The International Journal of
NAUTICAL ARCHAEOLOGY

The International Journal of Nautical Archaeology (2014) ••.••: ••–••
doi: 10.1111/1095-9270.12073

Construction Features of Doel 1, a 14th-Century Cog found in Flanders

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In 2000, a well-preserved, *c.*21 m-long shipwreck, Doel 1, was found upside-down in a silted-up creek near the river Scheldt (Belgium). An interdisciplinary research project was initiated, including 3D registration of all timbers, wood species identification, dendrochronology and archaeobotanical analysis of the caulking material. Doel 1, of which 70% is preserved, displays the construction features of a cog. Unseasoned wood was used and dated by dendrochronology to AD 1325/26. Remarkable features include the symmetrical layout of the bottom planks, the atypical arrangement of the frames to the fore, and evidence of partial dissassembly of the ship after intensive use.

Key words: maritime archaeology, cog, ship construction, 14th century, Flanders.

In the summer of 2000, a new dock near the town of Doel (municipality of Beveren) in the harbour of Antwerp, was under construction (Fig. 1). The infrastructural works located on the left bank of the river Scheldt were the object of a watching brief by the regional Archaeological Service Waasland (ADW). In August, the remains of a ship came to light. It was a nearly complete shipwreck, lying upside-down, in a silted-up medieval channel. In only eight weeks, the ADW disassembled the *c.*21 m-long wreck. Based on its construction features, the ship was identified as a cog, after which it was popularly referred to as 'the Doel cog'. The definition of late medieval vessels identified as cogs has been discussed in many publications, such as Maarleveld (1995); Weski (1999a, 1999b and 2006); Crumlin-Pedersen (2000); Englert (2000); Ellmers (2010); Paulsen (2010) and Jahnke (2011). In this paper 'cog' is used as an archaeological term, as described by Crumlin-Pedersen (2000).

Figure 1. Find location of Doel 1 at the Deurganckdock, near Antwerp, Belgium. (Drawing: Glenn Laeveren)

Given that no remains of its cargo or ballast were found, and that there is little archaeological context for the find, it was necessary to study all of the ship's components meticulously in order to provide a typological and historical framework. The aim of this article is to give a thorough description of the recorded ship timbers and construction features. Relevant information gained through other scientific disciplines, such as dendrochronology (Haneca and Daly, 2014) and archaeobotany (Deforce *et al.*, 2014), will be mentioned as appropriate.

Location, excavation and storage

The find location, near the town of Doel, is on the left bank of the river Scheldt, downstream and across the river from Antwerp (Fig. 1). Deurganck or Tonnekin was the name of a late medieval waterway which ran eastwards into the river Scheldt, then called the Honte. This river was not only an important artery for inland transport but also served for several centuries as the border between the county of Flanders (a fiefdom of France) and the duchy of Brabant (part of the Holy Roman Empire).

The area was an intertidal zone with surfacing peat and heath, woodland and thickets, cut by tidal creeks

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Figure 2. Doel 1 during its recording in the field. (©ADW)

that ran into the Honte river. One of these creeks, the Tonnekin, was mentioned in 1257 as the border between the parishes of Kieldrecht and Kallo. Further inland was an important peat-extracting area in the mid 12th–14th centuries before the creek was finally dyked and reclaimed in 1567. An early 15th-century settlement and small harbour located near the findspot was discovered during the works on the dock (Soens, 2009: 136–40; Soens *et al*., 2013a: 3–10; Soens *et al*., 2013b: 15). Furthermore, in 2002, a 14 m-long fragment of the carvel-built bottom of a second wreck (later referred to as Doel 2) was found and salvaged *c.*54 m north of the first wreck (Van Roeyen, 2004: 65–76).

During the construction works, the activities of the ADW were focused on recording the prehistoric occupation and the palaeo-environment, until a mecanical excavator dug up parts of a large wreck, situated under 7 m of sandy sediment containing shells and remains of peat (Fig. 2). Due to the lack of ship-archaeology expertise in Belgium at that time, at the request of the Institute for Archaeological Heritage (now Flanders Heritage Agency—FHA), a team from the former Netherlands Institute of Ship and Underwater Archaeology in Lelystad (NISA, now RCE Lelystad) came in to assist. Karel Vlierman of the NISA, together with the ADW and several volunteers, documented the wreck in the field (Van Roeyen *et al*., 2001: 468–84; Terfve, 2001: 9–16; Van Hove, 2005: 50–69; Vlierman, 2006: 29–32).

During the excavation all timbers were numbered according to their position and function in the wreck (Fig. 3). Hull planks are labelled ‘G’, for *gang* (strake), sequentially from GA for the garboard to GR for the sheer. For each strake, the planks are numbered from the aft to the fore. A second number indicates when a single plank was sawn for disassembly, and ‘BB’ (*bakboord*, portside) or ‘SB’ (starboard) indicates the side of the ship, for example GD3-1BB and GD3-2BB. Framing is indicated with an ‘S’ for *spant*. In total, there are 40 numbered frame stations (S0 to S39) and three additional frame stations, based on the treenail holes on one plank, situated abaft S1, thus giving a total of 42. Futtocks situated above the floor timbers were given an ‘a’, ‘b’ or ‘c’ the higher they were positioned in the ship, for example S32b-SB. Ceiling was labelled ‘W’ (*wegerplanken*) and chocks ‘K’ (*kattesporen*), and other timbers were labelled with their full function name in Dutch, such as *kielplank* (keel plank), *zaathout* (keelson) and *voorsteven* and *achtersteven* (stem and sternpost, respectively).

On site, 18 samples for dendrochronological research were taken and analysed at the Ring Foundation in the Netherlands. A construction date in the second quarter of the 14th century was determined, as two of the examined ship timbers had a felling date between the summer of 1325 and spring of 1326 (Hanraets, 2000).

The wreck was then disassembled, since lifting the remains in one or more large pieces was not feasible. The hundreds of pieces of timber were carefully placed in 29 purpose-built open containers filled with water and stocked in a field. Only at the end of 2009, nine years later, was a four-year research programme approved, under the name ‘De Kogge’. At that point the wreck was retroactively designated as Doel 1. As a first step, the containers were finally covered, after removal of the many plants that had grown on the wood in the upper parts.

Project set-up

In 2010, facilities at Flanders Hydraulics Research near Antwerp were made available to the FHA where a cleaning and documentation laboratory was set up. The research programme was intended to be multidisciplinary and included detailed recording of the ship timbers, dendrochronological analyses, botanical examination of the caulking material and analysis of the tar. One of the main goals of the archaeological

