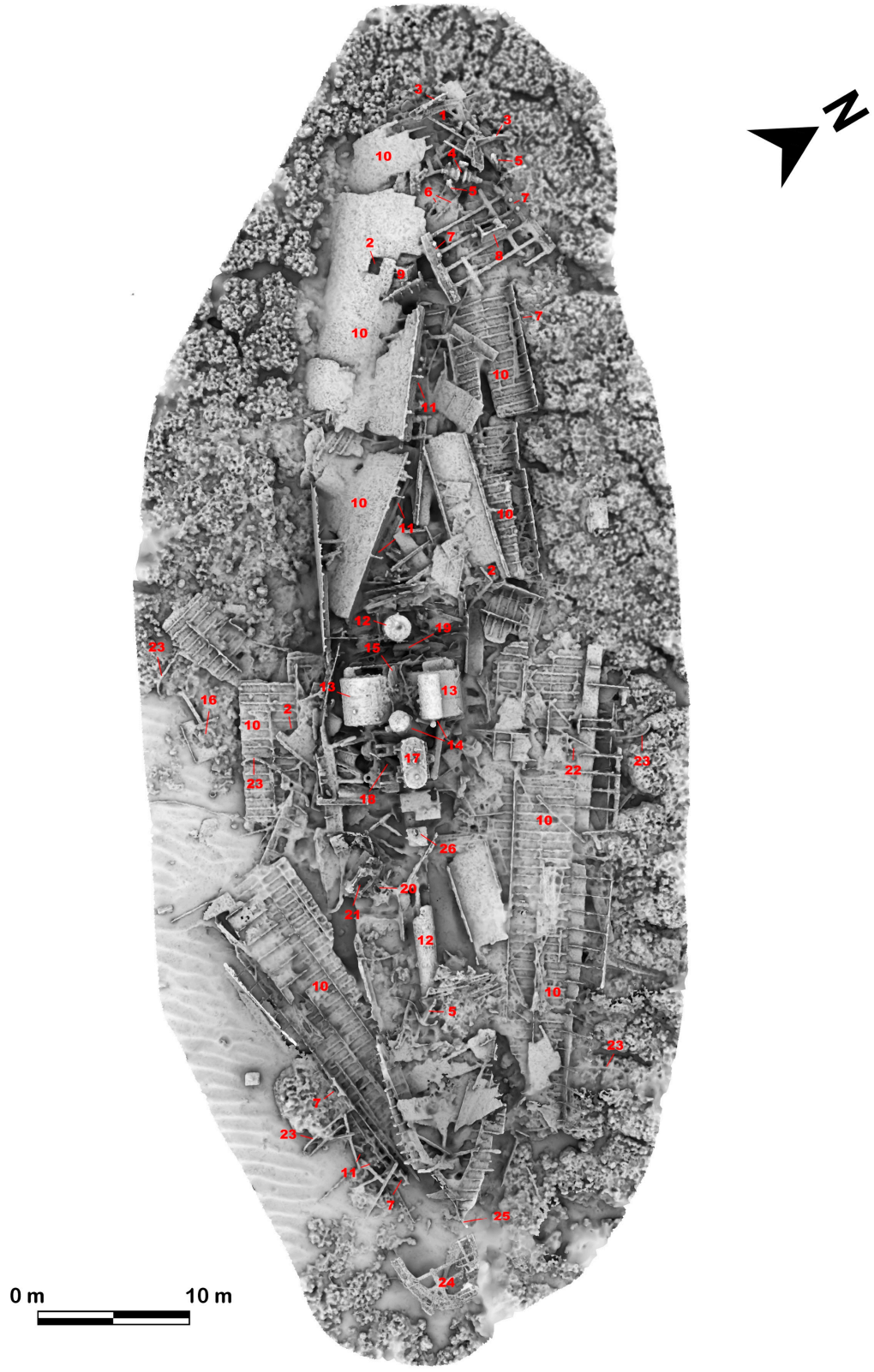


Figure 2. Plan view of the wreck taken from the 3D ambient occlusion map. 1. Bow; 2. door; 3. anchor davit; 4. anchor windlass; 5. anchor; 6. anchor cable; 7. bitt; 8. bow windlass; 9. accommodation ladder door; 10. hull; 11. stanchions; 12. condenser; 13. boilers; 14. steam dome; 15. hatch of 16; 16. shell (side) door; 17. engine; 18. connecting rods; 19. engine room ventilator; 20. mast deck collar (?); 21. windlass; 22. porthole; 23. boat davits; 24. stern; 25. stern post; 26. mast step (?). Elab. S.M.

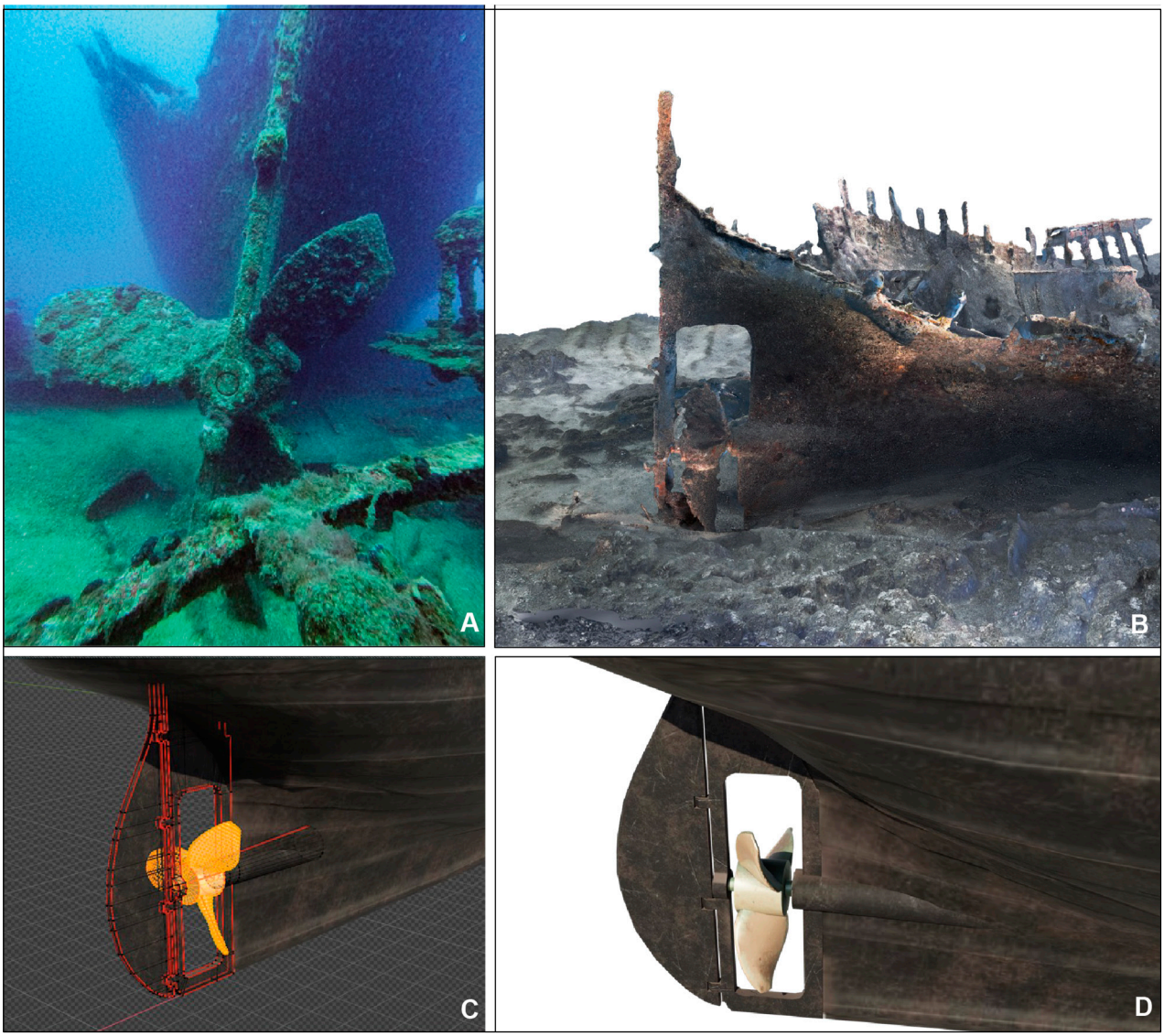


Figure 3. The rudder post and the propeller shaft well. (**A**): an underwater image of the three-blade propeller, (**B**): the 3D survey mesh, (**C**,**D**): the propeller editing in the 3D model (elab. R.P. and S.M.).

Figure 4. Wreck sector with remains of the steam propulsion system. Images extracted from the 3D survey mesh (elab. M.C. and F.F.).

First of all, we must take into account the aforementioned portions of the broadsides that collapsed inwards (Figure 2, n. 10) and are preserved up to the sheers and up to the height of the hand rail (as indicated by some stanchions and, on the stringer, by the bitts

and fairleads still in place) (Figure 2, n. 7, 10). A further detail of these pieces of the port side is the presence of the rectangular openings pertaining to the ship doors, the shell side door with an arched upper frame, and the gangway (Figure 2, n. 2, 9, 16). On the terminal segment of the wreck, there is a displaced part of the main deck structure whose tapering shape is clearly shown by the framework composed of the beams and the longitudinal girders edged by the deck stringer plate. On the sides of the latter, there are bitts and fairleads of the same type as those found in the stern sector (Figure 2, n. 7). On the beams of the deck structure, there is a displaced capstan winch, leaning on its side and equipped with the heavy plate that fixed it on the deck (Figure 2, n. 8). Three metres forward, there is the anchor windlass with chains coming from the chain locker still in tension, wrapped around the gipsy wheels and reaching first the hawse pipes and then the Admiralty bow anchors with a square shank (Figure 2, n. 4–6).

The final pieces of evidence relating to the hull are the pointed bow structure (Figure 2, n. 1) and two arched davits that are still standing (Figure 2, n. 3). Other chocks for supporting the lifeboats, more slender and longer than the others, are present in several points of the wreck, both on the port and starboard sides (Figure 2, n. 23).

2.3. Underwater Optical Survey

The underwater optical survey of the *SS Bengala* steamer wreck represented a pivotal phase in the development of a high-resolution dataset for 3D reconstruction and analysis. This stage required meticulously planned imaging workflows, optimised to address the specific challenges posed by the site's environmental and structural conditions. The survey combined advanced optical and photogrammetric techniques to ensure the production of scientifically robust and spatially accurate results.

The *SS Bengala* wreck lies at a depth of approximately 22 to 28 m, spanning a substantial area on a slightly sloping seabed. The extension of the site, combined with its depth, introduced significant logistical and technical challenges to conducting the survey. Additionally, the wreck is located in a region characterised by strong underwater currents, which further complicated the fieldwork. These environmental factors demanded careful planning and adaptive field strategies to ensure the integrity and accuracy of the data collection process.

To support the planning and scheduling of survey activities, a bathymetric map of the site was utilised. This map served as the basis for dividing the site into four primary working areas, each assigned to specific teams for systematic coverage. The subdivision facilitated an organised approach to data acquisition, ensuring the efficient allocation of resources and minimising redundancy.

