A Formidable War Machine: Construction and Operation of Archimedes' Iron Hand

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Summary

Twenty-three centuries ago in the Sicilian city of Syracuse, the Greek mathematician Archimedes was called upon by his king to design war machines that could fend off enemies set to invade this Greek city-state. Among the numerous war machines designed by Archimedes was the fearsome *Iron Hand*, a device so terrifying that it became the primary defense for Syracuse against an invading Roman fleet in 213 BC.

According to ancient historians, the Iron Hand (or Claw, as it was also termed) was a grappling hook suspended from a huge lever that caught the bow of a ship as it approached the city wall. It then jerked the bow skyward, shaking the ship while suspended and then suddenly releasing the hook, causing the ship to crash into the water or onto the rocks below the wall. Thus the Roman ship was smashed apart and the crew hurled into the sea. So effective was the Iron Hand that the Romans were forced to abandon their sea invasion plan and to pursue a longterm blockade.

Throughout the ages, tales of Archimedes' defense of Syracuse grew more and more imaginative, and the proposed design of his Iron Hand grew less and less plausible. Here we present an investigation of Archimedes' Iron Hand that is firmly based on the earliest historical descriptions of it, specifically the writings of Polybius (circa 200-118 BC), Livy (59 BC-AD 17), and Plutarch (circa AD 45-120). Our investigation focuses on descriptions of other war machines that (like the Iron Hand) utilized levers, cranes, and grappling hooks. These historical investigations are supplemented with a structural analysis of the types of materials available to build them in ancient Sicily as well as a review of construction techniques used at the time. Finally, we present visuals of our Iron Hand and Roman quinquereme models which were constructed and tested at Drexel University's Structural Models Laboratory.

Introduction

When the struggle between Rome and Carthage for control of the western Mediterranean basin erupted into the Second Punic War (218-201 BC), the Greek city-state of Syracuse in Sicily resisted being drawn into it. But situated as it was midway between those two cities, it could not avoid becoming entangled in their conflict. Syracuse's old king, Hiero II, had been a loyal ally of Rome for more than fifty years; however, many in his family and court were drawn to the Carthaginian cause by the early victories of Hannibal. After Hiero died in 215 BC his 15-year-old grandson and successor, Hieronymos, began negotiations with Hannibal. This led to his assassination thirteen months after his coronation and to civil strife in Syracuse between its pro-Roman and pro-Carthaginian factions. The pro-Carthaginian faction was eventually victorious and the city prepared for the inevitable Roman response. This response came in the spring of 213 BC in the form of Marcus Claudius Marcellus, the consul of Rome assigned to deal with the Syracusan situation. (We follow the chronology of Lazenby, 1978.)

After his attempts at negotiation failed, Marcellus launched a two-pronged attack on Syracuse by land and by sea. His co-commander, Appius Claudius Pulcher, attacked the northern land walls of Syracuse while Marcellus directed a fleet of quinqueremes against the sea walls of the section of the city known as Achradina [᾽Αχραδίνα] (Figure 1).
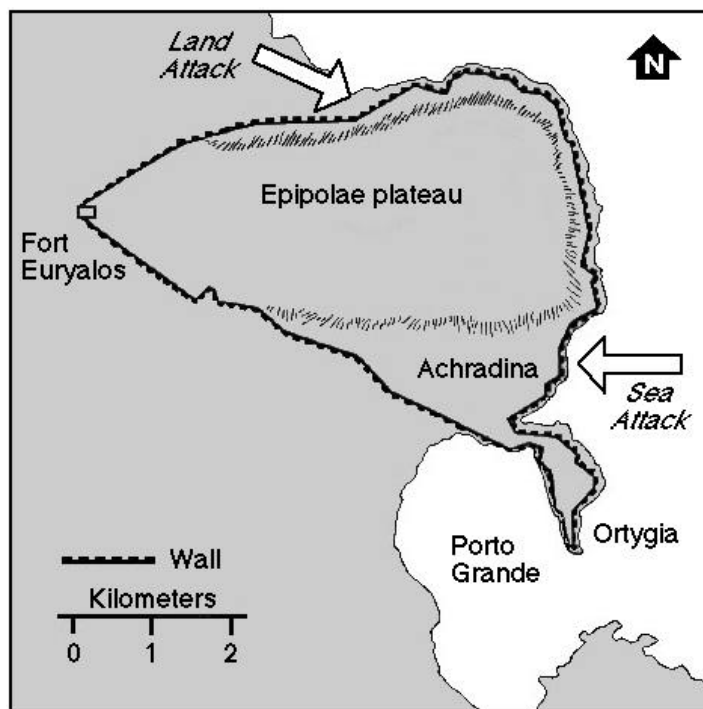

FIG. 1 Map of Syracuse in Archimedes' time showing its 27-kilometer defensive wall. The arrows indicate where the Romans attacked the wall by land and by sea.

However, as Livy [24.34.1-2] wrote, Marcellus had not taken into account the fact that Syracuse's chief military engineer was Archimedes, the foremost engineer, scientist, and mathematician of antiquity. At the request of Hiero, Archimedes had spent the many peaceful years Syracuse enjoyed as a result of Hiero's alliance with Rome preparing the city's defenses. Polybius [8.7.2], Livy [24.34], and Plutarch all attest to this fact; for example, Plutarch [Marcellus 14.9] wrote:

"... the king persuaded Archimedes to prepare for him offensive and defensive engines to be used in every kind of siege warfare. These he had never used himself, because he spent the greater part of his life in freedom from war and amid the festal rites of peace; but at the present time his apparatus stood the Syracusans in good stead, and, with the apparatus, its fabricator."

The three historians describe the many military machines Archimedes used against Marcellus' attack, but in this paper we are concerned only with the machine known as the 'Iron Hand' (*ferrea manus* in Livy's Latin and χεῖρα σιδηρᾶν in the Greek of Polybius and Plutarch). In the Appendix we quote the complete passages, in English translation, of those writings of Polybius [8.6.1-6], Livy [24.34.10-12], and Plutarch [Marcellus 15.2-3] that describe the construction and operation of the object of our interest.