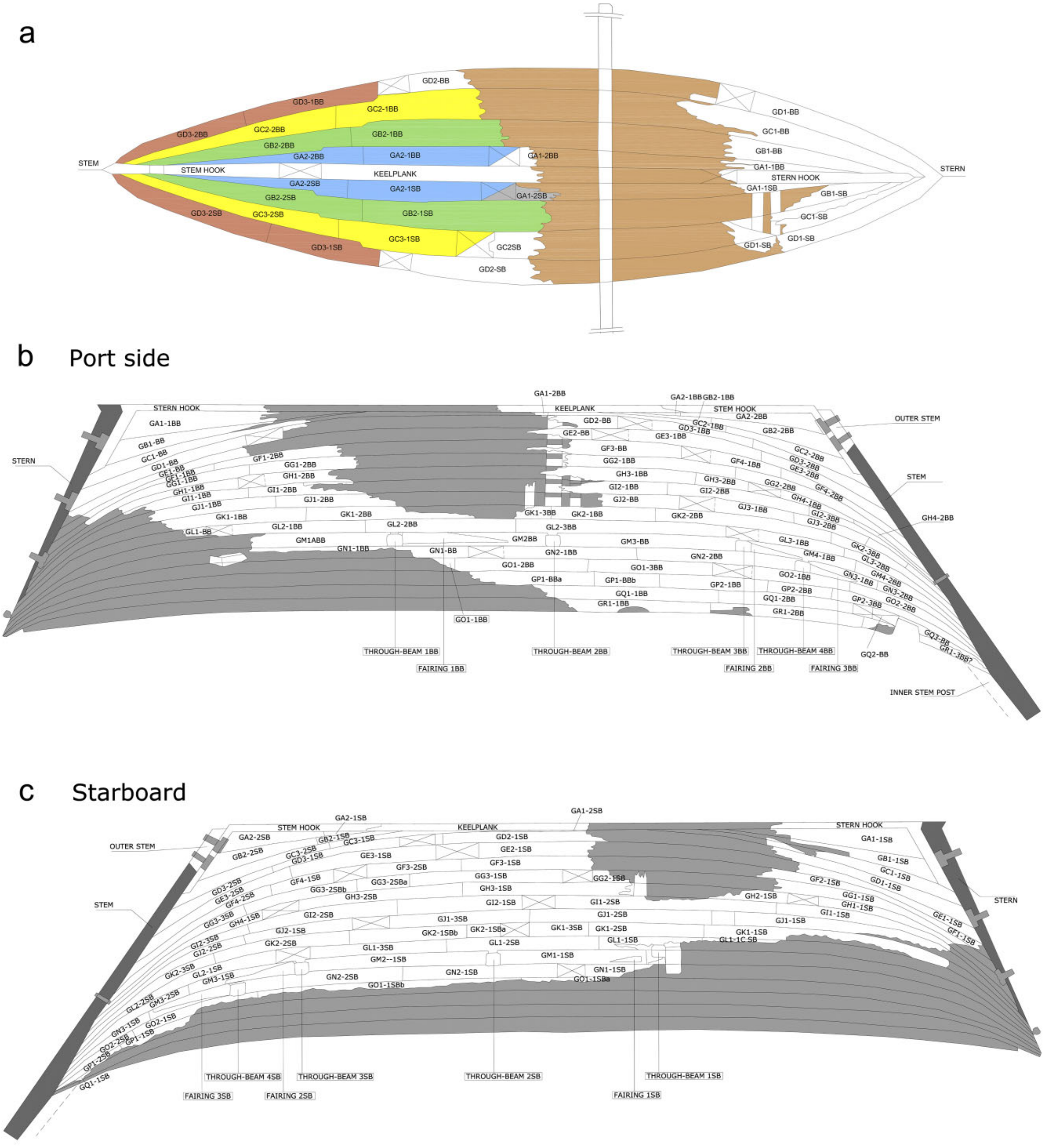

Figure 3. *a)* Schematic drawing of the *c.*14 m-long carvel-built bottom of Doel 1. Planks fashioned from the same tree trunk have an identical colour (see Haneca and Daly, 2014: 95–6), grey indicates the missing parts of the wreck; *b)* schematic view of the portside; *c)* schematic view of the starboard side. (All drawings: Johan Van Laecke)

research and detailed 3D-registration of the ship timbers was to create a scale model representing the original shape of Doel 1.

In the laboratory, before the timbers were cleaned, samples were taken and all ship parts were given unique numbers (K1-001 to K1-744). In total 358 samples were taken from the various ship components to study the caulking material, the chemical composition of the tar, for wood species identification, and iron and sediment analysis. The sawn ends of the planking and the joggles of the frames served as ideal surfaces for the dendrochronological examination, whereby 150 tree-ring series have been studied (Haneca and Daly, 2014).

All sides of the timbers were photographed with a camera mounted on a horizontal rail located above the research table. Additional photos were taken with a hand-held camera. The timbers were then described and sketched on a wood-recording form, similar to those used on the Newport Medieval Ship Project, on which both construction features and wood characteristics were described (see Nayling and Jones, 2014: 244–5). The timbers were recorded in 3D with a FARO-arm, coupled to a layered database system, based on the system used at the Archaeological Workshop at the Viking Ship Museum in Roskilde (Jones, 2009; Lenaerts *et al*., 2011a; Lenaerts *et al*., 2011b). Wood condition was assessed in view of the later conservation process (Jensen *et al*., 2011). After recording and sampling, the timbers were carefully stacked in containers, awaiting desalination and conservation.

Construction

Condition of the vessel

Doel 1 is a very well-preserved cog. Nearly all elements of the hull are present. Most of the bottom and side strakes were preserved, as well as some of the internal construction, such as the framing, ceiling and through-beams with their fairings. An estimated 70% of the original ship is present. This makes it one of the better-preserved cogs found to date.

Some of the planking and many other parts, such as the heavy through-beams, were broken as a consequence of the ship being inverted. Fortunately, the wreck had gradually filled with riverine sediment, which served as a good support preventing the hull from sagging completely. However, the weight of 7 m of overlying sediment had caused the hull to flatten and spread. Moreover, most of the iron parts, such as bolts, nails and sintels, had corroded away. The most obvious recent damage is the large gap in the bottom of the ship, created by the mechanical excavator at its discovery. The gap is situated just abaft of midships, between frames S8 and S15, over *c*.3.7 m of the keel. The gap in the hull extends up to the 11th strake (GK) to port and the 9th strake (GI) to starboard. According to the ADW, about 20% of the hull was damaged by the machine (Van Hove, 2005: 51). Unfortunately, none of the timbers dug up by the excavator were recovered.

The wreck thus showed both recent and historical damage, and some parts were absent. Even though the ship was upside-down in the mud, most of the upper edge of the hull was missing with only a short stretch of port sheer-strake (GR-BB) towards the bow present. The rudder, the outer sternpost and most of the outer stem were missing, as was a large part of the after part of the planking and framing. Hence, no remains of a sterncastle have been found. Little survives of the internal arrangements: there are no stringers, standing or hanging knees, or deck. Furthermore, no direct or indirect traces of rigging, such as rope, capstan, mast or sail were found in or near the ship, nor remains of any ballast or cargo.

Disassembly in 2000 resulted in some unavoidable damage. In particular, the ceiling planks, the last element removed, were difficult to separate from the framing. However, fragmentation and deformation of these planks both during the use of the ship and while it was buried cannot be excluded.

Keelplank

The backbone of the ship consists of the keel and inner posts, connected by a stem-hook and stern-hook. As with most cogs, the keel is a plank (0.33 x 0.13 m), with a preserved length of 5.33 m fore of the gap, the rest is missing (Fig. 4). Given the gap is an estimated 3.7 m, it cannot be said whether the keelplank consisted of one piece or two. Tree-ring research cannot offer a definite answer since only one part of the keel could be analysed. However, the keel—consisting of one or two pieces—can be estimated to have had a length of *c*.9.27 m, taking into account the partly preserved scarf length of the stern-hook aft of the gap.

The underside of the keelplank is slightly convex in section, and it still shows a large amount of sapwood on its edges. The presence of sapwood allowed an estimation of the felling date for this timber of between 1307 and 1327 (95.4% confidence interval) (Haneca and Daly, 2014: 92). If the keel was cut earlier than the other ship timbers (dated to AD 1325/1326) it must have been stored, probably under water to avoid biological deterioration. This latter technique is referred to as ponding, which can improve the wood's workability and stability (Haneca and Daly 2014: 97).

No tool marks were observed on the keel. On the inboard face, mostly situated under the frames, pairs of *spijkerpennen* near the edge of the timber are visible. They indicate the temporary use of small cleats (*boeiklampen*) which held the keel and bottom planking together before the floor timbers were inserted (Witsen, 1671: 150, fig. R; Van Yk, 1697: 41).

The inboard face has a horizontal surface to which the floor timbers were connected with pairs of treenails, 0.035 m in diameter. Some unfinished treenail holes are visible on the inboard, which indicate that most, if not all, of the holes were drilled from the inboard of the keel with a spoon auger, the exact type of which could not be distinguished. At each frame one of the two holes passes entirely through the keel. The keel was connected to the stem-hook by a nibbed scarf, 1.10 m long, with four parallel rows of four nails each. At least one row was nailed from the outboard.

Hooks and posts

Well-preserved hooks connect and form the angle between the keel and the inner stem and inner sternpost

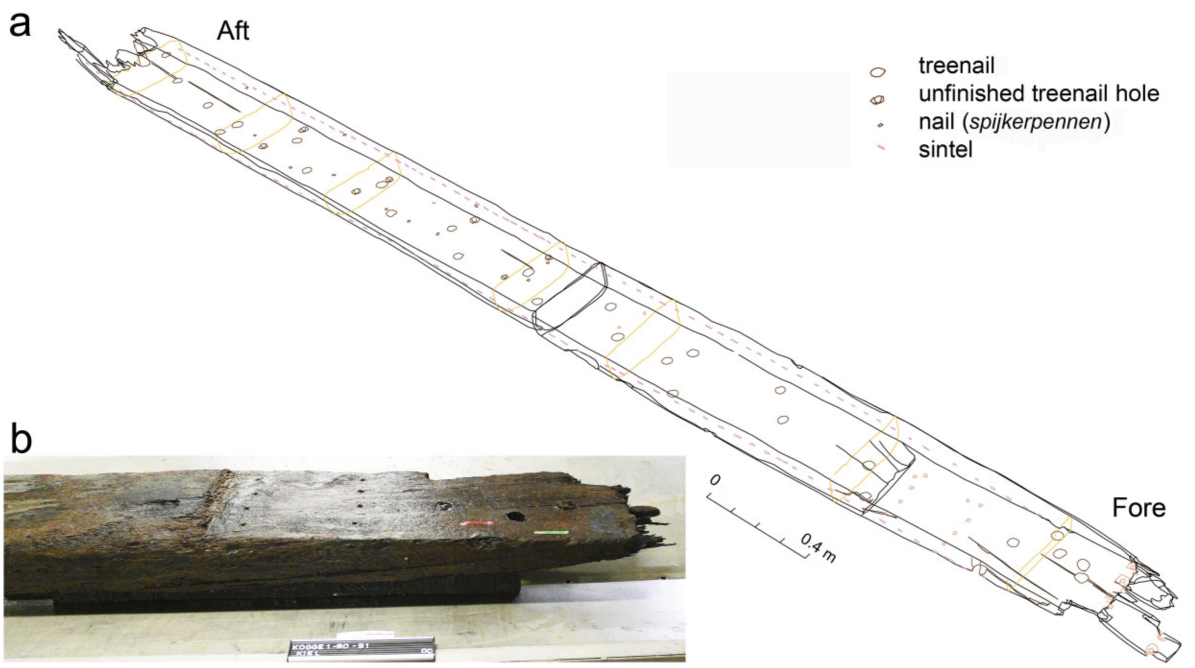

Figure 4. *a)* Simplified 3D-drawing of the 5.33 m remains of the keel (Drawing: Johan Van Laecke); *b)* outboard of the keel showing forward scarf used to connect the stem-hook. The two most forward nail rows broke off before taking this picture. (FHA)

Table 1. *Basic measurements of both hooks. Measurements marked > are incomplete*

	Horizontal length (m)	Vertical length (m)	Angle (°)	Length of scarf (m)	Max. Sided/ moulded (m)
Stem-hook	2.98	1.272	136	1.095	0.290/0.275
Stern-hook	>3.04	>1.03	126	>0.244	0.217/0.274

(Table 1). The combined length of the horizontal parts of the hooks and the keel is an estimated 14.17 m. The outer stem and outer sternpost had been joined by treenails and nails or bolts to the outboard face of the inner posts. Only a fragment of the outer stem was recovered.