Prior to image collection, 30 markers were strategically placed throughout the site to establish a robust geodetic network. These markers, distributed across the working areas, provided the framework for scaling and referencing the photogrammetric models. In particular, precise measurements of the marker positions were taken and a geodetic network was established through the application of a direct survey method (DSM). This network ensured centimetre-level accuracy and provided a critical reference system for aligning the photogrammetric data [37] (Figure 5).

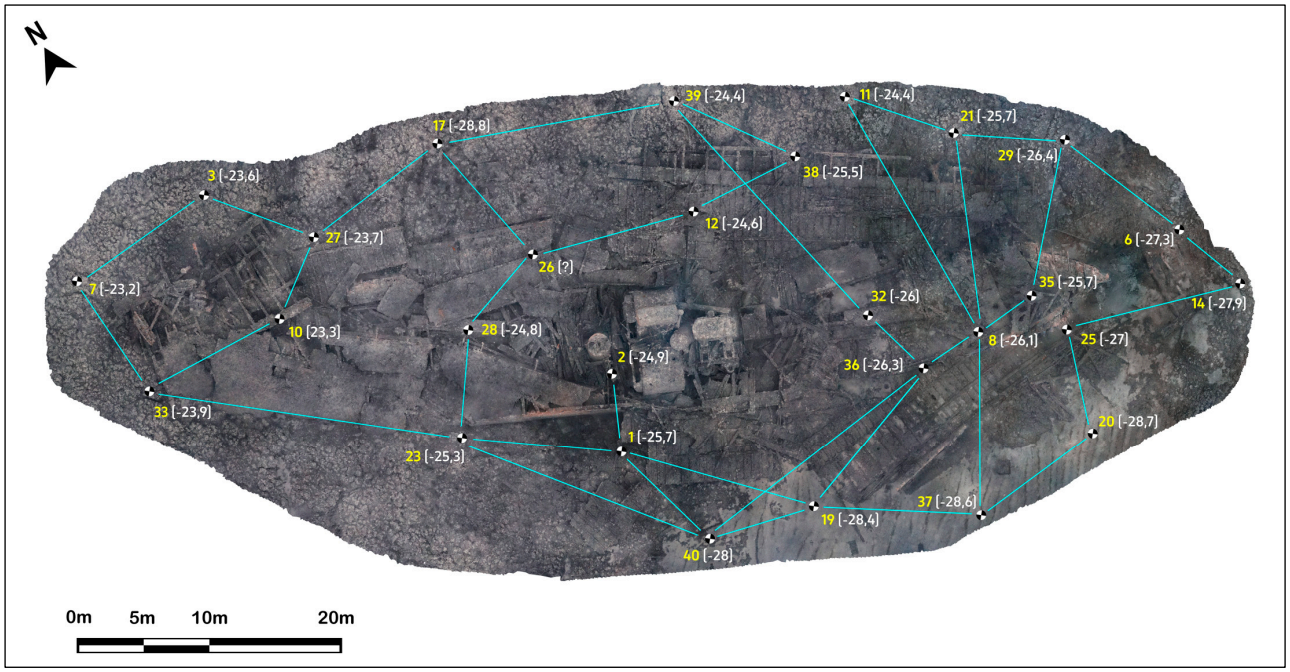


Figure 5. The network of ground control points displayed on the wreck orthophoto. The markers' identification numbers are shown in yellow; depth is indicated in white; cyan lines represent the measurement of the linear distance between two points (elab. F.F. and S.M.).

The survey was conducted over five working days by two specialised teams, each tasked with documenting distinct sections of the wreck. The workflows were tailored to address the complexities of the site. The first team focused on the hull and other vertical components of the wreck.

Employing a spin-around technique, the team captured overlapping images from multiple angles, ensuring comprehensive coverage of these challenging features. The second team concentrated on the bridge and deck, utilising a traditional photogrammetric approach. Images were captured in strips with 70–80% forward overlap and 50% side overlap, maintaining consistency in coverage and resolution.

Both teams relied on Sony A7III mirrorless cameras, featuring 24.3 MP full-frame sensors, equipped with Sony 14 mm f/1.8 GM lenses. These cameras were housed in Easydive Leo3 Wi cases with spherical 160 mm dome ports, ensuring waterproofing and optical clarity. Illumination was provided by Easydive Revolution 15,000 video lights, delivering consistent lighting conditions and reducing the effects of light absorption and scattering.

The imaging workflows maintained an average ground sample distance (GSD) of approximately 0.075 cm/pixel, enabling the precise documentation of fine structural details. Despite these technical preparations, strong currents often disrupted operations, requiring additional stabilisation measures and occasional re-collection of images to maintain dataset quality (Figures 6 and 7).

Figure 6. Three-dimensional underwater model: top view mesh (elab. M.C., F.F. and A.L.).

Figure 7. Three-dimensional underwater model: oblique view of the wreck captured from the north (elab. M.C., F.F. and A.L.).

3. Results

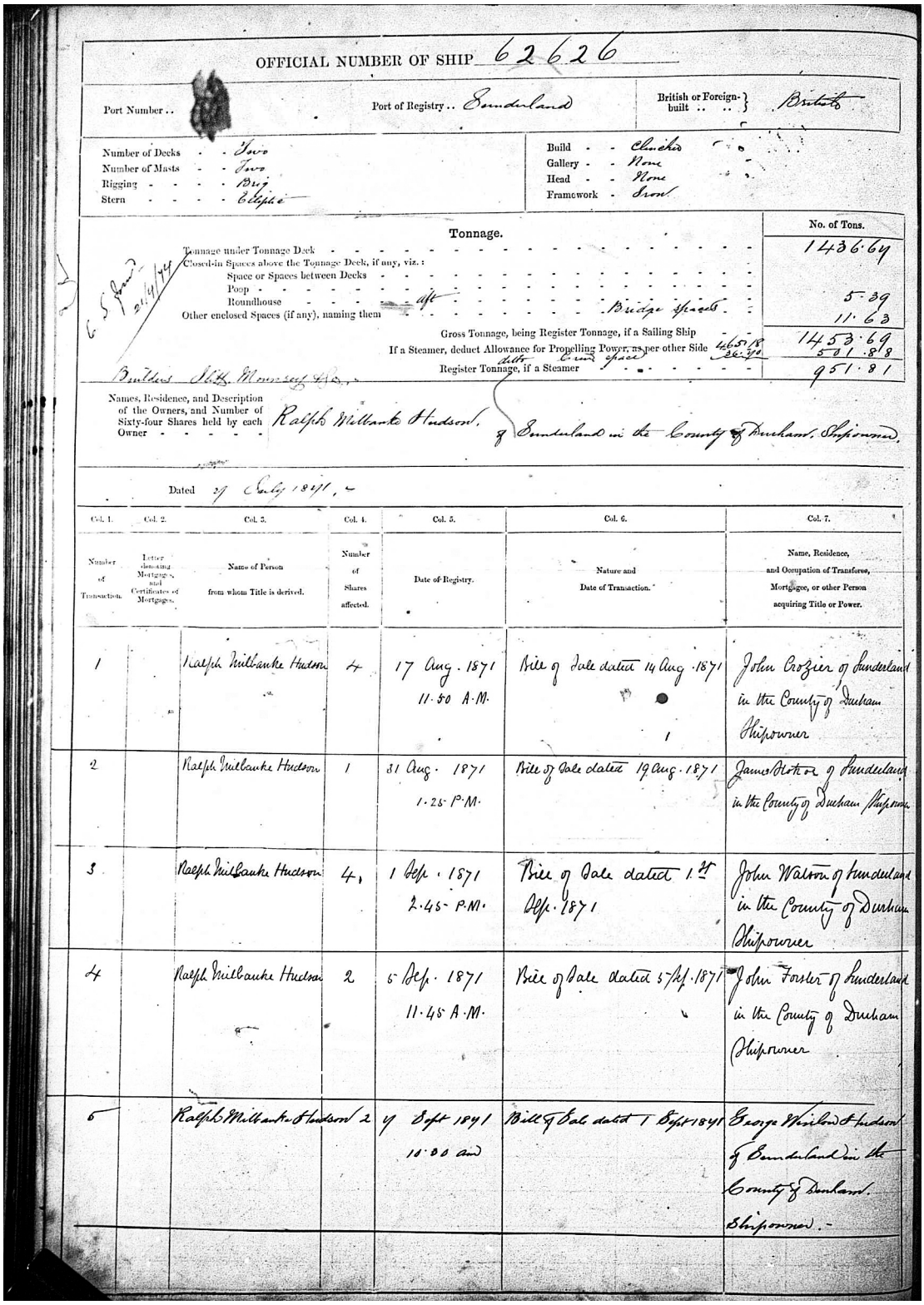
3.1. Technical and Metric Data About the Steamer Taken from Documentary Sources

A whole series of technical–constructional data helped to drive the 3D reconstruction of the steamer. The information was obtained from various documentary sources, summarised below.

Among the documents in our possession, the most precious one is preserved in the Tyne & Wear Archives & Museums in Newcastle. These are two sheets filled out by hand on 7 July 1871, part of the volume that collects the documentation relating to the HM Customs and Excise registers for the Port of Sunderland produced between June 1870 and June 1872 [38]. The document in question, i.e., the *Register of Shipping* of *Mecca*, made up of two pages, clarifies that it was a "Steam Ship" and was powered by propellers [38] (Figures 8 and 9).

Concerning the measurements of the hull, its "length from the forepart of the stem under the bowsprit to the aft side of the head of the sternpost" was 246 feet and 1 tenths (75.01 m).

It had a maximum beam ("main breadth to outside of plank") of 31 feet and 4 tenths (9.57 m) and a "depth in hold from tonnage deck to ceiling at midship" of 24 feet and 3 tenths (7.41 m) [38] and [3] (p. 894, Figure 3).



OFFICIAL NUMBER OF SHIP 62626

Port Number .. Port of Registry .. Sunderland British or Foreign-built .. .. } British

Number of Decks - - Two
Number of Masts - - Two
Rigging - - - - Brig
Stern - - - - - Elliptic

Build - - Clinched
Gallery - - None
Head - - None
Framework - Iron

Tonnage.

	No. of Tons.
Tonnage under Tonnage Deck	1436.64
Closed-in Spaces above the Tonnage Deck, if any, viz.:	
Space or Spaces between Decks	
Poop	5.39
Roundhouse aft	11.63
Other enclosed Spaces (if any), naming them Bridge spaces	
Gross Tonnage, being Register Tonnage, if a Sailing Ship	1453.69
If a Steamer, deduct Allowance for Propelling Power, as per other Side 465.18 36.70 Engine space	501.88
Register Tonnage, if a Steamer	951.81

Builders Messrs Mounsey & Co

Names, Residence, and Description of the Owners, and Number of Sixty-four Shares held by each Owner - - - - - Ralph Millbanke Hudson of Sunderland in the County of Durham Shipowner.

Dated 29 July 1871.