Some English translators refer to this machine as 'Archimedes' Claw'. The phrase 'iron hand' is also used in the ancient literature to denote a grappling hook by itself, as we elaborate below. However, when capitalized, by 'Iron Hand' we shall mean the entire machine that the three historians described. Below we first discuss the military background and historical descriptions of the Iron Hand and then continue with the model simulations we performed to determine its proposed operation.
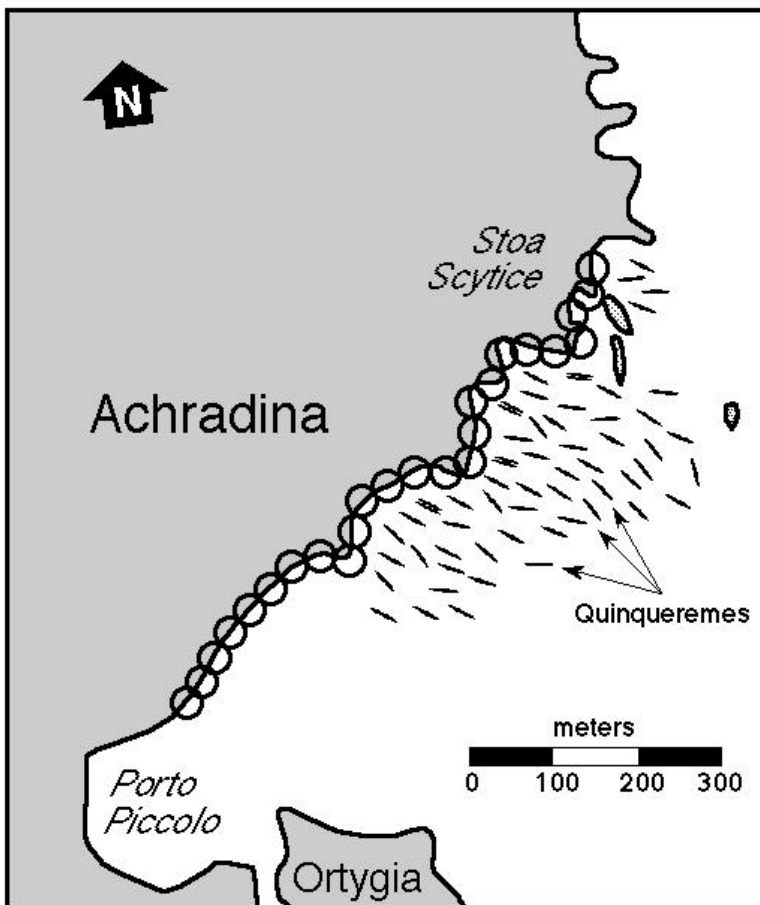

FIG. 2 *Map of the coastline of Syracuse where Marcellus' fleet attacked. The circles represent the ranges of the proposed twenty-five Iron Hands that protected the 900-meter stretch of wall. Also shown are the sixty quinqueremes that constituted the Roman fleet.*

Geographical Context

In Archimedes' time Syracuse was surrounded by a 27-kilometer wall (Figure 1). All traces of the wall along the seacoast are now gone, but a few portions of the inland walls survive, especially near the fortress of Euryalos which is anchored to the western-most portion of the wall (Winter, 1963). The land forces under Pulcher attacked the northern walls of Syracuse where they meet the sea (Polybius [8.3.2]). As for Marcellus' fleet, Plutarch does not identify the precise location where it attacked, while Livy [24.34.4] places it at "the wall of Achradina, which ... is washed by the sea ...". Polybius [8.3.2] is more specific, placing it "at the Stoa Scytice [Σκυτικὴν στοάν] in Achradina, where the wall reaches down to the very edge of the sea" (Figures 1 and 2). These descriptions of Livy and Polybius would narrow the sea attack to a stretch of coastline about 900 meters long shown in Figure 2.

FIG. 3 Photograph taken by the authors in 1999 of the coastline of Achradina shown in Figure 2. The left arrow points to the entrance of the Porto Piccolo and the right arrow points to the site of the ancient Stoa Scytice, where the cliffs of the Epipolae plateau begin.

Figure 3 is a recent photograph of that stretch of coastline. The Stoa Scytice was located where the cliffs of the Epipolae plateau descend to sea level to the right in the photograph. The fleet would not have attacked any further to the left where the island of Ortygia joins the mainland, forming the Porto Piccolo. Ships entering that port would have been vulnerable to attack from three sides by the defenders on the walls.

The Roman Quinquereme

The fleet that Marcellus commanded at Syracuse consisted entirely of quinqueremes (Latin: *quinqueremis*; Greek: πεντήρης), the main warships of the period. The Roman quinquereme was an exact duplicate of the Carthaginian quinquereme. Indeed, the Romans captured a Carthaginian quinquereme during the First Punic War and copied it nail-for-nail to build a formidable fleet. (Connolly, 1981, pp. 272-273; Warry, 1995, pp. 118-119).

The quinquereme was basically a ramming machine designed for ship-to-ship combat. It had a bronze-covered ram and was built for speed and maneuverability with a long streamlined hull designed to slice through the water quickly. Such ships were ill-suited for attacks on a city wall because of their inherent instability when stationary.

For ship-to-ship combat, the Roman quinquereme was equipped with a boarding plank with a 'beak' [Latin: corvus] or spike at its end. When the plank was dropped onto an enemy ship, the spike would dig into its deck and lock the two ships together, allowing the Roman marines to board the enemy ship and fight man-to-man. In the Punic Wars the Romans preferred this type of battle because the Carthaginians were superior seamen and excelled in ramming contests.

The quinquereme was 35-37 meters long and 4-5 meters wide, with an outrigger adding an addition meter or so to its overall width (Connolly, 1981; Morrison, 1996; Warry, 1995). In battle it was powered by five-man teams of rowers, each team probably pulling on three oars. Each ship held 420 men comprising 270 rowers, 30 crew members, and 120 marines. When attacking city walls the marines on deck were ready to scale the sea walls and to provide covering fire with arrows, slings, and javelins. In the battle of Syracuse the historians do not mention any heavy artillery on board the ships. According to Landel (1978, p. 151) a quinquereme displaced 75 tons (68 metric tons) and the 420 men with arms could have weighed

an additional 30-35 metric tons. Thus a fully manned quinquereme had a total weight of about 100 metric tons.

The outriggings or oar boxes of the quinqueremes extended the lengths of both sides. They were the most vulnerable area where a grappling hook from above could hook onto and lift or overturn the ship. Indeed, the oars themselves would provide a convenient place that a grappling hook could snag from above.

