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Further Evidence for the Use of Concrete in Ancient Harbor Construction

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Among the most impressive features of the harbor at Caesarea Maritima are the concrete structures built in wooden formwork, already so ably investigated under water, published, and discussed. These remains have given a new impetus to the search for parallels elsewhere and to the restudy of those already known. The discussion in this chapter does not seek to be exhaustive, but will focus on the remains, of similar date and/or technique to the Caesarea structures, that have been discovered at Les Laurons near Marseille; at Side in Pamphylia; at Anzio and other sites on the coast of Latium; and at Marseille itself.

The harbor of Les Laurons is situated on the Bay of Fos (ancient Fossae Marianae) east of the mouth of the Rhône. It probably began in the third century B.C.E. as a small port for the export of cut stone from quarries just to the north, and as a port of call for local traffic. Much construction dates from the first century C.E., and the port may have become, with Fos, a supplementary outport to the riverine port of Arles. It seems to have continued in use until the end of the seventh century C.E.[1]

The harbor is protected by two breakwaters, well placed on either side of the entrance to provide maximum protection for the harbor basin, which comprises three creeks: north, south, and east. The north creek is further protected by a jetty and apparently at least partly lined by dressed stone quays; these remains were only superficially studied before being destroyed in 1968 during the construction of a power station for Electricité de France – an experience which shows that the threat to our maritime heritage comes not only from the private entrepreneur! The experience of archaeologists at Caesarea seems to have been much more positive in this respect.

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[1] I should like to express my special thanks to Enrico Felici, for valuable discussion by correspondence; to Antoinette Hesnard, for showing me her records during my visit to Marseille in June 1994; and to Paul Knoblauch, for twenty-five years of friendship, collaboration, and argument.

This account is based on S. Ximenes and M. Moerman, "The Roman Harbour of Laurons: Buildings and Structures," in A. Raban, ed., *Archaeology of Coastal Changes*, BAR Int. Ser. 404 (Oxford, 1988), 229–52. See also references there, to which now add: Ximenes and Moerman, "L'Anse des Laurons: structures portuaires," *Cahiers d'archéologie subaquatique* 7 (1988), 121–29; and "Le quai de la crique est du port romain des Laurons: étude architecturale," ibid. 8 (1989), 179–91. The definitive study has now been presented by Martine Moerman, *Le port romain des Laurons (Martigues)*, doctoral dissertation (Université de Provence, 1993); publication in preparation.

All that survives now in the north creek at Les Laurons are the building complexes on the east shore (villas?), supplied by an aqueduct.

The south creek contains no clear remains of harbor structures, and is partly filled in. The east creek is further protected by a jetty projecting from its northern shore, 19 m. long, 9.50 m. wide narrowing to 7 m., and 0.75–1.80 m. high; it is extended by a number of wooden piles which seem to have supported a timber landing stage. Inside this jetty to the east lies a remarkable quay, around which are some 120 cut blocks whose role is not fully clear.[2]

The quay was constructed in the early first century C.E., with a superstructure of cut stone and a substructure of rubble fill in prefabricated timber formwork. The wooden caisson measures 22.90 x 2.20 m. and is now submerged to a depth of 1–1.5 m. It was clearly built out of the water. Its floor of wide, fitted planks, presumably intended to be watertight, was nailed to a horizontal frame of beams (14 x 18 cm. in section on the short sides and 11 x 18 cm. on the long sides), and then turned upside down. Two longitudinal horizontal beams strengthened the floor. A total of 32 vertical rectangular piles (13 x 11 cm. in section) were dovetailed into and nailed to the bottom frame of beams; a series of triangles and Roman numerals on the piles and on the beams close to the dovetails clearly relates to the assembly of the caisson. The wall planks fitted into grooves in the upper side of the frame beams. The excavators plausibly assume that the structure was completed and strengthened by an upper frame similar to the lower one.[3]

The caisson was then ready to be lifted into the water with ropes (remains of two ropes were found *under* the quay structure during excavation). Then, as it was filled with rubble, and the woodwork became saturated and lost its buoyancy, the caisson slowly submerged under the weight. Groups of cylindrical timber piles were fixed vertically around the quay – clearly to hold the joints intact under the increased pressure from the fill, and to keep the caisson in position; they were almost certainly driven in *before* being attached to the formwork. The problems of actually getting formwork into position are well discussed in a recent article by Oleson.[4]