Col. 1. Number of Transaction.	Col. 2. Letter denoting Mortgages, and Certificates of Mortgages.	Col. 3. Name of Person from whom Title is derived.	Col. 4. Number of Shares affected.	Col. 5. Date of Registry.	Col. 6. Nature and Date of Transaction.	Col. 7. Name, Residence, and Occupation of Transferee, Mortgagee, or other Person acquiring Title or Power.
1		Ralph Millbanke Hudson	4	17 Aug. 1871 11.50 A.M.	Bill of Sale dated 14 Aug. 1871	John Crozier of Sunderland in the County of Durham Shipowner
2		Ralph Millbanke Hudson	1	31 Aug. 1871 1.25 P.M.	Bill of Sale dated 19 Aug. 1871	James Potter of Sunderland in the County of Durham Shipowner
3		Ralph Millbanke Hudson	4,	1 Sept. 1871 2.45 P.M.	Bill of Sale dated 1st Sept. 1871	John Watson of Sunderland in the County of Durham Shipowner
4		Ralph Millbanke Hudson	2	5 Sept. 1871 11.45 A.M.	Bill of Sale dated 5th Sept. 1871	John Forster of Sunderland in the County of Durham Shipowner
5		Ralph Millbanke Hudson	2	7 Sept 1871 10.00 am	Bill of Sale dated 7 Sept 1871	George Whitwell Hudson of Sunderland in the County of Durham. Shipowner.

Figure 8. Document with the official registration of *Mecca* steamer. HM Customs and Excise, Newcastle Customs House, Register of shipping (Sunderland), June 1870–June 1872, EX.SU/1/43 (1008). By permission of Tyne and Wear Archives.

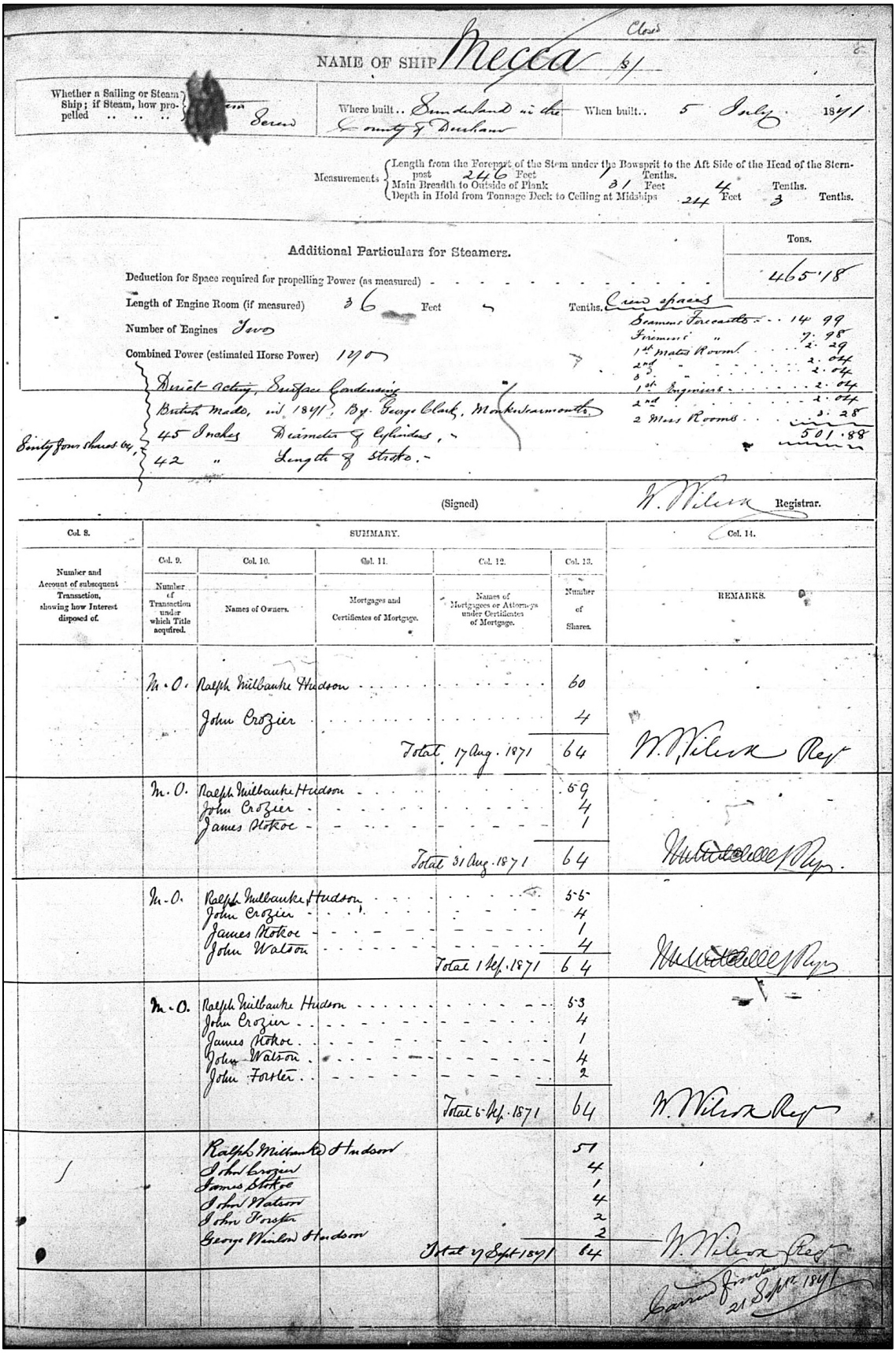
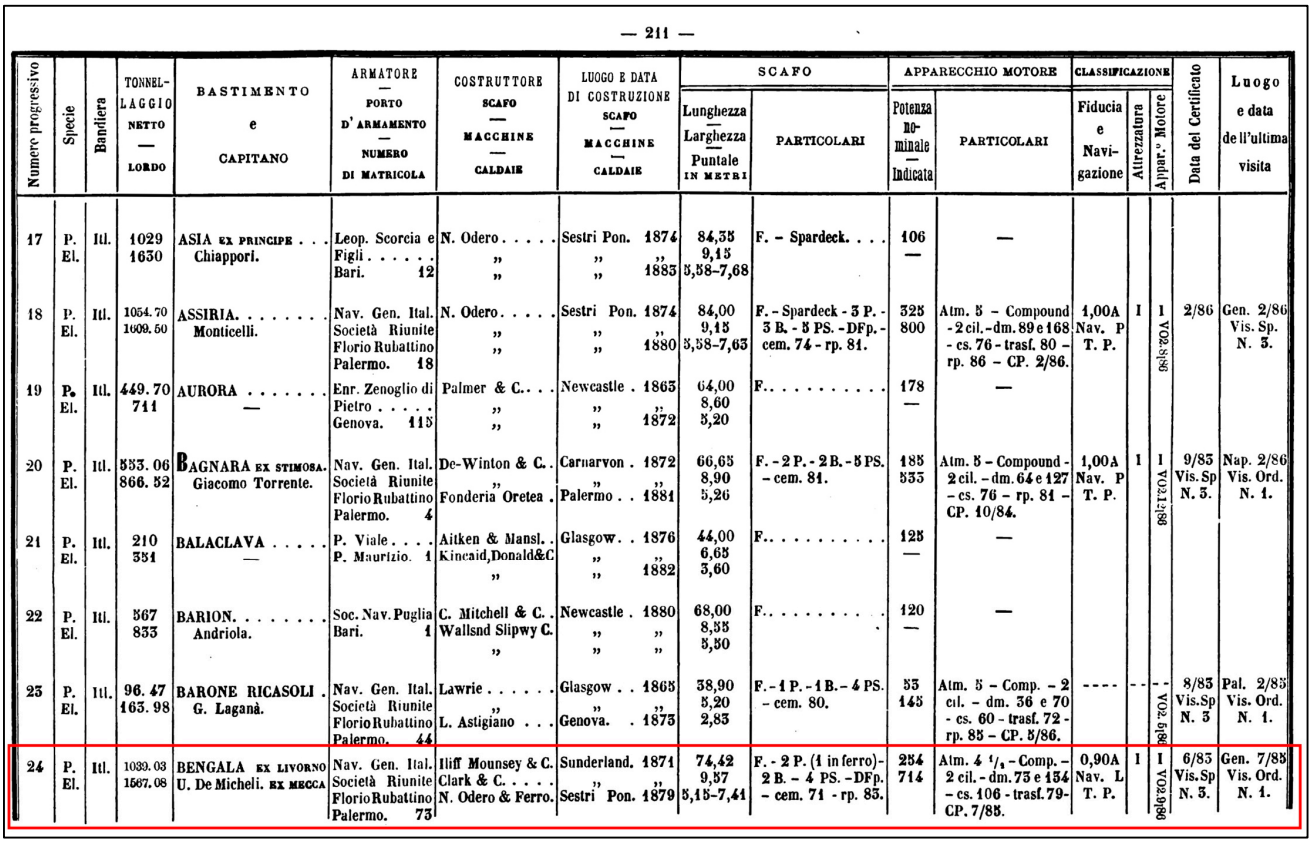


Figure 9. Document with the official registration of *Mecca* steamer. HM Customs and Excise, Newcastle Customs House, Register of shipping (Sunderland), June 1870–June 1872, EX.SU/1/43 (1009). By permission of Tyne and Wear Archives.

These data, although with small discrepancies, are confirmed by two newspaper articles of the time announcing the launching of the steamship on May 6. The first, dated 10 May 1871, appeared in *North & South Shields Gazette and Daily Telegraph*, which stated that it was "a large iron screw-steamer, 260 feet long, 32 feet beam, and 24 feet 6 inches depth of hold, about 1500 tons register" [20] (p. 4); the second, dated 26 May 1871, was published by *The Mechanics' Magazine*: "On the Wear Messers. Cliff, Mounsey and Co., have launched an iron-screw steamer 260 ft. long, 32 ft. broad, and 22½ ft. in depth; 1500 tons register" [21] (p. 365). In the *The Merchant Navy List and Maritime Directory* of 1872, we find the following measurements: 246.1 (length), 31.4 (breadth), and 24.3 (depth of hold) [39] (p. 52). These measures are the same as those reported a few years later in the *Record of American and Foreign Shipping* of 1885 (when the steamer was captained by A. Gavino): "Length" (from the foreside of the stem to the afterside of the stern post, measured on the range of the main deck) 246; "breadth" (to be measured over the frames at the widest part) 31.4; "Depth" (to be measured from the upper side of the floors to the under side of the main deck in vessels with two tiers beams; and to the under side of the upper deck in those having more than two tiers) 24.3 [40] (p. 217) [3] (p. 906, Figure 11).

In the *Registro Italiano per la Classificazione dei Bastimenti*, published in Genoa in 1887, when the steamer had already taken the name *SS Bengala*, the measurements are reported as 74.42 m (length) and 9.57 m (width) [41] (p. 211). This document also contains another metric-constructional information of great interest: it states that the depth to be measured from the upper part of the floors (of the depth required by rule) to the top of the upper deck beam amidships was of 5.15–7.41 m [41] (p. 211, n. 24). This last piece of data clarifies that the height between the two decks—the lower deck made of iron and the upper deck made of wood—was 2.26 m (Figure 10).