The Roman Fleet at the Siege of Syracuse

Polybius [8.4.1], Livy [24.34.4], and Plutarch [Marcellus 14.3] all write that the attacking Roman fleet comprised sixty quinqueremes. These would have constituted about one-fourth of the entire Roman fleet since Polybius [3.41.2] states that Rome had at least 220 quinqueremes in commission at the beginning of the Second Punic War. Counting 420 men per ship this comes out to 25,200 men involved in the sea battle, of which 7200 were marines on deck ready to shoot arrows, sling rocks, and throw javelins at the defenders on the wall.

Polybius and Livy state that eight of the ships were lashed side-by-side in four pairs to form stable platforms for four large scaling ladders, known as *sambucae*. Plutarch states that the eight ships were all lashed together to form one large platform; however, this seems unlikely. The fact that pairs of quinqueremes, rather than single quinqueremes, were used as the platforms for scaling ladders attests to the inherent instability of a single quinquereme.

Marcellus attacked the sea walls twice. The first attack, in daylight, was driven off by catapult fire before the fleet reached the walls. The second attack was at night to avoid the catapults (Polybius [8.5.4]; Plutarch [Marcellus 15.5]). It was this second attack that was greeted by Archimedes' Iron Hands, in addition to other short-range defenses that he had devised.

According to the three historians, the four large scaling ladders were attacked by stones and chunks of lead dropped on them. It does not appear that the Iron Hands were used against them. The Iron Hands seem to have attacked the 52 ships that provided cover fire for the scaling ladders.

Historical Description of Archimedes' Iron Hand

The writings of Polybius, Livy, and Plutarch quoted in the Appendix are consistent in describing the Iron Hand as a large lever with a grappling hook attached to the end of a chain hanging from one end of the lever beam. The machine was hidden from view, probably with the lever beam parallel to the wall, until a ship was within its range. The lever beam was then swung around and the grappling hook at its end dropped so that it caught onto an enemy ship. Polybius, alone among the three historians, states that stones were dropped to drive the marines from the bow of the ship before the hook was dropped. However, it is not clear whether that the stones were dropped from the Iron Hand or from some other machine on the walls. Once a ship was caught, the opposite end of the lever beam was lowered, hoisting the ship upward. The ship then was

swamped as a result of water flooding the stern or was shaken and dropped back into the water or onto the rocks at the base of the city walls.

Polybius and Plutarch do not make clear how the lever arm was lowered to raise a ship, but Livy states that once a ship was snagged by the grappling hook at the end of the lever arm, the other arm was "sprung backward to the ground owing to the shifting of a heavy leaden weight [*gravique libramento plumbi*]".

In spite of Livy's clear description of the use of such counterweights, many investigators have insisted on using men or oxen pulling on ropes and pulleys to actuate the lever (see, example, the figures in Landels (1978, p. 87) and James & Thorpe (1994, p. 225)). This method, however, is very slow and gives the enemy much time to free their ship from the grappling hook. This is in contrast to the use of a counterweight which would quickly snap the ship up before the enemy could react. In addition, the use of pulleys is very labor intensive, requiring many men waiting behind the wall ready to start pulling on ropes. By using a counterweight raised to the level of the wall, the energy needed to lift a ship can be expended before a battle rather than during it, thus freeing men to fight the invading ships from the top of the wall rather than behind it.

Another advantage of counterweights over pulleys is that once a counterweight has reached the limit of its travel, the ship and the counterweight would be in static equilibrium, similar to two people balanced on a seesaw. This equilibrium would be a weak one, almost a neutral one, and hence it would be easy for a few men to apply a small additional force on the lever beam to shake and bounce the ship and dash it against the wall and rocks, as the historians described. This would be difficult to accomplish with many men constantly pulling on ropes and pulleys under tremendous tension.

Another factor that mitigates against the use of pulleys is Polybius' remark that once the ship was lifted to the machine's limit, its operator "made fast the opposite end of the machine," prior to releasing the grappling hook and dropping the ship. Securing the machine would be essential if counterweights were used, as the entire structure would collapse if the ship were suddenly released from its equilibrium position without supporting the opposite end of the lever beam. Indeed, this collapse occurred several times in our laboratory simulations when we forgot to do what Polybius described.

Archimedes' Iron Hand appears to have been a rather simple device that represented an extension of the use of existing machines and devices. It may have simply been a modified crane such as was used at docks for loading and unloading ships (Landels, 1978, pp. 95-98; Simms, 1995, pp. 63-65). In this respect, Archimedes' contribution would have been similar to his contribution to catapult design. The catapult was in use centuries before Archimedes; what he did was improve its design by, for example, making it a variable-range device rather than a fixed-range device.

The Iron Hand need not have been too big a machine to accomplish its task. Because of its length, the bow of a quinquereme need only have been lifted a small amount before its stern started drawing water. In addition, if the ship were caught somewhere on its side (at its outrigging or on its oars, for example), then it would easily tip over due to its inherent

longitudinal instability. Archimedes had also placed Iron Hands along the inland wall and they did little more than lift a single attacking soldier and then drop him (Polybius [8.7.4]: "The besieged also inflicted no little damage by the above-mentioned hands hanging from cranes, for they lifted up men, armour, and all, and then let them drop.").

The ancient sources are not specific about the length of the lever beam of the Iron Hand. The models we discuss below were scaled so that each Iron Hand could protect a length of the wall equal to the length of a quinquereme; that is, about 36 meters. In this case, about 25 Iron Hands could have covered the 900-meter length of wall that was attacked (Figure 2).

Grappling Hooks

Because the term 'iron hand' was used long before Archimedes' time to describe a grappling hook, it would be instructive to discuss its mention in the historical literature. Diodorus Siculus describes the use of grappling hooks during the Peloponnesian Wars in the fifth century BC in ship-to-ship combat [13.16.1; 13.67.2; 13.99.4] and in dragging enemy ships moored on land out to sea [13.50.5]. In all instances he refers to them as iron hands (σιδηρᾶς χεῖρας).

Thucydides, likewise writing of the Peloponnesian Wars, mentions them in connection with ship-to-ship combat between the Athenians and the Syracusans [7.62.3]. In the following revealing passage [7.65.1-2] he remarks on the action the Syracusans took to prevent Athenian ships from snagging onto their own ships with grappling hooks:

> "They had also notice of the grappling-irons (σιδηρῶν χειρῶν), against which they specially provided by stretching hides over the prows and much of the upper part of their vessels, in order that the irons (χεὶρ) when thrown might slip off without taking hold".

This passage suggests that it was relatively easy to snag an unprotected ship (in this case a trireme) with a grappling hook.