A date in the early first century C.E. appears plausible for the Les Laurons quay, and this gives particular interest to comparison with remains of formwork found at Caesarea and other roughly contemporary sites, and with the text of Vitruvius written in the previous century. The timbers of the formwork at Les Laurons are much less massive than those at Caesarea, and the dimensions of the caisson are longer and narrower (22.90 x 2.20 m. compared with 15 x 11.50 m. for the concrete block in area G at Caesarea);[5] there is no double walling at Les Laurons; there are no tie-beams

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[2] Ximenes and Moerman, "Roman Harbour," figs. 4, 7 (N creek), 5 (S creek), 8–9 (E creek).

[3] Ibid., figs. 10–16.

[4] J. P. Oleson and G. Branton, "The Technology of King Herod's Harbour," in *Caesarea Papers*, 49–67, esp. 60–65; cf. J. P. Oleson, "The Technology of Roman Harbours," *IJNA* 17 (1988), 147–57, esp. 149–52.

[5] Area G (W tip of N breakwater): J. P. Oleson, "Herod and Vitruvius: Preliminary Thoughts on

(*catenae*) within the structure; and there *is* a floor. Oleson and Brandon assume that the Caesarea caissons were prefabricated on shore and floated into position, though this is not one of the methods described by Vitruvius; a similar procedure must be assumed for Les Laurons also, though there are differences at Les Laurons which have to be explained (existence of a floor; lack of tie-beams). On this we must await the final publication of Les Laurons by Mme Moerman.

At Les Laurons we have evidence of use of the latest techniques, which might surprise one at a site of relative insignificance. Most of the structures, however, are of traditional type – the two rubble breakwaters, the inner jetties, and the (now lost) ashlar quay – even though they may be of similar date. Much of the evidence has unfortunately been lost; again we must await the final publication to learn whether more can be added to the preliminary reports. If we *do* have to assume that contemporary structures were built in different techniques, then we must suppose that particular attention was paid to one particular feature, while other structures were constructed or reconstructed in cheaper traditional methods.

Hohlfelder had already pointed out that at the same period in Kenchreai traditional rubble breakwaters were thought sufficient; he had argued that local engineers would not have had easy access to the innovations that distinguished Sebastos. I had argued in response that it is likely that the innovations were soon widely known, and that the constructions at Kenchreai must be explained as resulting from a deliberate choice, perhaps influenced by economic considerations.[6] If the two techniques were used at Les Laurons in structures of similar date, then we clearly do have there an example of deliberate choice. It is generally accepted now that Herod imported engineers as well as materials from central Italy for the work at Caesarea;[7] it seems that a similar procedure must also have been used at Les Laurons, on a much smaller scale.

At Side in Pamphylia the NE mole was built of concrete in formwork up to water level, and of ashlar above water level.[8] The (SE) head of the NE mole bears imprints

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Harbour Engineering at Sebastos, the Harbour of Caesarea Maritima," in A. Raban, ed., *Harbour Archaeology*, BAR Int. Ser. 257 (Oxford, 1985), 165–72; Oleson, "Technology," 153–54; Oleson, in Raban, *Site*, 127–30; cf. 280–81, 287 (Raban). For the newly discovered formwork in area K (N end of the S breakwater), see Christopher Brandon's chapter in this volume.

[6] R. L. Hohlfelder, "The Building of the Roman Harbour at Kenchreai: Old Technology in a New Era," in Raban, ed., *Harbour Archaeology*, 81–86; D. J. Blackman, in I. Malkin and R. L. Hohlfelder, eds., *Mediterranean Cities: Historical Perspectives* (= *Mediterranean Historical Review* 3.1 [1988]), 7–20, esp. 7–8. Hohlfelder's chapter in this volume shows that our views are now close.

[7] Cf. Hohlfelder, "Building," 81; Oleson, "Herod and Vitruvius," 165, 168, 172; Oleson and Branton, "Technology," 56–60.