— 211 —

Numero progressivo	Specie	Bandiera	Tonnellaggio netto — lordo	Bastimento e capitano	Armatore — porto d'armamento — numero di matricola	Costruttore scafo — macchine — caldaie	Luogo e data di costruzione scafo — macchine — caldaie	Scafo: Lunghezza — Larghezza — Puntale in metri	Scafo: particolari	Apparecchio motore: Potenza nominale — Indicata	Apparecchio motore: particolari	Classificazione: Fiducia e Navigazione	Classificazione: Altrezzatura	Classificazione: Appar.° Motore	Data del Certificato	Luogo e data de l'ultima visita
17	P. El.	Itl.	1029 1630	ASIA ex PRINCIPE . . . Chiappori.	Leop. Scorcia e Figli . . . . . Bari. 12	N. Odero . . . . . „ „	Sestri Pon. 1874 „ „ 1885	84,35 9,15 5,58-7,68	F. - Spardeck. . . .	106 —	—					
18	P. El.	Itl.	1054.70 1609.50	ASSIRIA. . . . . Monticelli.	Nav. Gen. Ital. Società Riunite Florio Rubattino Palermo. 18	N. Odero. . . . . „ „	Sestri Pon. 1874 „ „ 1880	84,00 9,15 5,58-7,63	F. - Spardeck - 3 P. - 3 B. - 3 PS. - DFp. - cem. 74 - rp. 81.	325 800	Atm. 5 - Compound - 2 cil. - dm. 89 e 168 - cs. 76 - trasf. 80 - rp. 86 - CP. 2/86.	1,00A Nav. P T. P.	I	I Vol. 2/86	2/86	Gen. 2/86 Vis. Sp. N. 3.
19	P. El.	Itl.	449. 70 711	AURORA . . . . . —	Enr. Zenoglio di Pietro . . . . . Genova. 115	Palmer & C. . . „ „	Newcastle . 1865 „ „ 1872	64,00 8,60 5,20	F.	178 —	—					
20	P. El.	Itl.	333. 06 866. 52	BAGNARA ex STIMOSA. Giacomo Torrente.	Nav. Gen. Ital. Società Riunite Florio Rubattino Palermo. 4	De-Winton & C. . „ Fonderia Oretea .	Carnarvon . 1872 „ „ Palermo . . 1881	66,65 8,90 5,26	F. - 2 P. - 2 B. - 5 PS. - cem. 81.	185 535	Atm. 5 - Compound - 2 cil. - dm. 64 e 127 - cs. 76 - rp. 81 - CP. 10/84.	1,00A Nav. P T. P.	I	I Vol. 2/86	9/85 Vis. Sp N. 3.	Nap. 2/86 Vis. Ord. N. 1.
21	P. El.	Itl.	210 351	BALACLAVA . . . . . —	P. Viale . . . . P. Maurizio. 1	Aitken & Mansl. . Kincaid, Donald & C „	Glasgow. . 1876 „ „ „ 1882	44,00 6,63 3,60	F.	125 —	—					
22	P. El.	Itl.	367 833	BARION. . . . . Andriola.	Soc. Nav. Puglia Bari. 1	C. Mitchell & C. . Wallsnd Slipwy C. „	Newcastle . 1880 „ „ „ „	68,00 8,35 5,30	F.	120 —	—					
23	P. El.	Itl.	96. 47 163. 98	BARONE RICASOLI . G. Laganà.	Nav. Gen. Ital. Società Riunite Florio Rubattino Palermo. 44	Lawrie . . . . . „ L. Astigiano . . .	Glasgow . . 1868 „ „ Genova. . 1873	38,90 5,20 2,83	F. - 1 P. - 1 B. - 4 PS. - cem. 80.	53 145	Atm. 5 - Comp. - 2 cil. - dm. 36 e 70 - cs. 60 - trasf. 72 - rp. 85 - CP. 5/86.	----	- -	- - Vol. 5/86	8/85 Vis. Sp N. 3	Pal. 2/85 Vis. Ord. N. 1.
24	P. El.	Itl.	1039. 03 1567. 08	BENGALA ex LIVORNO U. De Micheli. ex MECCA	Nav. Gen. Ital. Società Riunite Florio Rubattino Palermo. 73	Iliff Mounsey & C. Clark & C. . . . . N. Odero & Ferro.	Sunderland. 1871 „ „ Sestri Pon. 1879	74,42 9,57 5,15-7,41	F. - 2 P. (1 in ferro) - 2 B. - 4 PS. - DFp. - cem. 71 - rp. 85.	254 714	Atm. 4 1/2 - Comp. - 2 cil. - dm. 73 e 134 - cs. 106 - trasf. 79 - CP. 7/85.	0,90A Nav. L T. P.	I	I Vol. 2/86	6/85 Vis. Sp N. 3.	Gen. 7/85 Vis. Ord. N. 1.

Figure 10. The section dedicated to *SS Bengala* in the 1885 *Registro Italiano per la Classificazione dei Bastimenti.* From [41] (p. 211, n. 24).

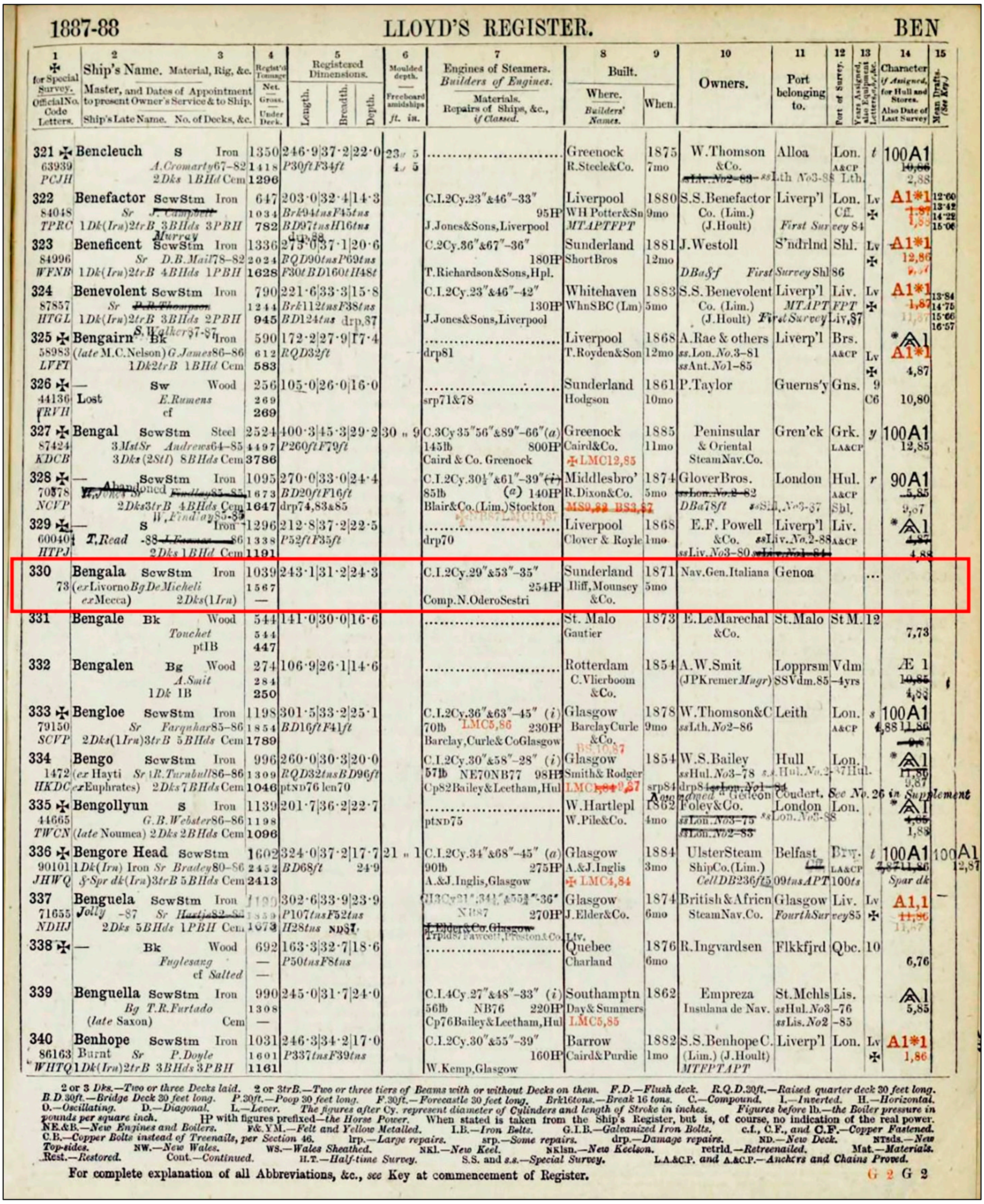
In the *Register of Shipping*, it is also reported that the steamer had an iron framework and it was equipped with two decks, two masts with a brig rigging, and an elliptical stern. The fact that it was clinker-built is of great interest as well [38]. This technique provided that "the plates of adjacent strakes were lapped over each other, and the edge-riveting passed through both thick-ness" [42] (p. 181). According to the same source, the *Register of Shipping*, she had a tonnage under deck of 1436.67 tons, to which, adding the 5.39 tons of the roundhouse and the 11.63 tons pertaining to "other closed spaces", we obtain a gross tonnage of 1453.69. After deducting 456.18 tons of propelling machinery space and 36.70 tons of crew space, for a total of 501.88 tons, we obtain a net tonnage of 951.81 tons [38].

A series of precious handwritten elements present in the Sunderland register contain further information to better detail how the 36.70 tons of crew spaces were articulated: 14.99 for seamen for the castle, 7.98 for firearms, 2.99 for the first mates room, 2.4 for the second mates room, 2.04 for the third mates room, 2.04 for the first engineer, 2.04 for the second engineer, and 3.28 for both mess rooms [38].

The tonnage data, although rounded, are also confirmed by other registers: the *Appropriation Books of the Registrar General of Shipping and Seamen of Cardiff* (net: 951) [23] (n. 62626) [3] (p. 898, Figure 6), *The Merchant Navy List and Maritime Directory* of 1872 (net tonnage; gross tonnage 1454) [39] (p. 52), the *Lloyd's Register of British and Foreign Shipping* of 1876–1877 (net: 952, gross: 1454, under deck: 1437) [43] (n. 511), of 1883–1884 (net: 952, gross: 1454, under deck: 1437) [44] (n. 308), of 1885–1886 (net: 952, gross: 1454, under deck: 1437) [45] (n. 311), and, finally, the *Record of American and Foreign Shipping of 1885* (net: 952, gross: 1454) [40] (p. 217, n. 329). The *Lloyd's Register* of 1886–1887 [46] (n. 319) and that of 1887–1888 [47] (n. 330) and the Report from the General Director of the Merchant Navy, dated December 1889 and addressed to the Minister of the Navy, B. Brin [36] (pp. 71, 376), report a net tonnage of 1039 and a gross tonnage of 1567. These values could be due to some modifications, unknown at present, which could have impacted on the disposition of the steamer (Figure 11).

With regard to the tonnage data, it should be noted that two handwritten notes by the Sunderland Register Officer in May 1871 provide us with further elements for reconstructing the appearance of the steamer. The first concerns the aforementioned roundhouse, to which the note "aft" is added by hand, so it was certainly placed in the stern sector; the second is related to the enclosed spaces as well—specifically the 11.63 tons mentioned above—and concerns the presence of a "bridge space" [38]. The latter, slightly more than double the size of the roundhouse, was clearly an enclosed space intended for passengers, most likely in the centre of the ship.