Polybius, Livy, and Plutarch use the same terminology as Diodorus and Thucydides in describing the device Archimedes used to snag the Roman ships; namely, an 'iron hand' (χεῖρα σιδηρᾶν in Polybius's Greek and *ferrea manus* in Livy's Latin).

Plutarch, alone among the three primary historians, refers to another attachment used in Archimedes' engines. He states that the Roman ships "were seized at the prow by iron claws [χερσὶ σιδηραῖς], or beaks like the beaks of cranes [στόμασιν εἰκασμένοις γεράνων]" [Marcellus, 15.2]. These beaks refer to large spikes, such as the Romans used at the end of boarding planks, as was described earlier. On the basis of Plutarch's testimony, it is possible that Archimedes' engines were equipped with both grappling hooks and spikes, or possibly a modified grappling hook with an attached spike, to permit greater flexibility in snagging the enemy ships.

None of the ancient sources, however, describe the complicated mechanisms that some later writers use to describe the Iron Hands (see, for example, the figures in Lazos, 1995, p. 231, and

Strandh, 1979). The above references, and their use of the phrase 'iron hand' in Greek and Latin support our contention that Archimedes' Iron Hand made use of a simple grappling hook. Indeed, the simplicity of a grappling hook is a major advantage in warfare, much to be preferred to some complicated mechanism whose operation could be easily disrupted by the enemy.

Scientific Context

In his extant works Archimedes has no mention of his Iron Hand, or, for that matter, of any of his engineering endeavors. However, in his works that have survived to our day, he formulated those scientific principles on which his Iron Hand was based (Dijksterhuis, 1987; Heath, 1953; Stamatis, 1970). In his work "On Levers" he formulated his famous Law of the Lever, the most fundamental law governing the physics of his Iron Hand and one of the most fundamental laws of mechanics. Of course, Archimedes did not invent the lever, but his understanding of the quantitative relationships between the forces at the ends of a lever and the lengths of the lever arms would have served him well while he was designing his war machines.

Similarly, in his work "On Floating Bodies" Archimedes formulated his Law of Buoyancy. This work, his most profound, contains a brilliant exposition on the stability of a floating paraboloid. Although a paraboloid has a simple geometric shape, Archimedes clearly had in mind the stability of ships and the mathematics governing such stability. Here, again, his understanding of the principles that make floating bodies unstable would lead naturally to his interest in war machines that would capsize an invading ship.

The Law of the Lever and the Law of Buoyancy are two of the most fundamental laws of nature and two of the first laws of nature articulated and quantified. That Archimedes could formulate these scientific laws, place them on an axiomatic foundation, give geometric applications of them in his mathematical works, and then apply them to the construction and operation of his Iron Hand, demonstrate why he is considered the greatest mathematician, scientist, and engineer of the ancient world.

Building of the Models

To further examine the design and operation of Archimedes' Iron Hand, we performed various experiments at the Structural Models Laboratory of Drexel University (Harry G. Harris, Director). The Iron Hand was simulated using a 1/60-scale working model. The model consists of a portion of the walled city of Syracuse, a basin of water, two different designs of the Iron Hand, and a 1/60-scale model of a Roman quinquereme (Figures 4-10). The choice of model scale was dictated by the overall requirement of a 'table-top' size model and the availability of block masonry for the construction of the wall. In our figures showing the simulated wall, portions of the wall have been removed to show the Iron Hands, which ordinarily would have been hidden from view behind the walls.

Since wood and rope were the main construction materials of the period (Korres, 1997), our designs of the Iron Hands use wooden beams readily available in the Sicilian forest with
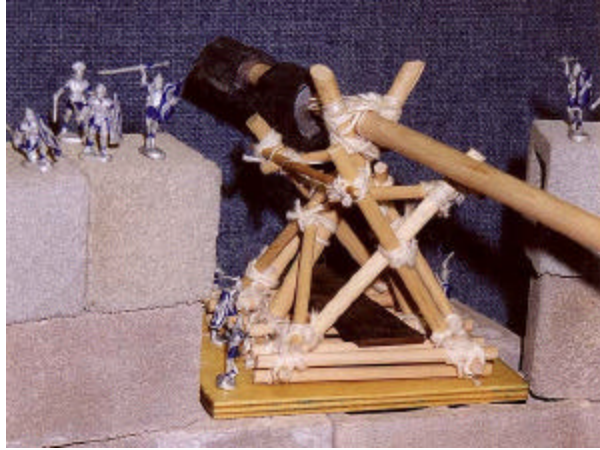
FIG. 4 One of two 1/60-scale Iron Hands. Leaden weights on the rear of the lever beam are ready to slide backward when an enemy ship is caught.
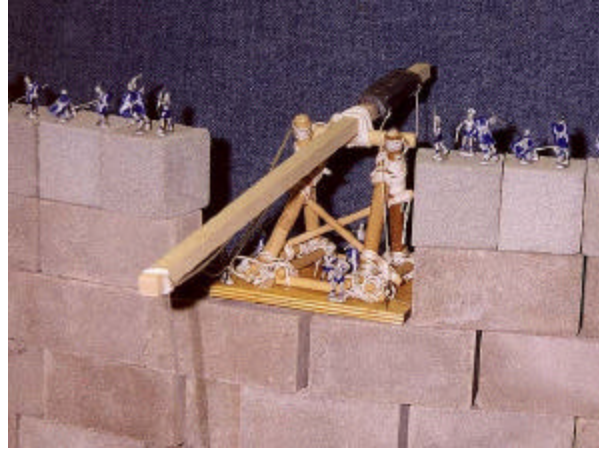

FIG. 5 The second of two 1/60-scale Iron Hands. It differs from the one in Figure 4 in the horizontal pivoting arrangement of the lever beam.

minimum cutting and dressing. Both model Iron Hands are mounted on platforms that allow for rotation about a vertical axis. The intention was to keep their lever beams parallel to the wall, and thus hidden from the invading ships, until the ships were right under the walls. Then the entire structure would be rotated about the vertical axis until the grappling hook attached to the end of the lever beam was over or beside the ship. This rotation could have been accomplished with man and/or animal power using pulley magnification. The platforms themselves could have been on wheels or rollers to facilitate the rotation. Leaden weights are attached to the shorter end of the lever beam to provide the suddenly applied lifting force once the hook catches the ship.

The two designs differ in how the lever beam is rotated about a horizontal axis. In the first design (Figure 4) the lever beam pivots directly within a single V-shaped support of the frame, while in the second design (Figure 5) the lever beam rests on a shorter beam perpendicular to it which pivots about a pair of V-shaped supports of the frame.