[8] H. Schläger, "Die Texte Vitruvs im Lichte der Untersuchungen am Hafen von Side," *Bonner Jahrbücher* 171 (1971), 150–61; P. Knoblauch, *Die Hafenanlagen und die anschliessenden Seemauern von Side*, Untersuchungen in der Gegend von Antalya 11, Turkish Historical Society (Ankara, 1977). The remains described here are the only ones included in this chapter which cannot be certainly ascribed to a date close to that of the Caesarea structures; I have included them because of the interest of the techniques

in its concrete of the formwork: horizontal planking, with vertical piles on the inner side. The piles were 30 x 15 cm. in section, and stood at intervals of 0.80 m.; Schläger thought that they were used on the inner side at the head of the mole only, and not on the long sides, but Knoblauch disagrees. The mole head is 7.5 m. wide and 3 m. high, with the concrete and formwork just reaching sea level.[9]

This feature was studied by Schläger and discussed by him in his last public lecture before his untimely death; the lecture notes were prepared for publication by Knoblauch, whose contribution to the study of the harbor at Side has been underestimated. His fuller study of the harbor, in a book that has been largely and unjustifiably ignored, gives fuller details on this mole and on the rest of the harbor.

The concrete and formwork construction is used only in the stretch NW of the main harbor entrance; the stretch to the SE is built of rubble and mortar with ashlar facing on both sides, and the two gaps in it (*Rinnen*) probably served as anti-silting devices, according to Knoblauch. To the NW of the harbor entrance the concrete and formwork construction is built in stretches of 10–11 m., with slight changes in course (the total length of the mole is 225 m. and its width 7 m.). One westerly stretch (G6) still preserves in place the lowest course of ashlar resting on the concrete; another stretch (G5), some 40 m. from the head of the mole, has the upper surface of the concrete laid bare and still well preserved, with the grid of slots clearly visible: the slots are 30 cm. wide and deep and 2 m. apart, and run across to the outer edge of the mole; in one or two places the concrete is still preserved above the slot.[10] The presence of cross timbers at the top of the formwork serves to confirm the excavators' hypothesis of a second, upper frame of beams in the formwork of the quay at Les Laurons.

Knoblauch was able to correct one point in Schläger's article: the inner vertical piles were used along the sides of the mole and not only at its head; he helpfully notes that these inner verticals would probably have remained in place even if the planking was removed and reused, and in that case would have served a useful secondary purpose in protecting ships' hulls when moored against the sides of the mole.[11] Further, in view of the presence of these verticals along the sides of the mole, Knoblauch prefers the second alternative already mentioned by Schläger, but rejected by him: the use of double-walled formwork.[12]

Valuable new evidence for concrete and formwork construction has been provided by Enrico Felici's study of Roman harbor sites in Latium, notably Antium and Astura.[13]

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used. Schläger does not propose a date; Knoblauch suggests the fifth–sixth century C.E., but I would prefer the later second century C.E.

[9] Schläger, "Die Texte Vitruvs," 150–53 and figs. 3–5; Knoblauch, *Die Hafenanlagen*, 28–31 and figs. 5, 71, 74.

[10] Schläger, 153–54 and fig. 6 (*südöstlich* on p. 153 is a mistake for *nordwestlich*); Knoblauch, 29–31 and figs. 75–77.

[11] Knoblauch, 30 and fig. 78.

[12] Schläger, 156–60 and figs. 7–8; Knoblauch, 31 and figs. 79–80.

[13] Well published in the first volume of the new *Archeologia subacquea* (1993), 71–104: "Osservazioni sul porto neroniano di Anzio e sulla tecnica romana delle costruzioni portuali in calcestruzzo."

In this chapter I can only highlight certain details of his work; the article deserves close attention by those interested in the subject.

Antium must have had a port since the Volscian period, but the principal ancient remains belong to the large-scale work undertaken under Nero (as attested by Suetonius *Nero* 9). We are thus dealing with work carried out half a century after Caesarea (and probably somewhat later than Les Laurons).

The archaeological remains had already received attention in the nineteenth century C.E. and again in the twentieth century, by Lanciani, Lugli, and Schmiedt.[14] The port has converging moles: the E mole runs S and then curves slightly W; the W mole runs S for about 100 m. from the shore and then turns E to run parallel to the coast for about 850 m., overlapping the head of the E mole to provide a protected harbor entrance, opening eastward and thus protected from the dominant southwesterly storms (Libeccio and Ponente).