The stern-hook was shaped from the trunk of an oak tree with a substantial, naturally curved side branch (Fig. 5 and Table 1). On both sides of the horizontal part of the stern-hook, a row of sintel holes indicates the position of the garboard. On the fore end of the hook, the horizontal scarf connecting the keel was damaged by the mechanical excavator and is incomplete, measuring only 0.24 m. Similarly to the keel, the bottom part of the hook is slightly convex in section. At the stern, it ends in a projecting skeg which protected the bottom corner of the rudder and the lower part of the outer sternpost. The upper arm is rebated on both sides to fit the hood-ends of the two lowest strakes. That part of the hook runs upwards into a scarf, where both the fragmentary remains of the inner sternpost and the missing outer sternpost had been connected by three treenails and several nails or bolts of varying sizes, as can be seen by the holes situated on the fore and aft side of the timber.The remains of the inner sternpost consist of five fragments, with a combined length of 1.6–2 m. Due to its fragmentary nature, its original form and size is difficult to discern. One of the larger fragments measures 0.22 m sided and 0.26 m moulded. On its sides about a dozen nail holes are related to the connection of the hood-ends of the planking, which end on three preserved rabbets. Large treenail holes present in the fore and aft part of the timber could be linked with the fasteners for frames, the outer sternpost or gudgeons.

The completely preserved stem-hook is also made out of a straight-grained tree trunk forming the horizontal part, with a side branch forming the upper arm. It has a slightly wider angle than the stern-hook (Table 1). Similarly to the stern-hook, the stem-hook receives the hood-ends of the lowest two strakes. The third strake is connected to both the hook and the inner stem. On the underside of the hook, three treenails along the axis, situated on the scarf, connected the

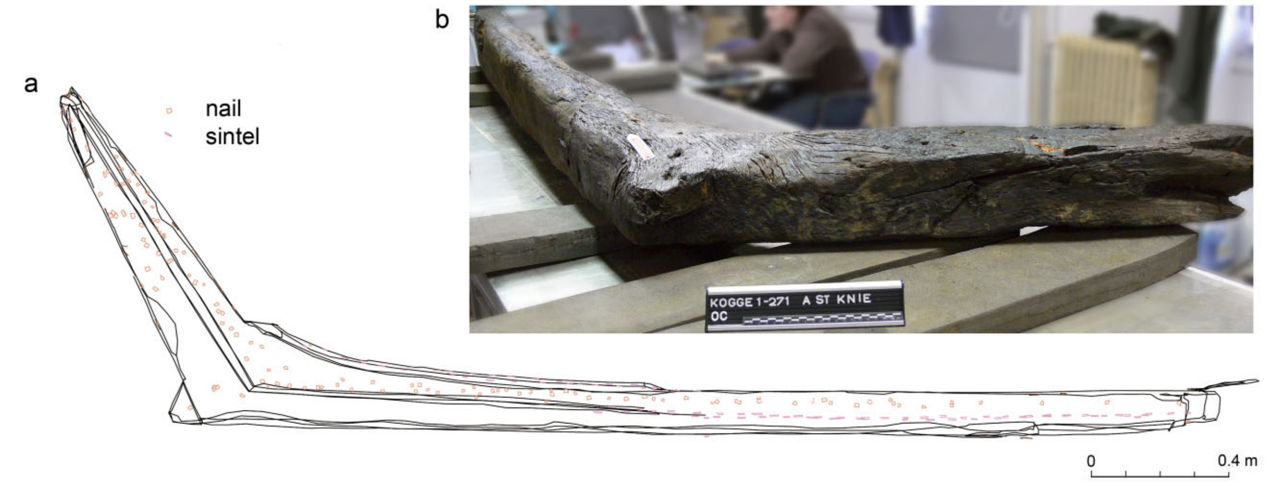

Figure 5. *a)* Simplified 3D-drawing of the starboard side of the stern-hook (Drawing: Johan Van Laecke), *b)* the aft and port side of the stern-hook showing the projecting skeg. (FHA)

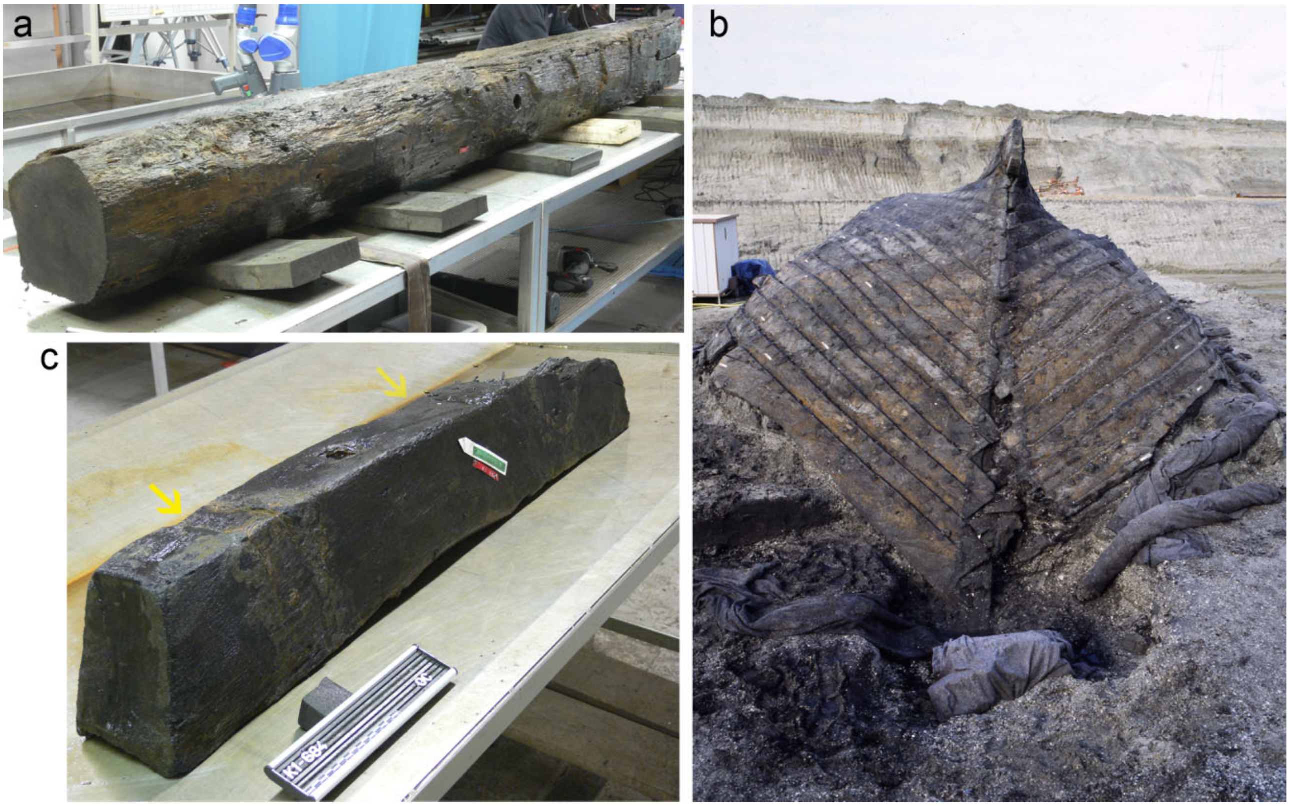

Figure 6. *a)* The upper part of the inner stem (*binnensteven*) of Doel 1, bevels to receive the planking can be seen on the upper outboard face of the post (FHA); *b)* the bow of Doel 1 showing strakes ending in pairs on the inner stem; the former position of the outer stem is visible on the planking (© ADW); *c)* the starboard side of the upper part of the outer stem; position of metal straps marked with arrows. (FHA)

frames. Four transverse rows of four nails, situated on the scarf, connected the keelplank, as described above.

The inner stem was preserved almost completely, with a length of about 6.76 m, but had to be sawn in two for logistical reasons, following the guidelines described by Jones (2010: 10, 14 and 19) (Fig. 6 a, b). As a consequence, the tree-ring pattern could be recorded in optimal conditions. The inner stem has a 0.86 m-long scarf which was connected to the upper arm of the hook with two treenails (0.038 m diameter) with an interspace of 0.22 m. Higher up, the stem has a rounded pentagonal profile in the lower part (0.253 m sided x 0.277 m moulded) with a convex curve to the outboard, which becomes rectangular in profile towards the upper part of the timber (0.280 m sided x 0.150 m moulded). Past the scarf, the post has five treenails (0.045 m diameter) with an interspace of 0.63–1 m that connected the inner with the outer post. The outboard face of the bottom of the post is bevelled to fit the hood-ends of the strakes, which end on the post in pairs.