The construction of the model quinquereme was based upon the method of construction of ships at the time. The ancient method was a labor intensive one of joining hull planking edge to edge held together by a large number of closely spaced hardwood tendons (Morrison, 1996; Tzalas, 1997). The wooden tendons were tightly fitted into individual mortises cut into the plank edges, giving the planking great strength and
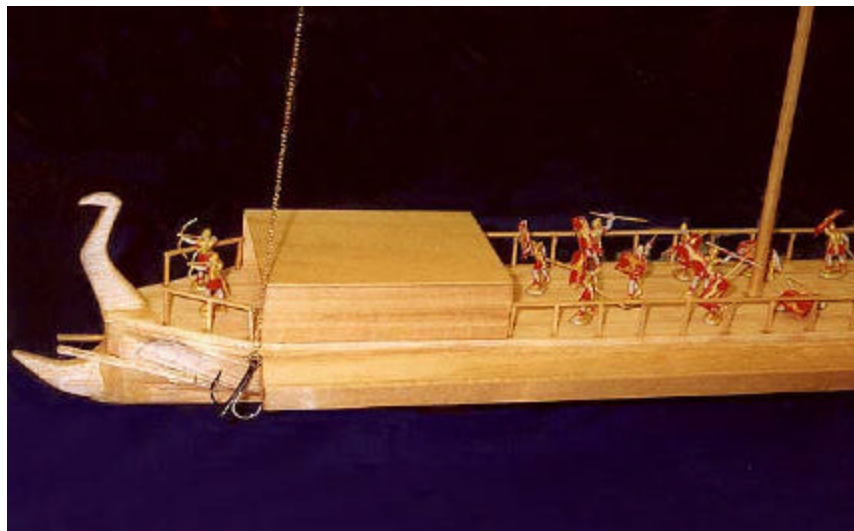

FIG. 6 Close-up of the 1/60-scale Roman quinquereme. Also shown is the grappling hook of the Iron Hand hanging from its chain.

stiffness. The technique used in the 1/60 scale model was slightly modified to decrease the cost and construction time. Cross frames of the desired hull shape were cut from thin plywood and shaped strips of balsa-wood planking were glued to the frames edge to edge having a tight fit using a water resistant glue. The assembled model was lightly sanded and given three coats of exterior polyurethane varnish. A close-up photograph of the finished model is shown in Figure 6, together with a scale grappling hook hanging on a chain.

Model Experiments

The operation of the Iron Hand was simulated with the models and recorded using stop-action photography. Figures 7-10 exhibit frames from four representative simulations using the model Iron Hand shown in close-up in Figure 4. In those frames in which the ship is caught by the hook, the lead counterweights on the lever beam kept the ship and Iron Hand in balance while the photograph was taken.

The simulations showed that the easiest way to snag onto the model ship was by dropping the hook by the side of the ship and then swinging the lever beam until the hook caught onto the outrigging or ram. The action involved bringing the hook down into the water and then catching the ship on the upswing. It was actually difficult *not* to snag onto the ship by this method.

Our simulations also showed that the ship turned over quite easily when caught on its side (Figures 7 and 10). It was not necessary to raise the ship from the water at all, it simply tipped over like an unbalanced canoe. While not as dramatic as catching the ship by its bow and lifting it up some distance, the tipping action was just as effective in capsizing the ship. Even when caught by the ram or rigging on the bow, the ship was likely to twist around before the bow was lifted much out of the water (Figures 8).