Many previous researchers, including myself, had thought that the moles of the Neronian port were built with a system of separate *pilae,* linked by arches, to avoid the harbor infilling with silt brought by the littoral current. But Felici insists that there was no such use of *pilae;* in any case, he thinks that they would have provided insufficient protection on this exposed coast.[15] Lugli also thought that there were circular apertures through the moles to help with de-silting, but Felici puts forward two arguments against this: (1) the littoral current was not powerful enough to transport silt (and I should guess that in that case it was also too weak to scour the harbor basin); (2) in any case, according to Felici, modern harbor engineers contest the idea that such channels would help with the siltation problem (on which I would comment that nevertheless we cannot exclude a priori the possibility that Roman harbor engineers believed that they *would* help).[16]

Most of the remains of the moles are now rubble piles submerged to a depth of 1–8 m., but two sections of the E mole and three sections of the W mole still break surface.[17] These structures were built of *opus caementicium* (pozzolana and tufaceous chips); the horizontal layers of the successive "casts" are clearly distinguishable – in color, quality, or thickness – and there are also vertical junction lines. The above-water superstructure was faced in *brick,* and under water a large number of cavities in the concrete, thoroughly studied by Felici, attest the use of formwork.

In the E mole two "blocks" still emerge from the water, rising to 1.20 m. above sea level; there is a passage between them, which according to Felici is clearly not origi-

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[14] See esp. G. Lugli, "Saggio sulla topografia dell'antica Antium," *Rivista dell'Istituto Nazionale d'Archeologia e Storia dell'Arte* 7 (1940), 153–88; other references in Felici. Lugli and Schmiedt exploited the first air photos of Antium, taken in 1939.

[15] Personal communication, Nov. 27, 1994.

[16] Evidence for de-silting methods: Blackman, "Ancient Harbours in the Mediterranean," *IJNA* 11 (1982), 199–202 (referring to de-silting channels at Mytilene, Egnatia, Centumcellae, and Caesarea Maritima).

[17] "Blocchi est I/II"; "blocchi ovest I/II/III" – counting outward from the shore. Introduction: Felici, "Osservazioni," 73–74 and figs. 4–6; E mole: 74–76 and figs. 7–11; W mole: 77–81 and figs. 12–20.

nal. Both blocks have many traces of the timber formwork, as holes or impressions in the concrete. Felici's analysis has shown that the moles were built out from shore with a recurring "module," with horizontal cross-timbers about 1 m. above sea level and extending across only part of the width, and vertical timber piles descending to the seabed, at intervals of ca. 2.5 m.[18] Submerged to the E of these two "blocks" are some large portions of similar nucleus, which leads Felici to suppose that the mole was originally twice as wide (ca. 12 m.). If so, then the original construction method was to build out from shore parallel pairs of concrete blocks ca. 6 m. wide and 2.50 m. deep, in a sort of advancing checkerboard pattern, with timber formwork needed around two and three sides alternately (and probably removable for re-use when the concrete was nearly set).

In the W mole three "blocks" still emerge above sea level, rising to various heights. The gaps between them are not original – in fact, from its base to the N edge of the outermost of the three "blocks" the mole is built on a solid concrete platform (*platea*), wider than the mole itself. This platform has a clear outer edge, and immediately beyond it "Block III" was built directly on the sandy seabed.[19] The imprint of the timber shuttering of the formwork is clearly visible on the E side of "Block III," and some slivers of timber survive on the W side. Felici adduces as parallels the imprints found at Side, Portus, Carthage, and Cosa (the piers on the breakwater).[20]

On "Blocks" I and II remains of the *super*structure are also visible. "Block I" seems to have the complete sequence of eight "casts" or levels above the *platea*, and one of them seems to have been a walkway, since it is at the same height as the floors of structures behind the shore platform (the *grotte*), and the level above has traces of brick facing. Some vertical timbers seem to run up into this level all the way from the seabed.

The shore platform or *platea*[21] can be discussed only briefly, and it must be stressed that reinforced shorelines and riverbanks must be treated as a distinct category requiring specific construction methods, which are not necessarily identical with those of free-standing harbor structures. The shoreline at Anzio facing the harbor basin was built up with layers of concrete, cast in blocks within formwork, which may have been at least partly removed as the work progressed. A large number of vertical post-holes are traceable up to the surviving upper surface of the platform, and others may lie buried still within the concrete. The seaward edge probably served as a quay; Felici estimates

[18] Felici, 76 n. 19, compares the intervals of ca. 2 m. at "Sidone" (read "Side").