A small fragment of the lower part of the outer stem was preserved (Fig. 3b, c and 6c). It measures 1.17 m in length with a sided dimension of 0.09 m, widening to 0.17 m and a moulded dimension of 0.20 m. It thus has a trapezoidal profile with a concave inner side. This fragment was connected with one large nail (0.014 m square) of which the head (0.044 m diameter) was situated in a countersink on the outboard face. The location of two metal straps with a width of 0.06 m are present with an interspace of 0.68 m. The position of the straps are sunk slightly into the wood, probably by hammering them into position. One or two smaller nail holes are present on each side as extra fastenings for these metal straps. The lower end of the outer stem is damaged but it is not clear how this occurred. The upper part shows a straight-sawn cut. Based on the inner post and its fastener holes, which are spaced at 0.90–1.30 m intervals, it can be supposed that the outer post had a greater width of *c.*0.30 m and was connected to the inner post with iron bolts. It would have served to protect the hood-ends of the strakes, the hooks and the inner post.

Planking

All types of planking are represented, from the garboard up to the sheer. The ship had 18 strakes which can be divided into the carvel-built bottom planks—which turn into lapstrake fashion towards their extremities (strakes GA–GD)—and the lapstrake side planks (strakes GE–GR) (Fig. 3).

No strake is completely preserved from stem to stern. In general, strakes would have consisted of three planks, with a maximum of four. All planks are made out of European oak (*Quercus robur* or *Q. petraea*) and most were tangentially sawn (Haneca and Daly, 2014: 98–9). Saw marks are not visible on the bottom planking but are often very legible on the inside faces of the lapstrake planks. They run at an angle of 77° to 80° in relation to the plank edge, and end towards each other at the saw-kerf-join scar (Goodburn, 1997: 35). Experiments carried out in England sawing baulks on a single trestle (see-sawing) have shown that it is feasible to saw 5.5 m-long timbers this way. Baulks longer than 6.2 m become more difficult to saw in this manner. It is therefore reasonable to believe that the sawyers of Doel 1 used a sawing method on two trestles (two higher trestles, or one high and one lower trestle) or a sawing pit with a frame saw, as seen on medieval depictions from the Mediterranean (Goodburn, pers. comm. 2013; Unger, 1991: fig. 57). Most hull planks were sawn close to the pith, resulting in many cracks running along the surface of the planks which required repair either during construction of the ship, or later, during its use.

It has been observed in some cogs that the planks are deliberately oriented with the pith side inboard, as on the Almere cog (Hocker and Vlierman, 1996: 27). However, this does not seem the case in Doel 1 (Haneca and Daly, 2014: 99, fig 13), and no particular pattern of pith orientation was observed, which might suggest the shipbuilder(s) did not consider this to be an important factor in the construction of the ship.

Planks within a strake were connected by plain scarfs (Tables 2 and 3), each fastened with three or four rows of nails that ran across the width of the planks. These rows were hammered in alternately from the inside to outside, or vice versa, and double-clenched. The outboard edges of the scarfs are caulked with a thin length of moss, lath and sintels. Scarfs vary in length with an average of *c.*0.89 m and a recorded range of 0.71–1.13 m for the bottom planks and an average of *c.*0.71 m (range: 0.26–0.89 m) for the lapstrake planking.

Treenail holes were recorded, spaced at intervals along the length of the planks of 0.29–0.89 m, which were used to join the frames. Generally, the centre-to-centre distance for the frames is 0.40–0.45 m. The hood-ends of the planks are connected to the hooks or inner posts by two rows of nails running parallel to the end of the plank. The remaining end of the plank, beyond the rows of nails, was bevelled off, as was observed also on the Bremen cog (Lahn, 1992: 49).

Bottom planks

The bottom of Doel 1 consists of four carvel-built strakes on each side of the keel. This part is clearly built according to the conceptual approach of bottom-based construction (Hocker, 2004: 65–93), as can be seen by the presence of the *spijkerpennen,* symmetry in the position of the scarfs and the mirrored layout of the bottom planks (Haneca and Daly, 2014: 95, fig. 12) (Fig. 3a).

During construction, the carvel parts were initially held together with temporary fasteners (*boeiklampen* in Dutch 17th-century literature) that were nailed over the plank seams on the inside of the bottom. After the instalment of the framing these fasteners were removed and the nail holes were filled with wooden plugs, called *spijkerpennen*.

The transition from carvel to lapstrake construction is clearly visible on plank GB2-2SB (Fig. 7). At this tab-and-rabbet arrangement an offset in the width was cut so that the plank becomes 0.09 m wider. This land serves as the overlap with which the upper strake is connected to the lower strake. The tab-and-rabbet arrangement between GA and GB occurs 3 m from the stem (Fig. 3a). During construction, this transition was strengthened with additional clamps, as can be seen by

Table 2. *Basic measurements of the bottom planks, strakes GA, GB, GC and GD on starboard (SB) and portside (BB). Measurements marked > are incomplete*

Strake	Complete reconstructed plank length (m)	Max. width (m)	Max. thickness (mm)	Scarf length (m)
GA1-SB	>3.02	0.31	35	—
GA1-BB	>3.45	0.31	42	—
GA2-SB	6.74	0.327	53	0.97
GA2-BB	7.04	0.345	53	0.89
GB1-SB	>2.29	0.41	46	—
GB1-BB	>3.87	0.38	46	—
GB2-SB	>8.31	0.42	47	>0.57
GB2-BB	7.74	0.55	45	>0.57
GC1-SB	>3.51	>0.32	63	—
GC1-BB	>4.53	0.43	50	>0.76
GC2-SB	>2.05	0.53	55	0.76
GC2-BB	7.77	0.47	54	0.84
GC3-SB	7.54	0.54	46	1.10
GC3-BB	—	—	—	—
GD1-SB	>4.07	0.38	45	0.71
GD1-BB	>4.05	0.37	48	0.81
GD2-SB	>4.21	0.39	60	0.91
GD2-BB	>2.33	0.38	65	1.13
GD3-SB	6.07	0.39	52	0.83
GD3-BB	6.25	0.37	68	0.885

Table 3. *Overview of the completely preserved lapstrake planks on starboard side with dimensions and features. Measurements marked > are incomplete*

Plank	Length (m)	Max. width (m)	Max. thickness (mm)	Av. nail interval (m)	Average treenail interval (m)	Scarf length (m)
GE3-SB	7.53	0.38	50	0.18	0.45	0.75
GF4-SB	5.81	0.39	45	0.163	0.49	0.89
GG3-SB	10.62	0.37	50	0.19	0.44	0.73
GH4-SB	5.30	0.35	50	0.18	0.49	0.44
GI2-SB	10.64	0.355	42	0.18	0.47	0.80
GJ2-SB	7.72	0.39	40	0.185	0.504	>0.66
GK2-SB	10.82	0.45	40	0.20	0.481	0.263
GL2-SB	6.85	0.355	50	0.159	0.476	0.87
GM1-SB	3.03	0.38	40	0.219	0.474	—
GM2-SB	4.175	0.388	40	0.19	0.415	—
GM3-SB	6.825	0.395	45	0.157	0.488	0.76
GN2-SB	6.84	0.36	50	0.161	0.439	0.82
GN3-SB	5.61	0.36	40	0.17	0.452	0.80

the extra *spijkerpennen* present on both the inboard and outboard faces of the bottom planks.

Amidships, at floor timber S16, situated just fore of the gap, the maximum width of the flush-built floor, the bottom between the bilges, is about 3.50 m.

It is difficult to discern the original lengths of many of the planks in the bottom part of the hull, because of the gap (Table 2). Some measure 7–8 m or more. In general, bottom planks are wider (0.55 m) and thicker (0.068 m) than those higher up in the ship (0.45 m wide and 0.05 m thick).

Side planks

The lapstrake-built sides of the ship consist of 14 strakes, GE to GR. As with bottom strakes GC and GD, these planks end in pairs on the outer face of the inner stem (Fig. 6b) and inner sternpost. Each strake usually consists of three planks covering the fore, middle and aft section of the ship. Strakes GF and GH consist of four planks, on both the port and starboard sides, while strake M consists of four planks only on the port side. On the starboard side 14 lapstrake planks were preserved to their full length (Table 3), while on the port side 13 complete planks were recovered. Their preserved width ranges from 0.37–0.39 m and they have a bevelled outer face with a maximum thickness of 0.04–0.05 m at the centre of the plank. The land, the bevelled strip of the plank onto which the overlapping plank is nailed, has a width of 0.07–0.08 m. There, the plank has a thickness of 0.03–0.035 m. One plank, GL3-1BB, has a square hole (0.13 x 0.11 m) cut out between frames S27 and S28 and is situated just below through-beam 3BB, fore of the scarf connecting GL3 with its aft plank GL2. The location might indicate its use as a window to allow ventilation and light into the cargo area.