These simulations verified how effective the Iron Hand is when it exploits the lateral instability of the quinquereme. They also showed, as mentioned above, that it is very easy to shake and rock the ship about when it is in balance with the counterweights. Finally, they confirmed the efficiency of a simple grappling hook in sagging and holding on to an attacking warship.
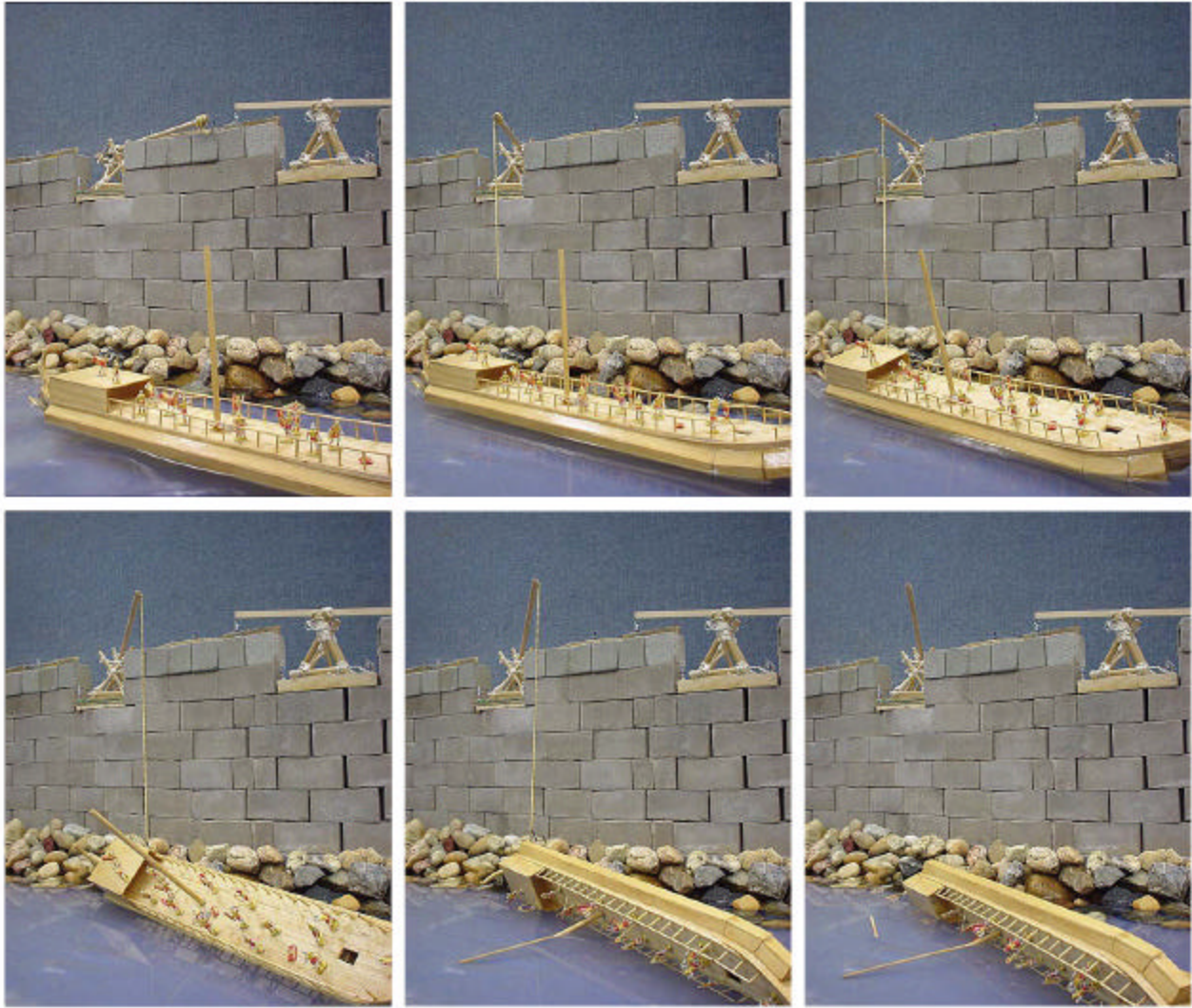
FIG. 7 Six frames from a stop-action sequence showing a quinquereme being caught by its outrigging and overturning.