[19] I am grateful to Felici for further discussion of this point. He confirms that there is no evidence here of any subsidence, and thinks that this is because of the effective use of vertical timber piles (*destinae*). This is clearly a factor not to be underestimated.

[20] Felici, 79 n. 20, and references there. His references to the Cosa publication (E. K. Gazda in A. M. McCann et al., *The Roman Port and Fishery of Cosa* [Princeton, 1987], 74–78, 81–82) show that he is thinking only of the breakwater piers: planking impressions on Pier 1 and the holes for formwork ties in Pier 2. Formwork was also used around the Spring House, but that is a very different type of structure (see below).

[21] Felici, 82–85 and figs. 21–23.

its original height at 2 m. above mean sea level. However, no remains survive of any mooring facilities (e.g., bitts) or other features indicating a quay face (e.g., steps). As has been mentioned already, this same *platea* formed the foundation for the first part of the W mole (which cannot have been arched – at least not at or below sea level). Felici firmly dismisses Lugli's theory that there was a *darsena* at the base of the W mole.[22]

As for the area west of the W mole, including the "West Moletto," clear evidence was found for the insertion of vertical timbers at mid-height in concrete construction; and good clear imprints were found of the bottom edge of the timber shuttering in a layer of mortar – that is, to hold the shuttering fast and to relieve pressure on the vertical timbers.[23]

The mole at Astura probably dates from the first half of the first century C.E.. Its first section, running out from the shore, provides evidence of a somewhat different construction method: a series of *pilae* were built, apparently on a solid platform or *platea;* and then the space between them was filled in, by setting a long horizontal beam longitudinally between the *pilae* and fixed into them, and then laying transverse timbers, and also oblique timbers set into the *pilae* themselves; the longitudinal beam was supported by vertical *stipites*. The oblique timbers (*catenae*) seem to have held the outer formwork on the long sides, within which were poured levels of cementwork different from that of the *pilae*.[24]

It is not clear whether there was any interval between the two construction phases – the construction of the *pilae,* and the infilling between them – but certainly in the second phase the *pilae* became a key structural element in a continuous mole. There are in fact some indications of an interval in time between the two phases: the W side of *pilae* II and III, later covered by the concrete fill of phase 2, originally had brick facing.

Thus two of the northern *Bogenmolen* (arched moles) proposed by Lehmann-Hartleben are in considerable doubt, and the only candidates left in Latium are those at Terracina to the SE and Centumcellae to the NW. We may have to regard *Bogenmolen* as an almost purely Campanian phenomenon, and especially of the Phlegraean area: for example, Puteoli, Misenum, and Nisida. Felici thinks that the purpose of the construction method used at Astura was to save time and money – caissons were complex and costly to construct. It is worth recalling that Lehmann-Hartleben never maintained that the purpose of *Bogenmolen* was harbor de-silting – it was just the new, *economical* fashion.[25]

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[22] Felici, 83 n. 26.

[23] Felici, 85–88 and figs. 24–30.

[24] Felici, 91–92, figs. 36–37 and pl. I; for the combination with oblique *catenae*, Felici (n. 34) compares Cosa, where Pier 2 seems to have had one diagonal timber within the formwork. For Schmiedt's air photo and plan see Blackman, "Ancient Harbours," 89, fig. 6.

[25] K. Lehmann-Hartleben, *Die antiken Hafenanlagen des Mittelmeeres, Klio,* Beiheft 14 (Leipzig, 1923; repr.

There have been many references to the correspondence, or not, of the remains of concrete and formwork construction that have been studied in recent years, with the methods described by Vitruvius. This has encouraged me to include a third site studied by Felici, as a rather extreme example of deviation: the port-canal of Circeii.[26] Felici describes the structures at the head of the N mole (probably Neronian), of which the principal feature is the *re-use* of massive lumps of concrete, some still preserving a facing in *opus reticulatum.* Between them was laid a network of timber beams, with some of the vertical beams inserted into holes dug through the reticulate facing of the concrete. The horizontal timbers will have held side shuttering, and then concrete must have been poured over the internal timber framework.