Three fragments of the sheer-strake are preserved on the port side. The largest, GR1-1BB, runs from frame S18 to S26 (Figs 3b and 8). On the upper, forward edge, are two rebates for repair planks (which are missing) situated on both the inner and outer faces. A curved cut of undertermined function is situated in the same plank edge. Both of these features might relate either to the rigging or additional structures. Each frame was connected by three or four treenails to this plank, the majority situated in the lower half of the plank, indicating that extra strength in the construction was required in this area, possibly also related to the rigging. The position of the treenails in the lower part of the plank excludes that they were used to attach an inwale.

Figure 7. The outboard face of starboard hull plank GB2-2SB. The transition from carvel to lapstrake construction is clearly visible in the widening of the plank where adjoining garboard strake GA-SB becomes lapstrake. (FHA)

Framing

The ship's frames were labelled S0 to S39 from aft forward (Figs 9 and 10). Three additional stations evidenced by treenails aft of label S1 on plank GF1-SB were noted (S0, S-1 and S-2), giving a total of 42 frames. Based on the number of frames in the forward section of the ship, and through comparison with the Bremen cog, an additional seven frames can be estimated for the missing part of the stern.

Amidships, 10 horizontal floor timbers (average 0.22 m sided and 0.14 m moulded) were present forward of the gap (S15–S24) (Fig. 10). These cover the entire floor, the horizontal width of the bottom of the ship, and have one bilge scarf alternating to port and starboard. The floor timbers end either on strake GC or GF. The bottom parts have a maximum of eight cut-out limber holes (*c*.0.04 m high and *c*.0.08 m wide). The two central limber holes are located on the seams of the keel plank and the garboard strakes. Others are situated on the seam between strake D and E near the bilge, while limber holes on strakes B and C are situated over the middle of the planks. Towards the stern, at frames S0–S5, the central floor timbers are V-shaped and cut from a fork where both arms are at least partly naturally rounded. The outer faces of the frames are joggled to fit the lapstrake planks. The frames were probably initially fastened by nails driven through both the scarfs and sides of the frames into the planking. In most cases, a countersink was chiselled or cut into the wood to fit the nail head. In a second stage, holes were drilled through the frame and plank from the inboard to fasten them with treenails. In a few places, holes were drilled from the outboard, as can be seen by some half-worked holes.

The framing at S1 consists of two V-shaped floor timbers positioned one on top of the other (Fig 10a). At S3, two relatively flat V-shaped timbers, treenailed together, were placed atop another V-shaped frame. In these instances, the futtocks were connected to the uppermost V-shaped floor timbers.

Figure 8. *a)* The outboard face of GR1-1BB, rebate for repair plank marked with arrow (FHA); *b)* the outboard face of the modelled plank. (Drawing: Johan Van Laecke)

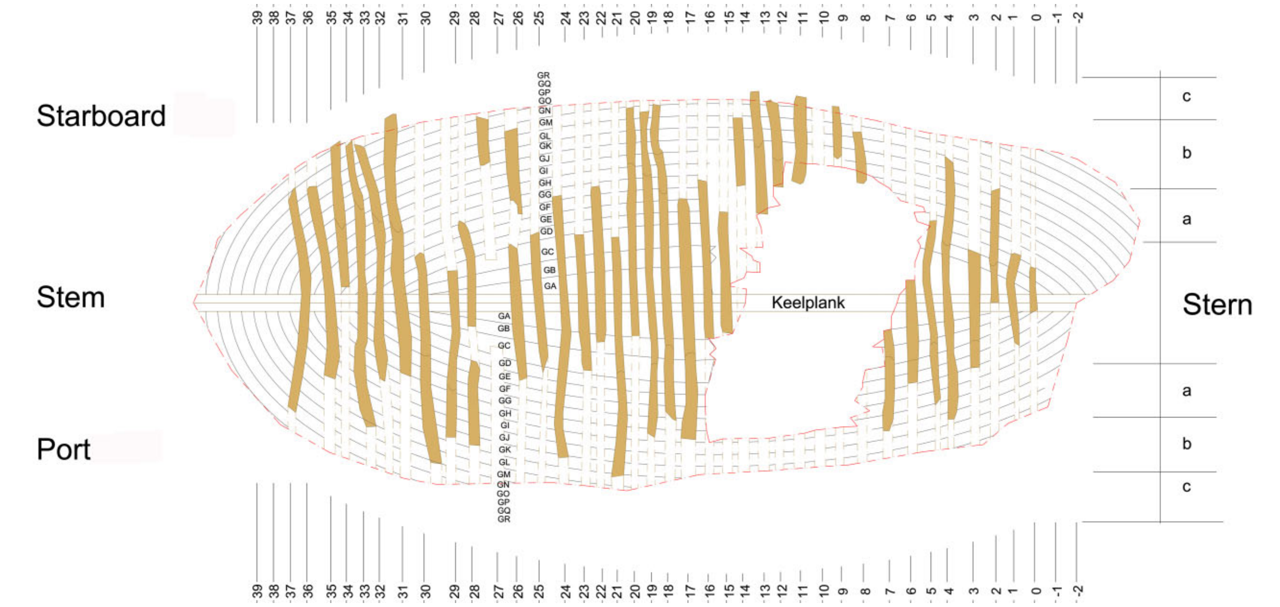

Figure 9. Schematic overview of the frames recovered from Doel 1. (Drawing: Johan Van Laecke)

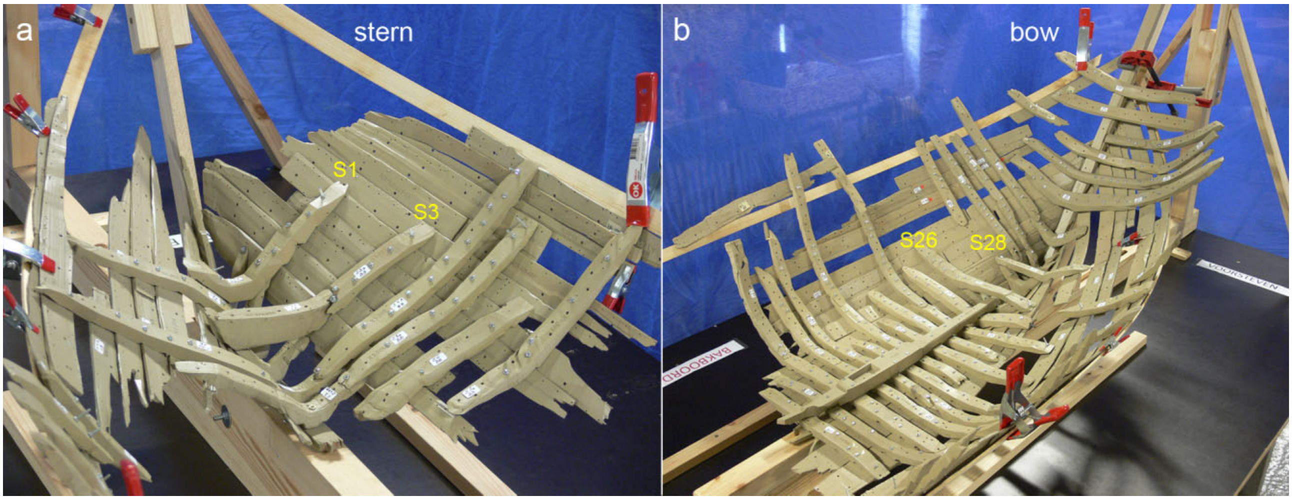

Figure 10 a) The aft part of the Doel 1 reconstruction model during assembly; *b)* the foreward part of the model during assembly. (FHA)

In the forward section, wider V-shaped floor timbers were used, cut from a trunk and a side branch. At frames S26 and S28, a knee-shaped timber sits atop, and is treenailed to, an underlying V-shaped floor timber. Each has an arm rising from one end that is joggled to fit the planking in the manner of a futtock. At S26 the arm lies to port (S26a-BB) and at S28 to starboard (Fig. 10b). At S27, no floor timber has been found and no treenail holes were present in the adjacent strakes to port or starboard. This gap in the framing pattern probably served to position a pump system but since no other traces on the wood have been found, the exact reason for this construction detail is unclear.

Two vertical stanchions were found in the fore part of the wreck near S26 and ceiling plank WA2-SB (Fig. 11). They measured 0.88 m and 1.22 m in length and have a square cross-section (*c*.0.11 x 0.11 m). On each stanchion, one end has a rebate, while the other end is broken. Since only two nail holes are present on one of the stanchions, their exact function and relationship to the framing remains unclear.