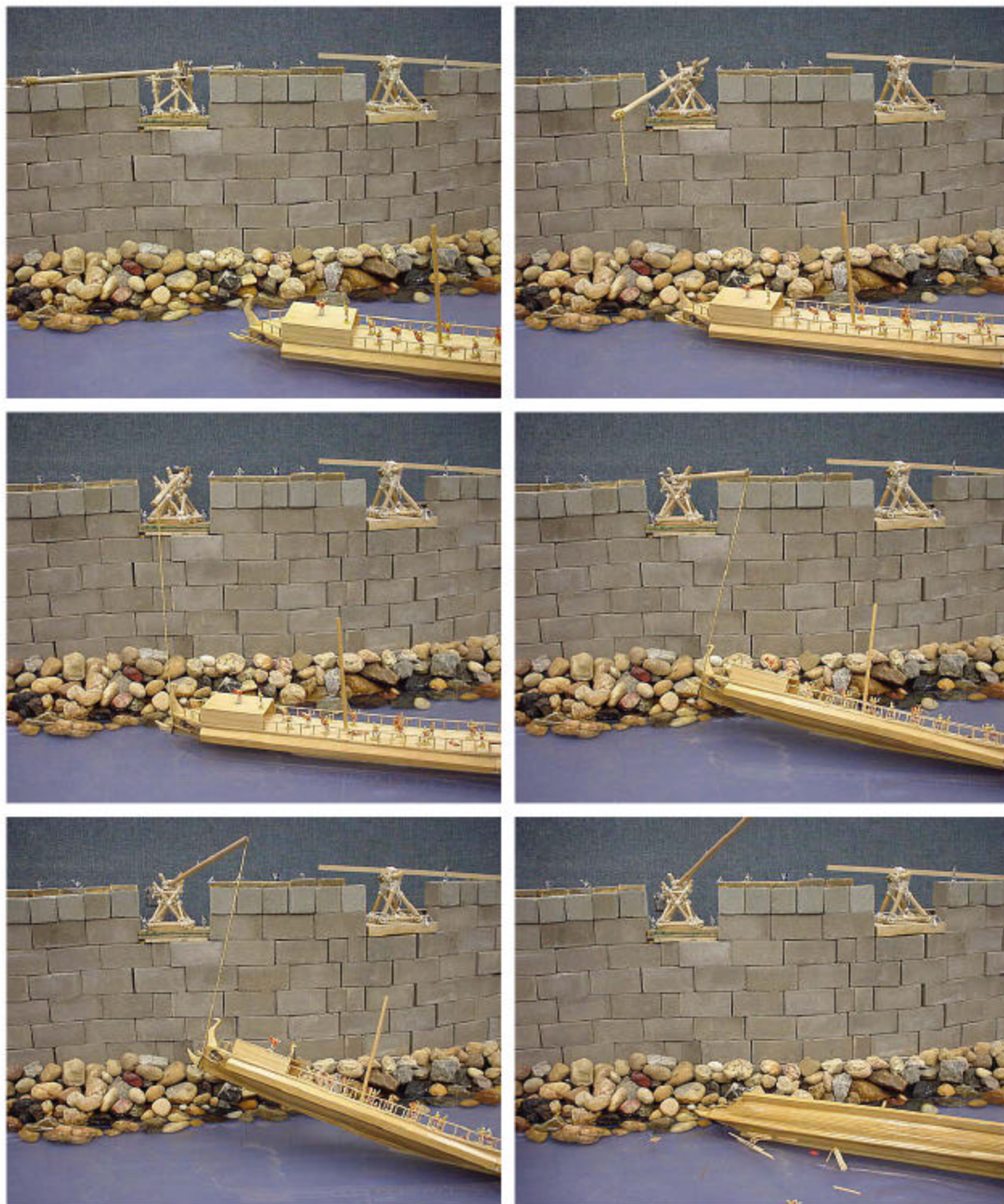
FIG. 8 Six frames from a stop-action sequence showing a quinquereme being raised by its ram and overturning.
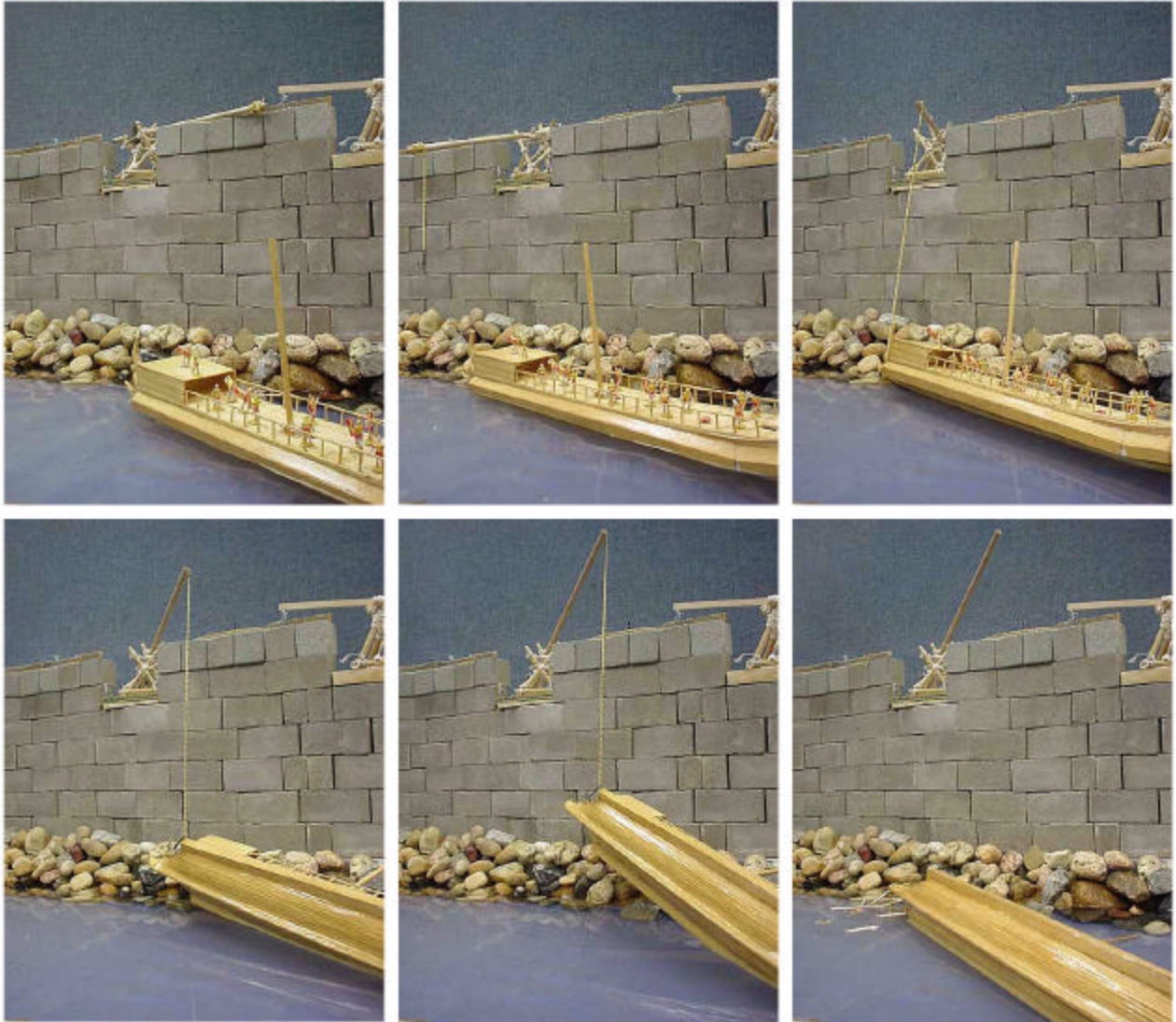
FIG. 9 Six frames from a stop-action sequence showing a quinquereme being raised by its bow and released.
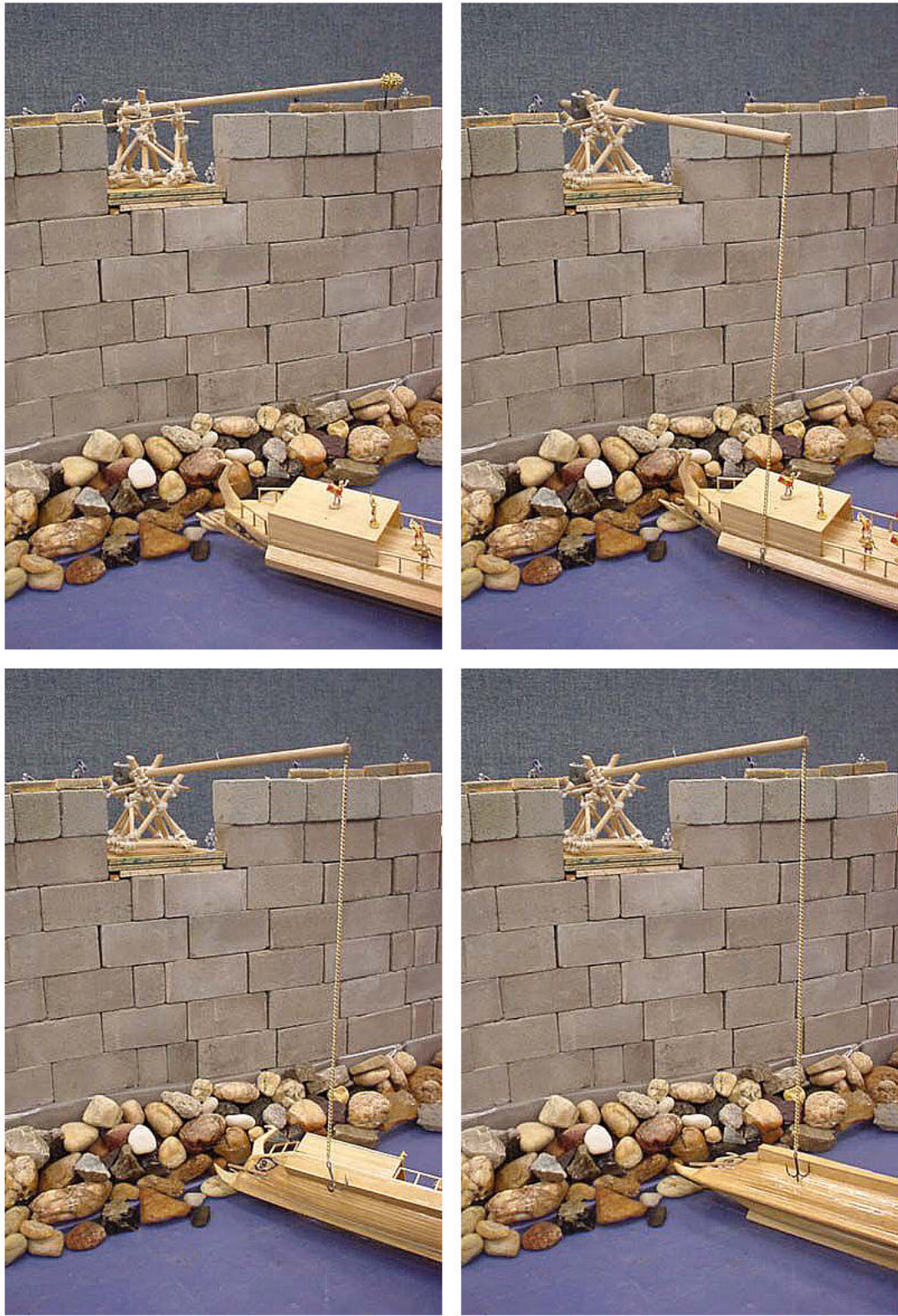
FIG. 10 Four frames from a stop-action sequence showing a quinquereme being caught by its outrigging and overturning.