From a section called "Additional Particulars for Steamers" of the *Register of Shipping*, we learn that the engine room was 36 feet long and that there were two engines, built in 1871 by G. Clark of Sunderland, with a 170 nominal horse power engine, twin cylinder, 45-inch bore, and 42-inch in stroke [38]. It must be noted that this direct-acting engine built by the naval engineer Clark is not the one currently visible on the wreck. In fact, in 1879, it was replaced with a new and more powerful compound engine of 254 NHP built by the shipyards N. Odero & Ferro of Sestri Ponente (Genoa) [48] (p. 705) [33] (p. 174) [3] (p. 902). With the repowering of the engine, it was therefore necessary to adapt the machines for a higher steam pressure, which now had to deal with a compound twin cylinder with 73 and 134 cm bore and 106 cm of stroke [41] (p. 211, n. 24). The engine replacement was recorded in the naval registers, including the *Lloyd's Register* of 1886–1887 [46] (n. 319) and the one for 1887–1888 [47] (n. 330), which list the following data regarding the two cylinders: 2Cy.29"&53"-35", 254 HP.


1887-88 LLOYD'S REGISTER. BEN

No.	Ship's Name	Material	Tonnage	Dimensions	Engines	Built, Where	When	Owners	Port belonging to	Character
321	Bencleuch	S Iron	1350	246·9/37·2/22·0		Greenock, R.Steele&Co.	1875	W.Thomson &Co.	Alloa	100A1
322	Benefactor	ScwStm Iron	647	203·0/32·4/14·3	C.I.2Cy.23"&46"–33" 95HP J.Jones&Sons,Liverpool	Liverpool, WH Potter&Sn	1880	S.S.Benefactor Co. (Lim.) (J.Hoult)	Liverp'l	A1*1
323	Beneficent	ScwStm Iron	1336	275·0/37·1/20·6	C.2Cy.36"&67"–36" 180HP T.Richardson&Sons,Hpl.	Sunderland, ShortBros	1881	J.Westoll	S'ndrlnd	A1*1
324	Benevolent	ScwStm Iron	790	221·6/33·3/15·8	C.I.2Cy.23"&46"–42" 130HP J.Jones&Sons,Liverpool	Whitehaven, WhnSBC (Lm)	1883	S.S. Benevolent Co. (Lim.) (J.Hoult)	Liverp'l	A1*1
325	Bengairn	Bk Iron	590	172·2/27·9/17·4		Liverpool, T.Royden&Son	1868	A.Rae & others	Liverp'l	A1
326	— (Lost)	Sw Wood	256	105·0/26·0/16·0		Sunderland, Hodgson	1861	P.Taylor	Guerns'y	
327	Bengal	ScwStm Steel	2524	400·3/45·3/29·2	C.3Cy 35"56"&89"–66" 800HP Caird & Co. Greenock	Greenock, Caird&Co.	1885	Peninsular & Oriental SteamNav.Co.	Gren'ck	100A1
328	— (Abandoned)	ScwStm Iron	1095	270·0/33·0/24·4	C.I.2Cy.30½"&61"–39" 140HP Blair&Co.(Lim.)Stockton	Middlesbro', R.Dixon&Co.	1874	GloverBros.	London	90A1
329	—	S Iron	1296	212·8/37·2/22·5		Liverpool, Clover & Royle	1868	E.F. Powell &Co.	Liverp'l	A1
330	Bengala (exLivorno ex Mecca)	ScwStm Iron	1039	243·1/31·2/24·3	C.I.2Cy.29"&53"–35" 254HP Comp.N.OderoSestri	Sunderland, Iliff, Mounsey &Co.	1871	Nav.Gen.Italiana	Genoa	
331	Bengale	Bk Wood	544	141·0/30·0/16·6		St. Malo, Gautier	1873	E.LeMarechal &Co.	St.Malo	
332	Bengalen	Bg Wood	274	106·9/26·1/14·6		Rotterdam, C.Vlierboom &Co.	1854	A.W.Smit	Lopprsm	Æ 1
333	Bengloe	ScwStm Iron	1198	301·5/33·2/25·1	C.I.2Cy.36"&63"–45" 230HP Barclay,Curle&CoGlasgow	Glasgow, BarclayCurle &Co.	1878	W.Thomson&C	Leith	100A1
334	Bengo (ex Hayti ex Euphrates)	ScwStm Iron	996	260·0/30·3/20·0	C.I.2Cy.30"&58"–28" 98HP Cp82Bailey&Leetham,Hul	Glasgow, Smith& Rodger	1854	W.S.Bailey	Hull	A1
335	Bengollyun (late Noumea)	S Iron	1139	201·7/36·2/22·7		W.Hartlepl, W.Pile&Co.	1862	Foley&Co.	London	A1
336	Bengore Head	ScwStm	1602	324·0/37·2/17·7	C.I.2Cy.34"&68"–45" 275HP A.&J.Inglis,Glasgow	Glasgow, A.&J.Inglis	1884	UlsterSteam ShipCo.(Lim.)	Belfast	100A1
337	Benguela	ScwStm Iron	1190	302·6/33·9/23·9	270HP	Glasgow, J.Elder&Co.	1874	British&Afrien SteamNav.Co.	Glasgow	A1,1
338	—	Bk Wood	692	163·3/32·7/18·6		Quebec, Charland	1876	R.Ingvardsen	Flkkfjrd	
339	Benguella (late Saxon)	ScwStm Iron	990	245·0/31·7/24·0	C.I.4Cy.27"&48"–33" 220HP Cp76Bailey&Leetham,Hul	Southamptn, Day&Summers	1862	Empreza Insulana de Nav.	St.Mchls	A1
340	Benhope	ScwStm Iron	1031	246·3/34·2/17·0	C.I.2Cy.30"&55"–39" 160HP W.Kemp,Glasgow	Barrow, Caird&Purdie	1882	S.S.BenhopeC. (Lim.) (J.Hoult)	Liverp'l	A1*1

For complete explanation of all Abbreviations, &c., see Key at commencement of Register.

Figure 11. A page from the *Lloyd's Register of British and Foreign Shipping* of 1887–1888 with the section dedicated to *SS Bengala* highlighted in red. From [48] (n. 330).

With regard to the structure of the ship, the *Registro Italiano* specifies that the two bridges were plated and that only one of them (the inferior) was made of iron. We also learn that the steamer had four watertight bulkheads and that the hull (i.e., the bottom plating, the frames, and the rivet heads, up to a height above that prescribed for the close ceiling), after having been covered with cement (most likely Portland) in 1871, was covered again in 1883 [41] (p. 211, n. 24). Curious is what appears in the *Record of American and Foreign Shipping* of 1885, where the decks are listed as three (perhaps due to the counting of

the bilge covering flooring?). In this document, the four bulkheads and the two compounds are confirmed [40] (p. 217, n. 329).

As reported by the *North & South Shields Gazette and Daily Telegraph* of 10 May 1871 [20], and confirmed some years later by A. Nattini, director of the company "Lloyd Italiano" [49] (p. 569, Table I), the surveyors of Lloyd's Register of Ships in Liverpool, following the stringent Rules for Iron Ships, awarded the steamer *Mecca* the Ships Classed A in red certification, valid for 18 years. The *Shipping and Mercantile Gazette* of 12 July 1871 recalls how the steamer was equipped with "very superior accommodation for passengers" [50]. The ship could carry as many as 28 passengers in first class and 260 in third class [36] (p. 376) [33] (p. 174) [3] (p. 892). Moreover, the free space on the open deck reserved for passengers was 105.50 square metres and the total number of third-class passengers potentially aboard was 936 in the summer (from 1 April to the end of October), of which 345 were on the open deck, 317 in the corridors, and 274 in other spaces, such as the quarter-decks, deckhouses, and holds. Between November 1 and the end of March, the total number of third-class passengers dropped to 591 [36] (p. 379).

According to the *Registro Italiano per la Classificazione dei Bastimenti* of 1887, the *Bengala* received the A90 Class just two years before the sinking [41] (p. 211, n. 24). This grade of trust was not worthy of the highest class (the 1.00 A), which was usually assigned for the overall quality of the hull, materials, equipment, engine room, etc. Taking into account that the steamer in 1887 was already 16 years old, we can deduce that her overall conditions were still rather good.

A final technical note pertains the consumption of coal needed to power the steam engines. The data reported by the Lloyd Italiano company in 1879 (when the steamer was equipped with the new compound) indicate that the ship's weight capacity, including the coal supply, was 1900 tons and that the capacity of the holds was 88,000 P.C. We also know that, at an average speed of 9 ½ nautical miles per hour, it consumed 72 kg of coal per mile and 16 tons in 24 h [49] (p. 569, Table 1).

3.2. Three-Dimensional Reconstruction of Underwater Site

During the survey, the two teams captured a total of 7330 high-resolution images to document the *SS Bengala* wreck comprehensively. All images were saved in RAW format (.arw, specific to Sony cameras) to preserve maximum detail and allow for extensive post-processing. Despite the use of video lights during data acquisition, the underwater environment introduced challenges such as light absorption, scattering, and colour distortion. Post-processing techniques were applied to recover accurate white balance, enhance contrast, and minimise artifacts caused by caustic phenomena, ensuring optimal image quality for reconstruction.

The 3D reconstruction process began with a structure-from-motion (SfM) workflow performed using Agisoft Metashape Pro. This step generated a sparse 3D point cloud from the captured images. A local metric coordinate system, based on a network of ground control points (GCPs), was implemented to scale and georeference the reconstruction. GCPs were integrated into the SfM process, and a non-linear optimisation strategy was applied to adjust both camera poses and intrinsic parameters, minimising errors at the GCP coordinates. The resulting sparse point cloud achieved a root-mean-square error (RMSE) of 0.02 m for ground coordinates, ensuring spatial accuracy across the model.

Following the sparse reconstruction, a multi-view stereo (MVS) algorithm was used to generate a dense 3D point cloud, refining the intrinsic and exterior orientations of the cameras based on the GCP network. The dense point cloud consisted of 435.647 million points, providing a detailed representation of the wreck's geometry. Meshing and texturing processes were then applied, resulting in a 3D model with 7.664 million polygons.

To ensure the model's usability and integrity, further corrections were performed using Blender. Blender was utilised to clean the model by removing noise, smoothing artifacts, and addressing geometric inconsistencies. Additionally, Blender was employed to close holes in the mesh, refine edges, and rectify surface irregularities caused by incomplete data capture. These steps ensured the creation of a watertight mesh, making the model suitable for further analysis, visualisation, and archival purposes.

4. Discussion

Hypothetical Reconstruction of the SS Bengala: Documentation and Data Collection

The use of three-dimensional modelling for the scientific reconstruction of historical hulls is increasingly popular, as demonstrated by various case studies, such as the very recent examples of *Batavia* [51], *HMS Falmouth* [52], *Barge Crowie* [53], or *HMCS/HMAS Protector* [54].

Regarding our investigation, the reconstructed 3D model will be used for a serious game, so many geometric details that could have been included through mesh modelling were recreated here through texturing and shading. In fact, a relatively low level of polygons allows us to use the model with game engines.

The software used for modelling is Blender. It is "the free and open source 3D creation suite. It supports the entirety of the 3D pipeline—modeling, rigging, animation, simulation, rendering, compositing and motion tracking, even video editing and game creation" (https://www.blender.org/about/ accessed on 22 December 2024). Substance 3D Painter by Adobe was used for texturing, as it offers the tools needed to define the texture of 3D resources.

So far, the reconstruction has been limited to the exterior of the ship and includes the hull, the upper deck, the superstructures, the masts, and the rigging. Without the original plans, the reconstruction of the internal and structural parts of the steamer implied that too many elements would have been left to the imagination and would therefore be unreliable. Many reconstructive choices are based, of course, on what has been possible to verify from similar and contemporary models to the *Bengala*, namely steamships with brig rigging of English production, whose features are known thanks to photographs, naval plans, or other iconographic materials that have fortunately been preserved (Figures 12 and 13).