Futtocks which continue up the sides of the ship were joined to the ends of the floor timbers. A maximum of three futtocks on each side rise to the sheer-strake. The futtocks, cut from branches, vary in length from 1.40–3.41 m and generally measure *c*.0.14 m moulded and *c*.0.20 m sided but can vary slightly. S31a-BB, situated in the lower part of the bow section, stands out with scantlings of 0.35 m moulded and 0.34 m sided. Joggles were cut out with an axe in order to fit on to the lapstrake planks. Then they were

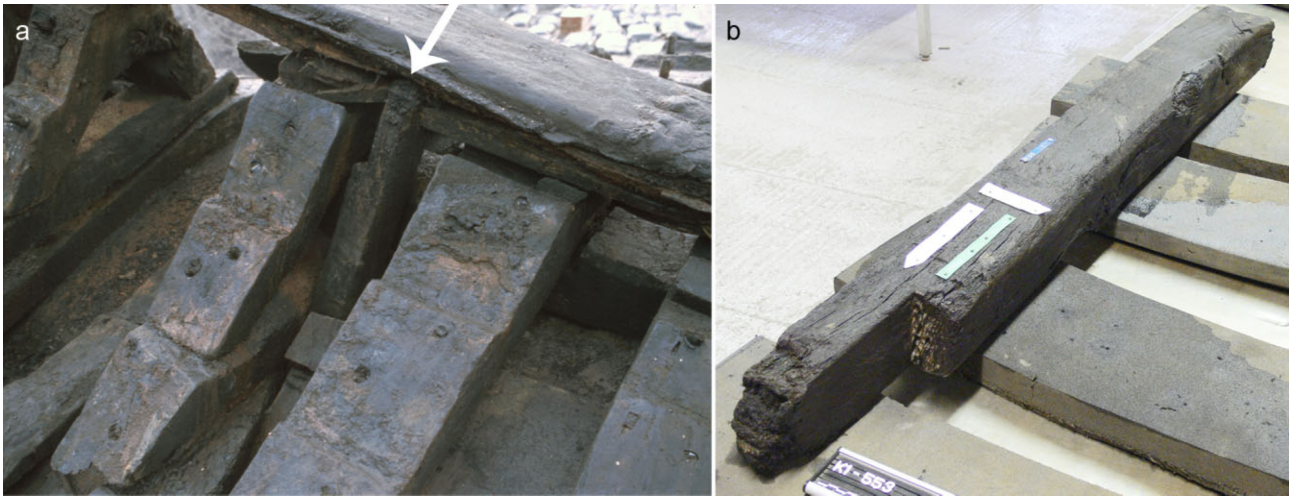

Figure 11. *a)* The bottom part of one of the vertical stanchions marked with arrow located just aft of S26 during excavation; *b)* view of one of the vertical stanchions. (FHA)

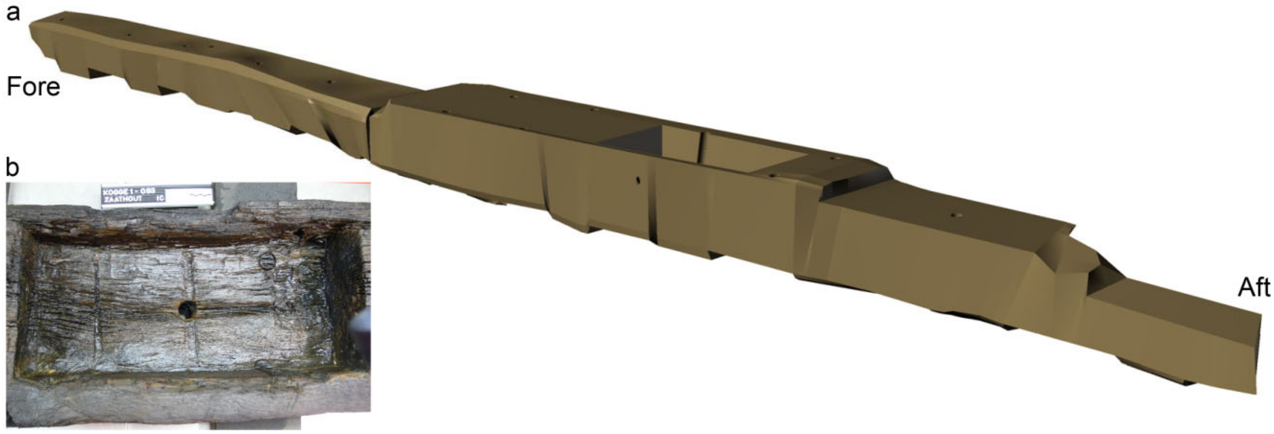

Figure 12. *a)* The 3D-modelled keelson (Drawing: Johan Van Laecke); *b)* the mast-step. Note the hole in the centre of the step which served to drain incoming water. (FHA)

joined to the underlying scarf and side planks, with nails that were hammered in chiselled-out counter-sinks. Once in place, treenail holes were drilled with an auger and treenails used to secure the futtocks to the ship.The scarfs between the floor timbers and the first futtocks are set alternately below or above the bilge (strakes GB/GC or GE/GF). The second set of futtocks starts at strakes GH or GK and ends between strakes GN or GP (Figs 9 and 10b). In the centre of the ship a third set of futtocks runs from GN or GP up to the sheer-strake. The uppermost futtocks, and those sup-porting the through-beams, are all cut horizontally at their top ends. The futtocks at S27, in the absence of a floor timber, are attached to the upper edge of strake GA, and run up to strake GJ.

Keelson and mast-step

An essential element in the ship construction is the keelson and its mast-step (Figs 10b and 12). The keelson is well preserved forward of the gap, where it runs from frame S15 to S26 and measures 5.46 m long, 0.30 m sided and 0.23 m moulded. A small part is preserved abaft the gap which measures 0.98 m long, 0.20 m sided and 0.18 m moulded. The main piece of the keelson has a central, bulky segment that houses the mast-step, located between frames S17–S19, measuring 1.80 m long, 0.37 m sided and 0.27 m moulded. The rectangular mast-step, 0.56 x 0.26 m, has a depth of *c.*0.11 m. In the centre of this mortise, a hole has been drilled to drain infiltrating water to prevent rot of the keelson and the lower part of the mast, which were valuable parts of the ship (Fig. 12b). The upper part of the keelson is slightly rounded in section, prob-ably following the curvature of the parent tree, while the bottom is notched over the floor timbers. The lower edges, between the frames, are bevelled on the under-side which can be seen as a means of accessing the space underneath the timber to clean it out, and to prevent damage of a vulnerable right-angle edge (Hocker, pers. comm.). The total length of the keelson

Figure 13. View of chock 2SB. (FHA)

might have been *c*.10.14 m, taking into account the two surviving pieces and the estimated length of the gap at *c*.3.70 m.

On either side of the mast-step, at frame stations S17, S18 and S19, three chocks (*steunders,* labelled *kattespoor* in 2000) supported the bulky part of the keelson (Fig. 13). They have a length of *c*.1.39 m with a sided dimension of *c*.0.12 m. The moulded dimension at the mast-step is *c*.0.21 m tapering to *c*.0.04 m towards the bilge. The underside was notched over the ceiling planks to which they were connected with treenails. They were nailed to the keelson and a first futtock at the bilge. A loose wedge associated with chock K3-SB was found, which had been wedged between the chock and the keelson to secure its position against the mast-step.

Ceiling

The use of the ship, the sagging of the wreck, and the pressure of the overburden over time resulted in a wavy distortion of ceiling planks. Many of them were broken into fragments in the process of removing the frames in 2000. In total eight strakes survived to port (WA-BB to WH-BB) and seven to starboard (WA-SB to WG-SB). WG served to support the through-beams. The planks had a space of 0.1–0.2 m between them. Generally the dimensions of the ceiling planks are similar to the hull planks, with widths of 0.30–0.35 m and thicknesses of *c*.0.035–0.04 m, but appear to have been much longer. The longest recorded, WG1-SB, has a preserved length of 14.52 m; its position high up in the ship meant it escaped damage from the mechanical excavator. It is almost complete since one end is undamaged and the other has the beginning of a scarf. On the underside of the ceiling some saw marks have been recorded. On the inboard, the surface is relatively smooth but in most areas signs of wear and irregular axe marks can be seen, indicating intensive use of the ship. In several areas, parts of the ceiling had been chopped away, which might indicate disassembly at the end of the ship's life. All ceiling planks are connected to the frames by two or three treenails, which also connect the framing and the hull planking. An additional third or fourth treenail is recorded where chocks were attached. Countersunk nails have been noted along the ceiling planks at each frame. These were used as initial fasteners before the treenails were put in place.

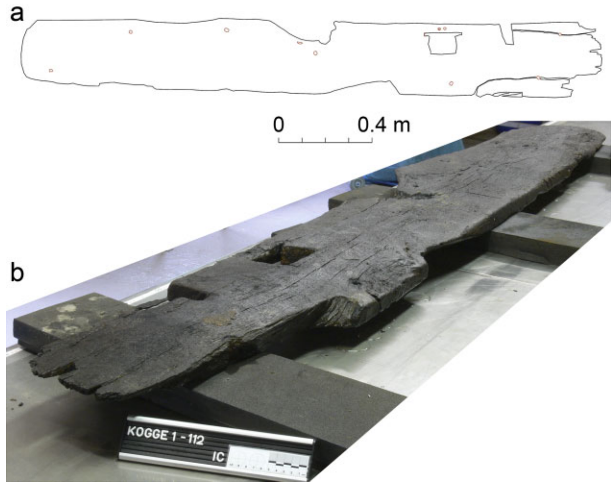

Figure 14. *a)* Simplified drawing of loose 'Plank onder WD2-WE1-SB'; *b)* the square hole and sawn-out cut are clearly visible. (FHA)

On several ceiling planks, nails were also hammered in from the underside. This may indicate that these planks have been reused, although this is not certain, since no other indications of pre-use were noted on these planks. Scarfs could be measured on three ceiling planks. They are only *c*.0.25 m long, which is significantly shorter than the scarfs measured on the planking.