Appendix

We present here those passages from the histories of Polybius, Livy, and Plutarch that describe the Iron Hand:

Polybius [8.6.1-6]:

There were some machines again which were directed against parties advancing under the cover of blinds and thus protected from injury by missiles shot through the wall. These machines, on the one hand, discharged stones large enough to chase the assailants from the prow, and at the same time let down an iron hand attached to a chain with which the man who piloted the beam would clutch at the ship, and when he had got hold of her by the prow, would press down the opposite end of the machine which was inside the wall. Then when he had thus by lifting up the ship's prow made her stand upright on her stern, he made fast the opposite end of the machine, and by means of a rope and pulley let the chain and hand suddenly drop from it. The result was that some of the vessels fell on their sides, some entirely capsized, while the greater number, when their prows were thus dropped from a height, went under water and filled, throwing all into confusion. Marcellus was hard put to it by the resourcefulness of Archimedes, and seeing that the garrison thus baffled his attacks not only with much loss to himself but with derision he was deeply vexed, but still made fun of his own performances, saying, "Archimedes uses my ships to ladle seawater into his wine cups, but my sambuca band is flogged out of the banquet in disgrace."

Livy [24.34.10-12]:

As for the ships which came closer, in order to be inside the range of his artillery, against these an iron grapnel, fastened to a stout chain, would be thrown on to the bow by means of a swing-beam projecting over the wall. When this sprung backward to the ground owing to the shifting of a heavy leaden weight, it would set the ship on its stern, bow in air. Then, suddenly released, it would dash the ship, falling, as it were, from the wall, into the sea, to the great alarm of the sailors, and with the result that, even if she fell upright, she would take considerable water.

Plutarch [Marcellus 15.2-3]

At the same time huge beams were suddenly projected over the ships from the walls, which sank some of them with great weights plunging down from on high; others were seized at the prow by iron claws, or beaks like the beaks of cranes, drawn straight up into the air, and then plunged stern foremost into the depths, or were turned round and round by means of enginery within the city, and dashed upon the steep cliffs that jutted out beneath the wall of the city, with great destruction of the fighting men on board, who perished in the wrecks. Frequently, too, a ship would be lifted out of the water into mid-air, whirled hither and thither as it hung there, a dreadful spectacle, until its crew had been thrown out and hurled in all directions, when it would fall empty upon the walls, or slip away from the clutch that had held it.

References

Connolly, P., *Greece and Rome at War*, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1981.

Dijksterhuis, E. J., *Archimedes*, translated into English by C. Dikshoorn, Princeton University Press, Princeton, N.J., 1987.

Dimarogonas, A. D., *History of Technology*, Symmetria Publications, Athens, 1984.

Diodorus Siculus, *Library of History*, Loeb Classical Library, in 12 volumes, Harvard University Press, 1933-1967.

Ducrey, P., *Warfare in Ancient Greece*, Schocken Books, New York, 1986.

Heath, T. L., *The Works of Archimedes with the Method of Archimedes*, Dover Publications, Inc., New York, NY, 1953. (Unabridged republication of *The Works of Archimedes* (1897) and *The Method of Archimedes* (1912). Both works were edited by Thomas Little Heath and published by The Cambridge University Press.)

James, P., and Thorpe, N., *Ancient Inventions*, Ballantine Books, New York, 1994.

Korres, M., "Natural Elements of Preindustrial Capstans", in *Ancient Greek Technology*, Proceedings of the 1st International Conference, Thessaloniki, Greece, 1997, pp. 447-457.

Landels, J. G., *Engineering in the Ancient World*, University of California Press, Berkeley & Los Angeles, 1978.

Lazenby, J. F., *Hannibal's War*, University of Oklahoma Press, Norman, Oklahoma, 1978.

Lazos, Ch. D., Archimedes: *The Ingenious Engineer*, Aiolos Publishers, Athens, 1995, [in Greek]: Λάζος, Χ. Δ., Αρχιμήδης: Ο Ευφυής Μηχανικός, ΑΙΟΛΟΣ, Αθήνα, 1995.

Lazos, Ch. D., *Engineering and Technology in Ancient Greece*, Aiolos Publishers, Athens, 1992 [in Greek]: Λάζος, Χ. Δ., Μηχανική και Τεχνολογία στην Αρχαία Ελλάδα, ΑΙΟΛΟΣ, Αθήνα, 1992.

Livy, *History of Rome (ab urbe condita),* Loeb Classical Library, Volume VI, English translation by F. G. Moore, Harvard University Press, 1940.

Morrison, J. S., *Greek and Roman Oared Warships*, Oxford Books, Oxford, 1996.

Plutarch, *Plutarch's Lives*, Loeb Classical Library, Volume V, English translation by B. Perrin, Harvard University Press, 1917.

Polybius, *The Histories*, Loeb Classical Library, Volume III, English translation by W. R. Paton, Harvard University Press, 1923.

Rodgers, W. L., Gre*ek and Roman Naval Warfare*, Naval Institute Press, Annapolis, 1937.

Simms, D. L., "Archimedes the Engineer", *History of Technology*, Volume 17, 1995, pp. 45-111.

Stamatis, E. S., *The Complete Archimedes*, Athens, 1970 [in Greek]:
Σταμάτης, Ε. Σ., Αρχιμήδους Απαντα, Αθήνα, 1970.

Strandh, S., *A History of the Machine*, A&W Publishers, Inc., New York, 1979.

Tassios, T. P., Editor, *Ancient Greek Technology*, Proceedings of the 1st International Conference, Thessaloniki, Greece, 1997.

Thucydides, *The Peloponnesian War*, Richard Crawley. London, J. M. Dent; New York, E. P. Dutton. 1910.

Tzalas, H., "The Shipbuilding Methods of the Greeks During the Pre-classical, Classical, and Hellenistic Times", in *Ancient Greek Technology*, Proceedings of the 1st International Conference, Thessaloniki, Greece, 1997, pp. 507-515.

Warry, J., *Warfare in the Classical World*, University of Oklahoma Press, Norman, Oklahoma, 1995.

Winter, F. E., "The Chronology of the Euryalos Fortress", *American Journal of Archaeology*, Volume 67 (1963), pp. 363-387.