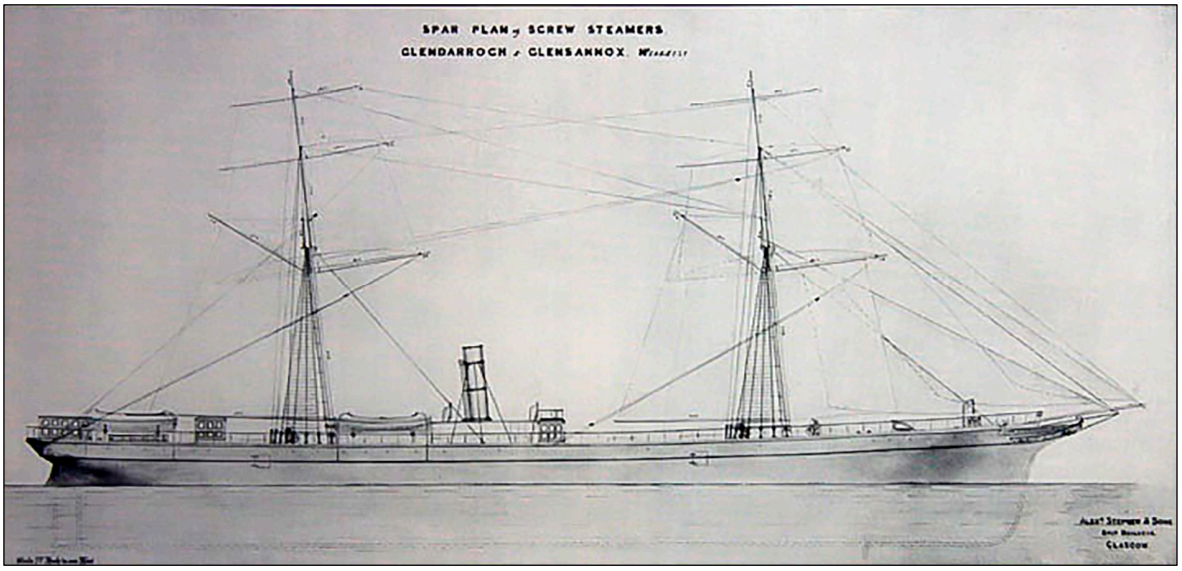


Figure 12. Spar plan of the *SS Glendarroch*, whose caption reads: "A steamer of 1509 tons for Wm, Ross & Co., the first ship at Linthouse, in 1870". From [55] (p. 66).

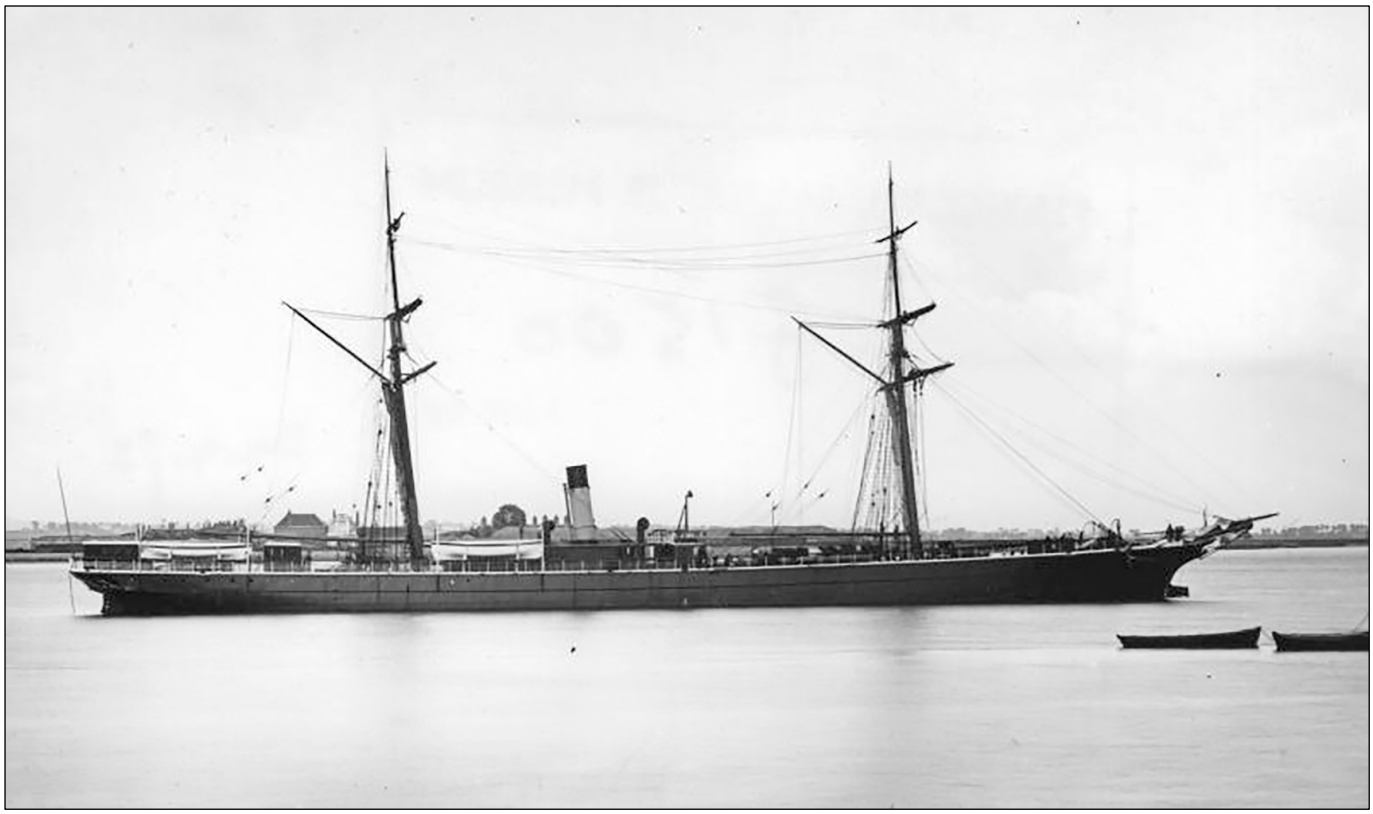


Figure 13. Photo of the *SS Atjeh* (ex *Glendarroch*). GRT: 1509; NRT: 954; 3 decks; length: 272.3 feet; breadth: 33.1 feet; draft: 24.2 feet; built: Stephen, Glasgow, November 1870; class: 100A1. Unknown date. From [56].

The first phase was the modelling of the hull (Figures 14 and 15). It should be noted that the main dimensions of the hull, both the transverse and the vertical ones (depth in hold from tonnage deck to ceiling at midship), did not pose any problems as they were well known (see Section 3.1).

As for the shape of the hull, no difficulty was encountered in reconstructing the stern and the bow. The elliptical stern sector is preserved from the keel to the quarters, with the rudder post and the screw aperture. The bow structure is well preserved; coming up to the breast hook, it becomes very sharp. This detail has been faithfully reproduced in the model.

The line that followed the iron hull on the wheel, and further up on the cutwater and on the post, has been hypothesised on the basis of the hulls of the same type, shape, and age, i.e., with propellers and brig-rigged. For both the quickworks and the topside, the rendering features the clinker-built technique. The sides were therefore designed with overlapped outside planting and fixing rivets.

On the topside, some rectangular scuttles have been placed on the sides, whose dimensions were deducted from the remains of the wreck's bulwarks preserved on both sides of the hull.

Figure 14. Three-dimensional model of the steamship *Bengala*: front views of the bow and stern (elab. R.P.).

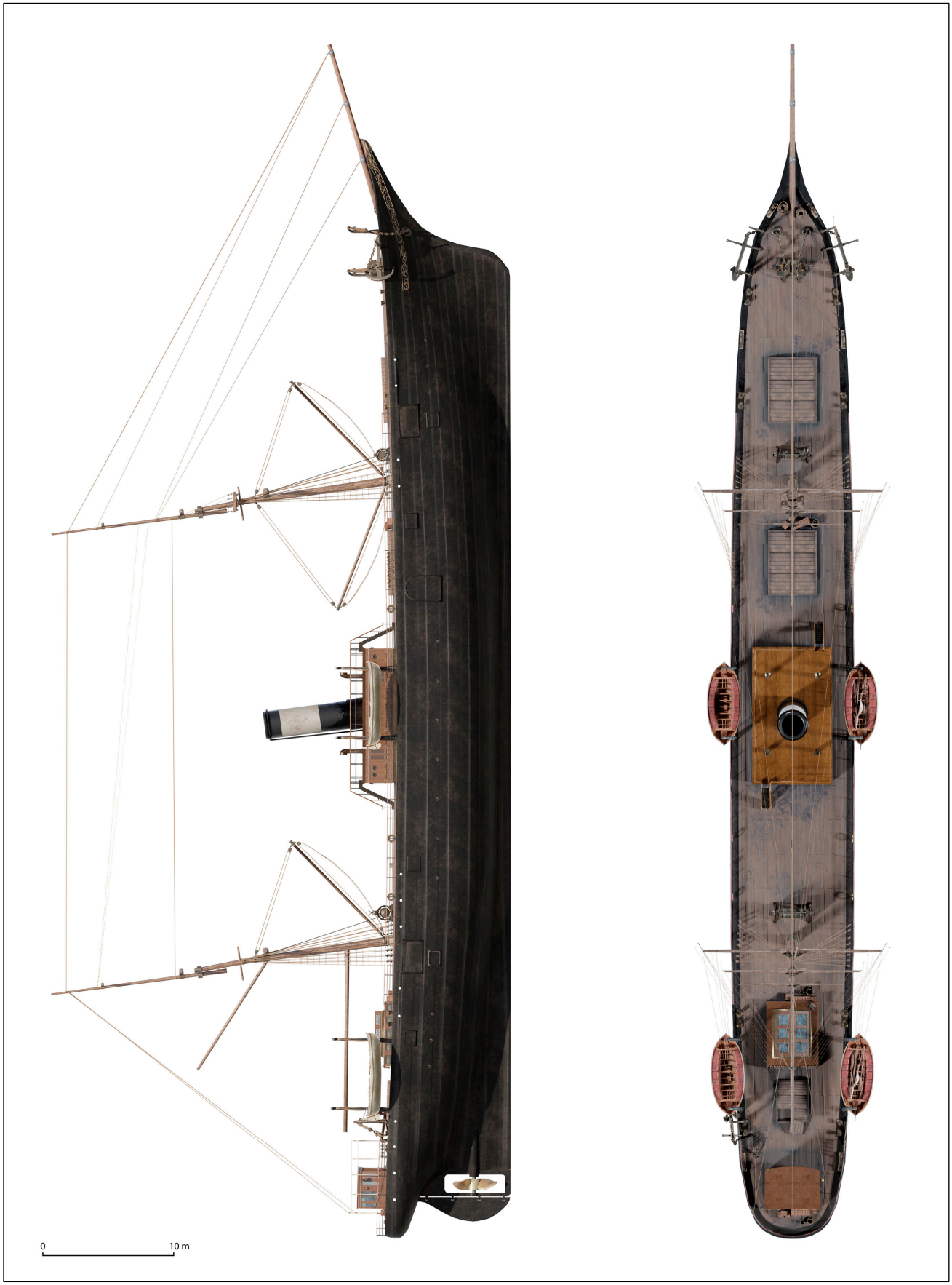


Figure 15. Three-dimensional model of the steamship *Bengala*: Top view and side view (elab. R.P.).