A loose plank (2.49 x 0.31 x 0.031 m) was found under ceiling planks WD2-SB and WE1-SB (Fig. 14). Both ends seem to have scarfs, but no treenail holes. The plank does have nail holes which are placed in an irregular fashion. On one side, a rectangular hole (0.09 x 0.03 m) seems to have been sawn out. A square hole is also present, measuring *c*.0.09 x 0.10 m. Due to the plank's location in relation to the ceiling, and its similar size, it could be interpreted as a ceiling plank that was originally positioned elsewhere in the ship. Alternativley, it could have served as part of an internal arrangement, such as a bulkhead, although this seems doubtful.

Through-beams

Four through-beams are present on the ship, two situated amidships (1SB, 2SB) and two towards the bow (3SB, 4SB) (Figs 3b, 3c, 15, Table 4). Three of the beams are positioned within strake GM, while the fourth (4SB), located nearest to the bow, is within strake GN. Of the latter, only the heads are preserved. There is an interval of *c*.3 m between 1SB and 2SB and 4.17 m between 2SB and 3SB. The end of the beams protruded through the planking, and complex rebates on all four sides were cut in the beam end to fit the lapstrake planking, the supporting futtocks (underside), and ceiling plank WG (Fig. 15b). The beams are approximately square in section (either 0.25 x 0.26 m or 0.28 x

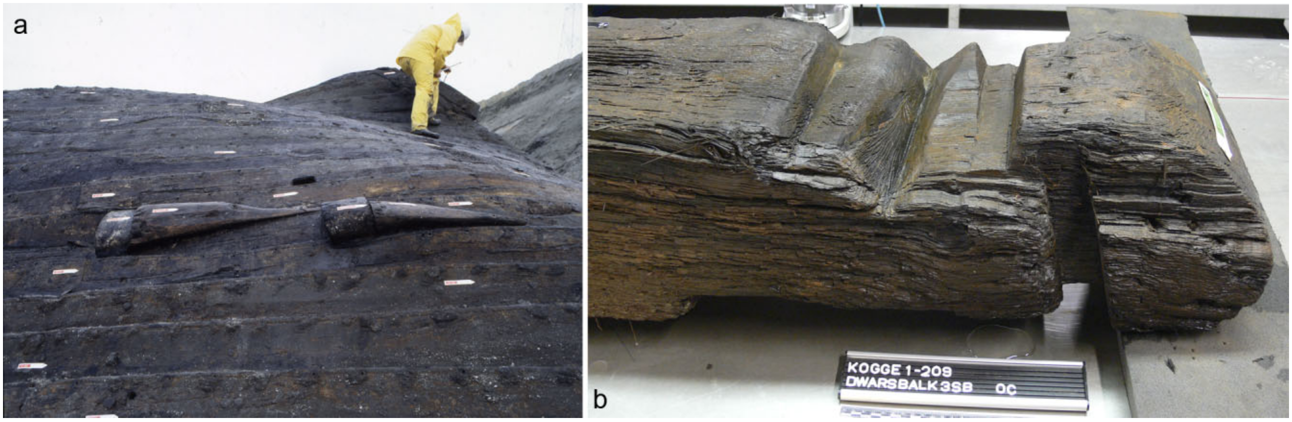

Figure 15. *a)* Two portside forward through-beams (3BB and 4BB) with their fairings (2BB and 3BB) during excavation (© ADW); *b)* the underside of the outer end of through-beam 'Dwarsbalk 3SB' showing rebates for lapstrake planking, the supporting futtocks, and ceiling plank WG. (FHA)

Table 4. *Measurements of the through-beams and fairings. Measurements marked * are reconstructed lengths of two or more parts, and thus are less secure. The length of the very fragmented fairing 1 SB is reconstructed on the basis of the nail holes on the underlying plank. Measurements marked > are incomplete. The futtocks marked # had cleats used as wedges between them and the beam they supported*

	Beam					Fairing			
	Supporting futtock	Length (m)	Sided (m)	Moulded (m)		Supporting Plank	Length (m)	Sided (m)	Moulded (m)
1 BB	10 #	6.55*	0.28	0.29	1 BB	GM2-BB	2.08	0.25	0.17
1 SB	10 #	6.55*	0.28	0.29	1 SB	GM1-SB	0.96	>0.9	>0.8
2 BB	17	6.80*	0.29	0.29	Absent	GM3-BB	—	—	—
2 SB	17 #	6.80*	0.29	0.29	Absent	GM2-SB	—	—	—
3 BB	26	6.49*	0.26	0.25	2 BB	GM4-BB	1.18	0.24	0.13
3 SB	26 #	6.49*	0.26	0.25	2 SB	GM3-SB	1.41	0.17	0.10
4 BB	Unknown	Unknown	>0.22	>0.12	3 BB	GN3-BB	0.87	0.17	0.17
4 SB	Unknown	Unknown	>0.24	>0.17	3 SB	GN3-SB	1.53	0.24	0.14

0.29 m) with lengths extending to 6.5 m (Table 4). The edges of the beam were all caulked and sealed with moss, laths and sintels on both the inside and outside.

The beams have groups of two or three treenails running vertically through them, which were probably fasteners for either bulkheads, longitudinal beams, or knees—none of which were found—which might have supported a deck structure. Three cleats (*Klamp* 1BB, 1SB and 2SB) were found in relation to through-beams 1BB and 2SB, which were used as wedges between the beams and the supporting futtocks. On some excavation photos a wedge can be seen between the supporting frame and beam 3SB but it was not recovered. Whether these cleats were added during construction or as later repairs is not certain.

Dendrochronological research on the Bremen cog suggested that the wood used for the crossbeams might have a more inland provenance than the other ship timbers (Bauch *et al.*, 1967: 290). This was not the case for Doel 1 where all timbers (framing, planks, through-beams, etc) appear to originate from the same area: NW Germany, along the rivers Elbe or Weser (Haneca and Daly, 2014: 97).

Fairings

The forward face of the beam heads have nail holes from the attachment of timbers of approximately hemi-conical form (Fig. 15a). Six of these are preserved. They were all made of alder (*Alnus* sp.) and were nailed to both the front of the beam end and the hull plank below. In the past, similar features have been referred to as 'fenders' (for example L'Hour and Veyrat, 1989: 288), but should rather be designated as 'fairings'. The tapering form of the timber indicates that their main function is to prevent objects passing alongside the ship near the water surface from fouling on the beams. By their shape and position they are able to guide obstacles alongside the beam-ends. They are therefore designed to withstand abrasion rather than impacts, as would be the case with fenders. It is clear

Figure 16. The outboard face of GN3-BB with a rebate for countersunk nails to left and a rebate and repair plank to right. (FHA)

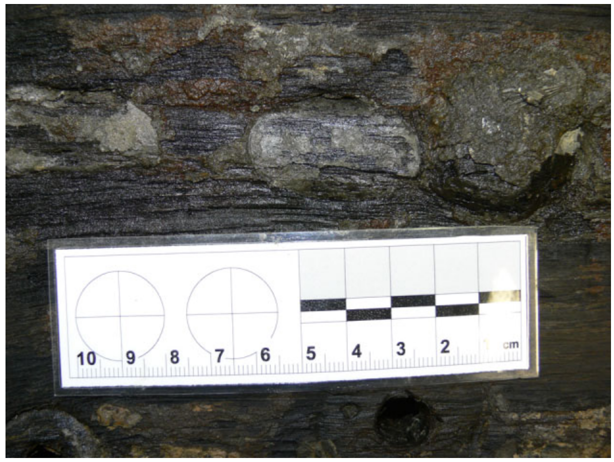

Figure 17. An impression of two sintels used in a repaired crack of plank GN1-SB. Their length is about 0.045 m and the width measured on the lath about 0.025 m. (FHA)

that these timbers will not fully protect the side of the ship from a transverse impact with a pier for example (Hocker, pers. comm., 2013). However, this does not explain why the fairings on Doel 1 were made of alder rather than oak, as are all the other ship timbers. We argue that the choice of a softer hardwood provides an additional advantage. On the occasion of an unintended transverse impact, these alder fairings would splinter more rapidly than an oak fairing, thereby absorbing some of the kinetic energy. Fairings made of oak have the same strength properties as the beams and hull planks they are supposed to protect and could, on such occasion, damage these parts.

Nails, treenails and sintels

All lapstrake planks are connected to each other with square shafted, 8 x 8 mm, double-clenched nails with a round head, *c*.25–30 mm diameter, spaced at intervals of about 0.13–0.15 m. These nail types correspond to the A-B/C-A type as described by Bill (1994: 57). Their shafts, some of which were still present in the wood, are mostly square towards the head but tend to become more rectangular towards the point. The nail heads are countersunk in a rebate worked in the outboard face that runs along the lower edge of the plank (Fig. 16). On strakes GP and GQ, situated at the centre of the ship, nails of the type D-C-A have also been observed. These larger nails, with a head diameter of *c*.0.035–0.04 m, were situated on the outboard, upper edge of the aforementioned strakes, where the framing was attached. These fasteners might be related to the standing rigging, with additional nails hammered in from the outboard to secure the frames more firmly.