This is very rough and ready work, but on reflection one sees that it is much like many modern harbor structures in the Mediterranean, where the remains of ancient harbor installations have been incorporated as foundations; and what is more, if one assumes that the re-used lumps of concrete were too massive to have been transported for re-use, then they would have had the advantage of being settled, solid foundations. The possibility of subsidence of harbor structures into the seabed, and the causes of this, are an important subject which deserves fuller treatment than is possible here.[27]

In his general discussion of building methods, Felici notes that at Antium we see the use of the flooded type of caisson, made possible by the use of pozzolana, and attested by the imprints of the side shuttering set into fresh mortar; he points out that at a site like Antium it would have been more manageable to fix the rectangle of piles (*destinae*) into the seabed and then add the shuttering: use of this quick-setting mortar made possible (according to Felici) a modular construction, using segments already set as one or two sides of the next caisson. Felici also suggests that the absence of traces of timber shuttering at the internal vertical joints indicates that where possible the shuttering was removed and re-used; he agrees with Oleson's argument that the mortar was brought to the bottom in tubes, and notes that at Antium, as elsewhere, the imprints of the *catenae* are found at sea level or above. He stresses that water level provided a demarcation between building methods: the more complex timber armatures were assembled *above* water level.[28]

Felici also refers to the caisson of Les Laurons, which he thinks was not intended to

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Aalen, 1963), 163–68; essentially a Campanian phenomenon: 167; purpose: 168. Blackman, "Ancient Harbours," 83–85 and nn. 18, 27; 197 and n. 86 (cf. 87, fig. 5 for the Stabiae wall painting showing an arched breakwater; 195, fig. 7 for the arched mole at Puteoli). Add now S. E. Ostrow, "The Topography of Puteoli and Baiae on the Eight Glass Flasks," *Puteoli: Studi di storia antica* 3 (1979), 77–140. Felici, personal communication, Nov. 27, 1994. The piers at Cosa (in Etruria) do not belong here, in my view (though a wooden gangway may have run across them).

[26] Felici, 93, fig. 38 and pl. II.

[27] See Blackman, "Ancient Harbours," 196–97.

[28] Felici, 95–99.

be watertight, even though it had a floor. Examples cited of formwork which *was* intended to be watertight are rather shore embankments than freestanding harbor-works: Felici quotes as parallels the shore embankments of Lake Nemi and the river port of Minturnae.[29]

A fascinating new example of timber and concrete construction in a shoreline embankment, serving as a quay, has been discovered in the new excavations at Marseille (Place Jules-Verne site). So far the excavator, Antoinette Hesnard, has published only brief reports and a few illustrations. The reports speak of quays "built in timber or in wood according to the techniques described by Vitruvius for hydraulic works." I quote one passage in full: "The humidity of the terrain has preserved the timbers of a caisson and the planks lining the foundation trench of a great quay with very deep foundations. The timber quay is formed of two rows of piles, between which planks are inserted, re-using fragments of ships' timbers, lying on a bed of clay. The interior is filled with stones. Three buttresses, carefully shored, reinforced the construction against the pressure of the earth behind."[30]

Most of this text and most of the illustrations refer to the timber quay in front of the *dolia* store (first–second century C.E.), which reminds one of the Roman quaysides of northern Europe, for example, London, but one illustration depicts "a Roman quay of the early first century C.E., with a view of the foundations in hydraulic concrete and the timbering of the construction trench." We eagerly await a full description and discussion.

What *is* clear is that the techniques used in building solid shore embankments (*berges renforcées*) and shoreline quays are not necessarily the same as those used in building freestanding moles and breakwaters.

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[29] Felici, 97, n. 45 (p. 98); see also C. F. Giuliani, *L'edilizia nell'antichità* (Rome, 1990), 133–34 and figs. 5.8–9.

[30] See esp. A. Hesnard, "Place Jules-Verne," in *Le temps des découvertes: Marseille, de Protis à la reine Jeanne* (Marseille, 1993), 55–59, esp. 57, 59 (top picture); more general accounts in Hesnard, "La découverte du port romain," *Méditerranée* 1 (March–April 1994), 32–37; A. Hesnard and M. Pasqualini, "Port et navires romains de Marseille," *Archéologia* 290 (May 1993), 32–33.