The upper deck has been covered with longitudinally running wooden planks that stop at the height of the painting stringers. Where present, bitts and fairleads were fixed to the latter, and their modelling is perfectly identical to the submerged remains. Similarly, the stanchions of the hand rail were hinged onto the painting stringers. Their spacing and height can be deducted from several preserved places on the wreck.

Based on the information in the Sunderland *Register of Shipping* about the superstructures, on the upper deck, there are two enclosed spaces: the aft roundhouse and a larger passenger cabin amidships [38]. They were modelled in wood according to the techniques of the time, taking inspiration from a wide array of photographic and iconographic comparisons. The roundhouse obviously featured large windows as it served as a command room, while, on top of it, we placed a sort of awning with a metal frame, as it was common at the time (Figure 16).

Figure 16. Three-dimensional model of the steamship *Bengala*: view of the stern with the roundhouse and the canopy above (elab. R.P.).

The passenger cabin of first class, which houses the chimney and some ventilation funnels, features two ladders on the short sides as in the majority of late 19th century vessels. On the upper deck, we have also placed three large hatchways for the passage of goods into the holds or for providing access to other internal spaces (Figure 17).

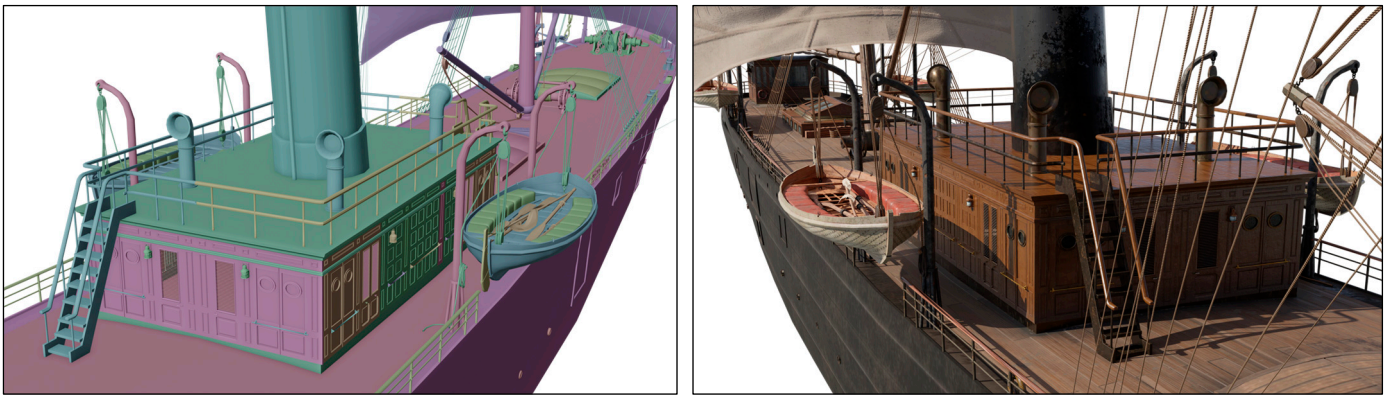


Figure 17. Three-dimensional model of the steamship *Bengala*: the passenger cabin (elab. R.F.).

Finally, we have positioned a butterfly hatch towards the stern, built with a wooden frame and two openable glass hatches with a pitched shape, intended to provide light and air to the spaces below the deck (Figure 18).

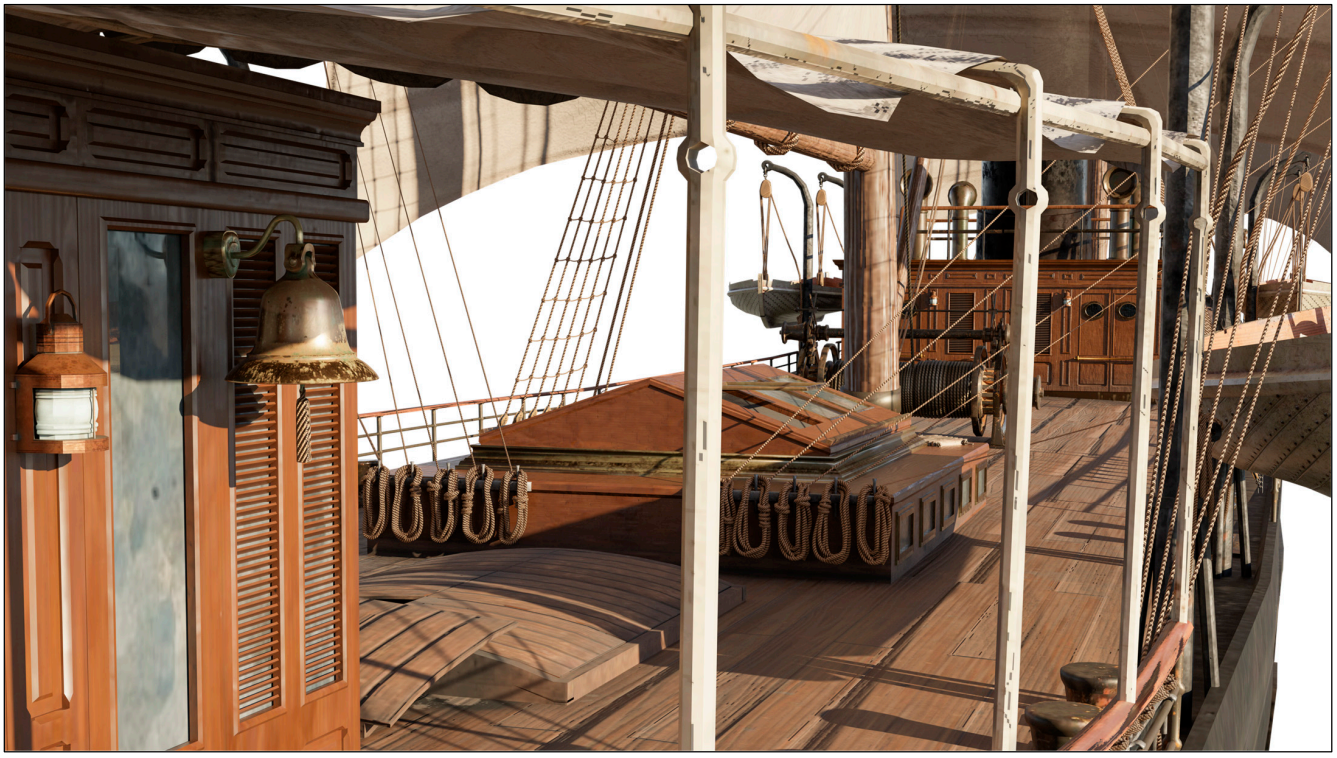


Figure 18. Three-dimensional model of the steamship *Bengala*: view of the main midship deck with the wooden butterfly hatch in the centre (elab. R.F.).

On the main deck there were two windlasses: one astern just below the main mast and the other near the foremast. Both were modelled very accurately on the basis of the submerged remains (Figure 19).

The same accuracy in the modelling was obtained for the anchor windlass, the chains, and the admiralty anchors placed on the sides of the bow (Figure 20). Since there are small davits with a curved profile towards the bow ends of the wreck, we suspended the two anchors on them. Other davits, much taller and with a less curved upper profile, were placed in pairs on the sides of the bridge amidships and at the stern, as these are clearly visible in the submerged remains. These boat davits were certainly meant to secure the four life boats of the steamer. The exact number of lifeboats does not come from official

documents but from two newspaper articles published after the sinking of *SS Bengala* on *Giornale di Udine e del Veneto Orientale* of 6 June 1889 [57] (p. 3) and on *Cittadino Italiano* of 6 June of the same year [58] (p. 2). In the *Giornale di Udine*, where the daring moments of the sinking are described, we read that "the four boats were thrown into the sea and the three passengers, who were running like madmen on the deck, sat in one of them, together with the ship's boys" [58] (p. 3). Since the arrangement of the lifeboats is unknown, we chose to suspend them outboard; however, the davits and the lifeboats could easily have been placed in the opposite direction.

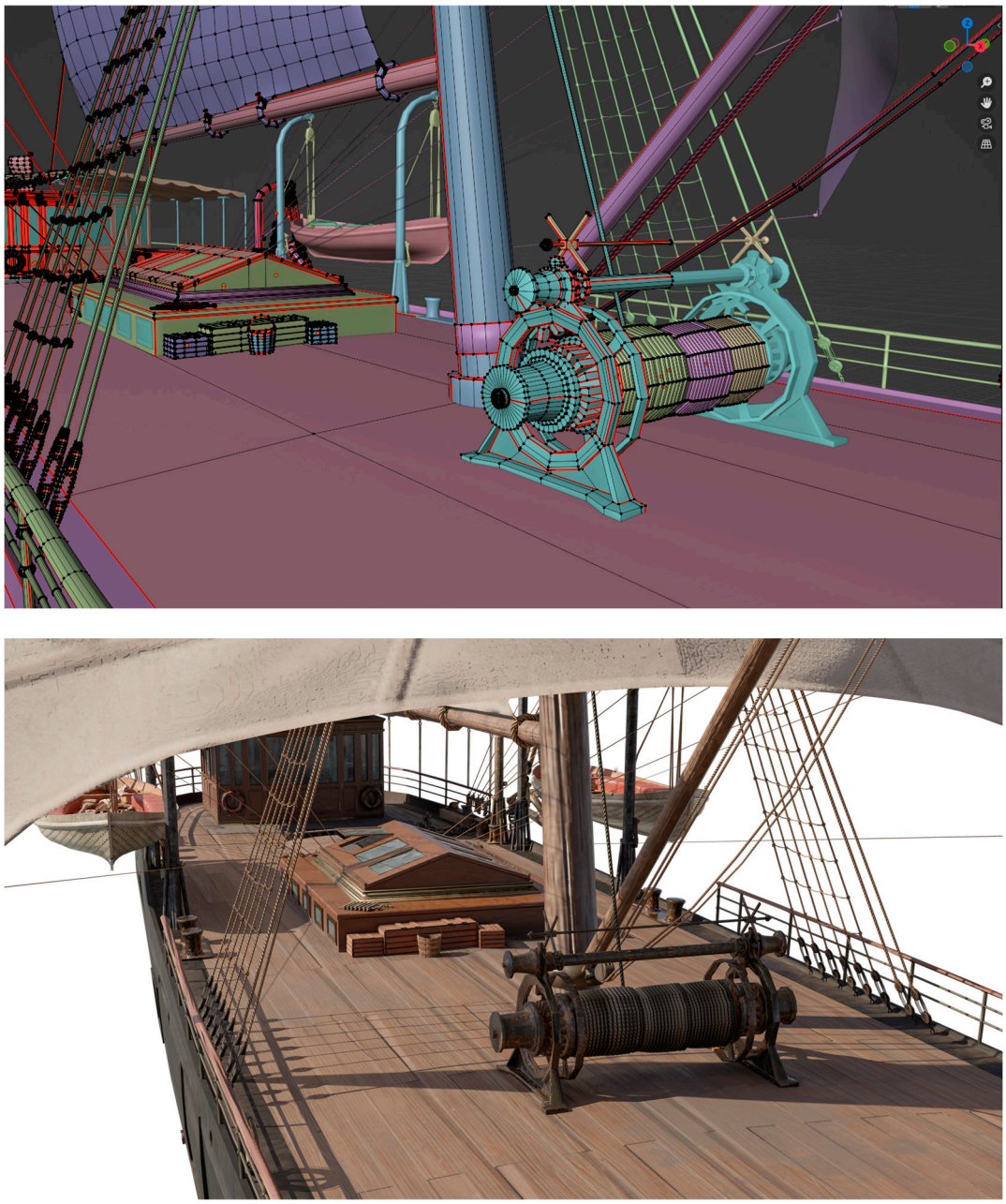


Figure 19. Three-dimensional model of the steamship *Bengala*: view of the upper deck with the windlass positioned below the main mast and, further aft, the butterfly hatch (elab. R.F.).

Figure 20. (**A**): One of the two bow anchors still in place; (**B**): admiralty anchor: selection in Edit Mode of Blender; (**C**): view of one of the anchors secured to the davits (elab. F.F., M.C., S.M., and R.P.).

We can consider the information taken from the newspapers regarding the dynamics of the shipwreck to be quite reliable. The state of the ship's remains, particularly in the bow area and the southwest sector, exactly matches the accounts from the time, which state that the keel and part of the starboard bow sector were struck by the impact against the rocks of the Capo Rizzuto shoal ("The keel of the Bengala on the starboard side of the bow had hit the rock and, scraping against it, had actually torn open. [. . .] The immense bow of the ship, after the impact, had risen above the waves, then had fallen back into the water, and the steamship had tilted violently to the right") [57] (p. 3). In fact, the mapping of the wreck reveals a chaotic and disjointed state of the hull, especially in the bow area and particularly in the southwest sector, which exactly corresponds to the area of the steamer mentioned in the contemporary sources.

A significant part of the modelling work was conducted on the sailing equipment. The masts were two and the deck collar of the main mast was still preserved, so we were able to determine its diameter exactly. Concerning the height of the masts, both of the aforementioned newspapers of the time reported an important detail, i.e., that, after the shipwreck, "nothing of Bengala could be seen, except the top of the main mast; some sacks of flour that were floating were saved" [57] (p. 3). The article is clearly reliable, as confirmed by the position of the wreck, which lies on its keel. Therefore, since the mast was lying at a

depth of about 25 m, we assumed a length of about 26.60. The sail arrangement, which was rendered entirely aloft to give an idea of its shape in the model, was reconstructed quite easily as we know that, on brigs, there were square sails on the two masts and a gaff rig on the main mast. Towards the bow, inserted onto the bowsprit, there are the traditional fore staysail, jib, and flying jib [59] (p. 887 ff.) (Figure 21).

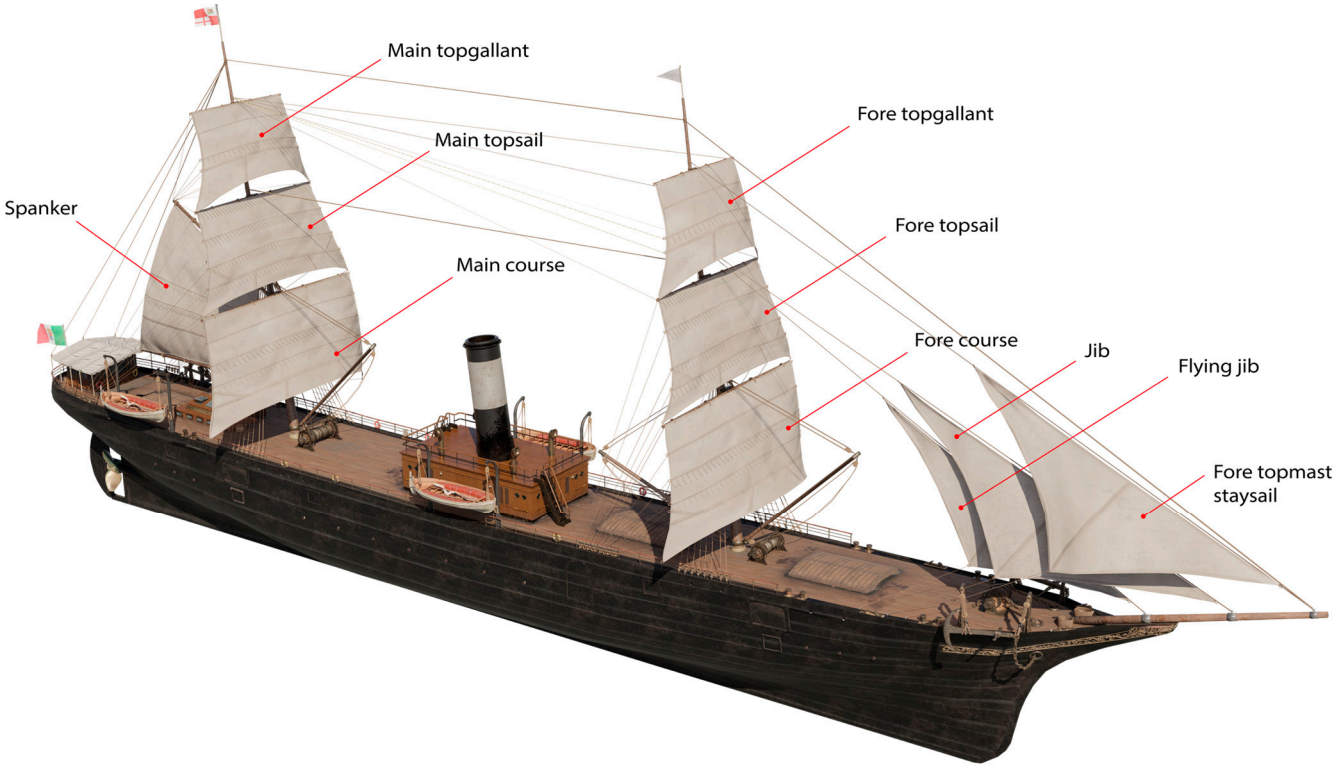


Figure 21. *SS Bengala*: hypothetical sail plan (elab. S.M.).

5. Conclusions

The lack of iconographic evidence, as extensively discussed before, is certainly to be considered as a hindering factor for studying the steamship. However, it should be noted that this is not an isolated case given the age of the ship, whose life span dates back to the last thirty years of the 19th century. In fact, no other steamship built in the shipyards of Iliff and Mousney & Co. in Sunderland in the same year as *SS Bengala*—that is, the *Meredith* (cargo, 976 grt), the *Marc Antony* (cargo, 1338 grt), the *Fairy Dell* (coaster cargo, 312 grt), the *Stephanotis* (cargo, 1042 grt), and the *Nymphaea* (cargo, 1138 grt)—was depicted in the section "Wear Built Ships" by the Shipping and Shipbuilding Research Trust, i.e., currently one of the largest data collections on shipbuilding in the area [60].

The lack of iconographic sources did not discourage the reconstruction work, although a complex machine such as a steamship, composed of thousands of parts that blend and harmonise together, makes digital modelling extremely difficult. Moreover, *Bengala* has two further elements that reinforce her complexity: firstly, it was both a cargo and a passenger ship; secondly, it had a mixed propulsion, i.e., sail and steam (Figure 22). Fortunately, a branch of maritime archaeology research focused on iron steamships is recently developing [61,62]. Therefore, there are some case studies that can serve as a reliable methodological reference, such as the one on *SS Xantho* in Australia, to which several publications have been dedicated [63,64], or the steamers *President Roca* and *Kaiser* in Argentina [65].

Figure 22. Three-dimensional model of the steamship *Bengala*: view of the bow sector (elab. R.P.).

In order to have a high degree of reliability, our study was consciously limited to the modelling of the hull and external structures, including the sails. The reconstruction of the interior spaces was deemed to be too risky, as it would have inevitably left too much room for hypotheses.

Therefore, the methodology merges and integrates information from both historical–archival research and data resulting from underwater investigations. These two data collection steps—between which, of course, there was a continuous interconnection in each phase of the study—are to be considered as preparatory for guiding the strategy of the subsequent digital modelling.

The historical–archival research, mainly conducted with the consultation of the official documents is Naval Registers, was compared with information acquired from the press of the time and from other documents. Various data, such as the longitudinal and transverse measurements of the steamer, the presence and function of the superstructures, the rigging, the layout of the main deck, and the materials used in it, have in fact been obtained from these precious documents. The research work was inevitably extended to include British naval treatises of the time, from which we were able to draw a comprehensive set of data on the architecture and construction materials of iron steamers. Among the most important manuals of the second half of the 19th century, there are, for example, those of E.J. Reed [42], S.J.P. Thearle [66], W.H. White [67], and T.H. Watson [68].

Historical research alone would not have been enough to put a face on the steamer. Therefore, it was followed by an underwater investigation that included the analysis of the wreck by archaeologists and a detailed optical survey. Centimetre-scale surveying has allowed for precise modelling that, in many cases, has led to the creation of identical copies of artefacts preserved underwater.

Furthermore, the three-dimensional optical survey constitutes a fundamental tool for the understanding and protection of the submerged site. Over time, it will be used

for the analysis of the state of degradation and the timing of iron corrosion as a useful comparison. In addition, there is a whole data set related to the analysis of the wreck's formation, starting from the situation that caused its sinking.

Another element that we would like to underline about the importance of the survey for the analysis of the site and, in particular, of the anthropic post-shipwreck factors that contributed to the formation of the site, concerns the evident bumping of the hull. Indeed, thanks to the broad view offered by the survey of such a large site, it was possible to obtain evidence of the fact that, in the area of the seabed where the wreck lies, well known as a biodiversity haven, fishing was once conducted using explosives. We had previously collected oral information about this activity from old local fishermen. The survey documents very clearly the collapse of some localised portions of the hull, especially the sides, whose fracture lines are not attributable to degradation alone (which would have affected the whole wreck) but rather to the detonation of the explosive. The area stretching from amidships to the stern provides us with a clear picture of the action of the explosive: the collapse of large sections of the sides started almost on the seabed and not, as one would expect from natural degradation, along the highest portion of the structures (Figure 23).

Figure 23. Virtual scenario with the steamship under full sail (elab. R.P.).

Both the underwater survey and the 3D model (the latter may also be improved in the future if there is the possibility of acquiring further data) should not be considered as useful only for the purposes of historical–archaeological research. They may be used to add value to the site, which falls within the "Capo Rizzuto" Marine Protected Area, which is a destination for scuba divers accompanied by guides who work for the diving centres authorised by the park.

The 3D model of the *SS Bengala* wreck provides innovative opportunities to enhance site accessibility and public engagement. For underwater visitors, augmented reality (AR) applications can overlay the reconstructed ship directly onto the real environment, enriching the diving experience and aiding spatial orientation. On land, the model can support multimedia exhibits in visitor centres or museums, offering interactive visualisations of the

ship's structure, its operational history, and the wrecking event. Serious games based on the model can educate users about maritime archaeology and 19th-century shipbuilding, expanding outreach to younger audiences. Additionally, the model serves as a valuable tool for monitoring the wreck's condition over time, supporting long-term conservation efforts. By leveraging these technologies, the *SS Bengala's* story can reach a wider audience, ensuring that its historical significance is both preserved and appreciated for generations to come.

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