Similar nails to those present on the planking and also smaller types of nails seem to have been used on repair planks. No traces of clinker nails have been noted on either repair planks or the main structure which could suggest a Scandinavian repair.

The framing was fastened with treenails. The bulk of the treenails have a diameter of *c*.0.03 m and are made of oak. In fact, only one exception has been observed, a treenail on plank GP1-BB was made of beech (*Fagus sylvatica*) (Haneca and Daly, 2014: 90).

The ship's caulking was covered with wooden laths held in place with sintels which measured 0.04 m long and *c*.0.025 m wide, evidenced only by holes left along the seams and some impressions left on the laths (Fig. 17). The few impressions recorded on the laths appear to indicate that the sintels did not overlap each other, but were separated by 5–15 mm. According to Vlierman's typology, the sintels found on Doel 1 correspond to type E (Vlierman, 1996: table II).

Caulking material and repairs

All planking of both the bottom and the sides had been caulked with moss. The carvel-built bottom strakes (GA to GD) are only caulked on the outboard face. These seams were covered with laths *c*.0.013–0.016 m wide, held in place by sintels. Lapstrake seams (GD to GR) were caulked both on the inboard and outboard (Figs 18 and 19). Here too, the caulking was covered with laths secured with sintels. All laths are made of radially split strips of oak wood (Haneca and Daly, 2014: 89).

Cracks are quite common on Doel 1 and could have occurred either during the construction process or later during the use of the ship. However, based on constructional details and analysis of the caulking material, many of the cracks must already have emerged during the construction of the ship, since several repairs are situated under framing elements. This can be considered a clear indication that the ship was built with fresh, green timber, that started to dry and develop cracks during the construction. Some of these

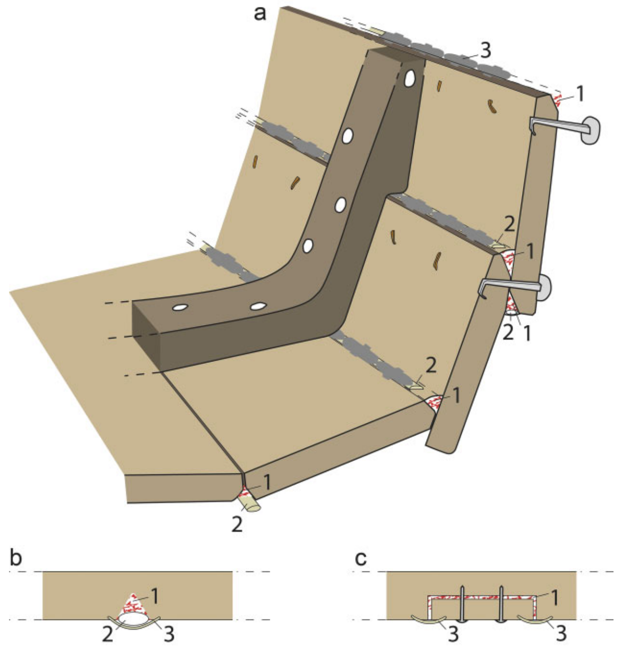

Figure 18. A schematic presentation of caulking used on Doel 1 (Deforce *et al.*, 2014: 301, fig. 3): *a)* the simplified construction of the carvel-built bottom and overlapping side strakes with caulking (1), laths (2) and sintels (3); *b)* indication of the way cracks were caulked. Note the V-shaped cut; *c)* plank repaired by cutting out damaged wood and filling it up with a repair plank. (Drawing: Glenn Laeveren and Nele van Gemert)

Figure 19. The inboard face of plank GQ1-BB with the *c.*0.09 m wide land on the right. Both strings of caulking material are still present. Note the curve in the lath (marked with arrow), where it is pushed aside by a treenail which was inserted after the caulking of the planks. (FHA)

caulked cracks are associated with treenail holes, which supports this interpretation. In many other cases the cracks run along the length of the planks, following the orientation of the pith. This tissue, from the centre of a tree trunk, is surrounded by the juvenile wood. This wood was laid down during the early stage of the tree's life and, due to its overall higher density, is prone to develop cracks while drying, either during construction or at a later stage. In all cases, when cracks in the planks had to be caulked, it was noted that cracks were first chiselled into a V-shape before the caulking material was hammered in (Fig. 18b).

Some 65 samples of caulking material recovered from seams, cracks and repair planks have been analysed. Both the mosses used as caulking material and macro-remains of vascular plants and pollen trapped in these mosses have been identified (Deforce *et al.*, 2014). Nine different moss taxa have been identified from the caulking material. All original seams and some repairs have been caulked with feathery bog moss (*Sphagnum cuspidatum*); the other moss taxa, mainly *Drepanocladus aduncus* and *Calliergonella cuspidatea*, only occur in cracks and other types of repairs. In one repair, a woven textile made of sheep wool (*Ovis aries*) was used (Deforce *et al.*, 2014: table 1 and fig. 8). It seems that this was a reused piece of textile used *ad hoc* for this repair.

Several methods of repair can be seen throughout the ship. The most common are cracks, which have been caulked in the same manner as the planks seams, and larger areas of damage repaired with short planks (tingles), which are nailed over cracks or rotten areas of planking, or inserted in the original plank (Figs 16 and 18c and Table 5). Caulking has also been found under these repair planks. These repairs have been subjected to dendrochronological and archaeobotanical analysis to derive information on provenance, date and possible sailing routes.

Tree-ring analysis was performed on eight repair planks, of which five could be dated (Haneca and Daly, 2014: 95). Three of the dated repairs proved to have a Southern Baltic provenance, and therefore differ from the bulk of the ship timbers. These repairs were probably performed a few years after the construction of Doel 1 as the earliest possible felling date of at least one of these planks falls after the estimated construction date of the ship (see Haneca and Daly, 2014: 97).

Nearly all of the repair planks were radially cleft, a method of wood conversion often used to produce a high-quality timber assortment, known from historical sources as wainscots. These planks are always straight grained and show a very high standard of finishing. The volume in which these wainscots were traded—often from present-day Poland—in the later medieval period, makes it difficult to pin-point the place where these repairs might have been made. Wainscots could easily have been available at ports all along the North Sea coast, or even have been part of the cargo of the ship itself. Based on the constructional details of the repair planks and their locations, some can be seen as repairs inserted during the phase of construction (such as K1-373 and K1-714) while others have been dated and provenanced in a later period and originate from a different region than the hull planks. This is the case

Table 5. *Overview of the repair planks in relation to the dendrochronological and botanical studies. An asterisk represents an unrecorded/unknown feature*

Function	K1-number	Underlying Plank	L (m)	W (m)	Th (m)	Conversion	Dendrochronology (end date and wood provenance)
Repair plank	K1-032	GM2-SB	0.72	0.20	0.02	Radially cleft	No dating result
Repair plank	K1-373	GE3	0.68	0.19	0.03	*	—
Cleat	K1-374	*	0.32	0.23	0.05	Tangentially sawn	—
Repair plank	K1-397	GM2-SB	1.06	0.07	*	*	—
Repair plank	K1-408c	GG3-SB	0.17	0.13	0.015	*	—
Repair plank	K1-433	GE3-SB	0.71	0.18	0.02	Radially cleft	—
Repair plank	K1-451	GK1-BB	1.62	0.28	0.04	Radially cleft	End date: 1320 (+ 7 sapwood rings), Southern Baltic
Repair plank	K1-458; 462; 463	GL2-BB	*	*	*	*	—
Repair plank	K1-459	GL2-BB	0.42	0.08	0.02	*	No dating result
Repair plank	K1-460	GL2-BB	0.445	0.085	0.015	*	End date: 1253 NW Germany
Cleat	K1-495	GD3-SB	0.30	0.14	0.04	Unclear	—
Repair plank	K1-502b	GN3-BB	0.60	0.16	0.02	Radially cleft	End date: 1281 Southern Baltic
Repair plank	K1-510	GO2-BB	0.87	0.16	0.017	Radially cleft	End date: 1291 Southern Baltic
Repair plank	K1-516	*	0.355	0.09	0.03	Radially cleft	—
Repair plank	K1-614	GM-SB	0.030	0.17	0.02	Radially cleft	End date: 1296 NW Germany
Repair plank	K1-621	GM2-SB	0.33	0.13	0.035	Radially cleft	No dating result
Repair plank	K1-649b	GA1-BB	0.087	0.074	*c.*0.015	Radially cleft	—
Cleat	K1-659	*	0.30	0.19	0.037	Radially cleft	—
Repair plank	K1-709	* GI2-SB?	0.83	0.11	0.03	Radially cleft	—
Repair plank	K1-714	GD3-BB	0.197	0.11	*	*	—
Repair plank	K1-715	GI2-SB	*c.*0.90	*c.*0.11	0.01	*	—

for repairs: K1-451, K1-502b and K1-510, which originate from the Southern Baltic.

Intentional marks

In several places marks can be seen which were intentionally inscribed on the wood. One plank on the port garboard strake (GA3-BB) shows a remarkable figure (Fig. 20). Its exact meaning is difficult to interpret but since it is situated partly under frame S23, it must have been inscribed before or during the earlier phase of construction.

Other marks noted include two concentric circular arcs, with diameters of *c.*0.095 m and 0.14 m, inscribed on the inside of a wainscot used as a repair of a hole in strake GN3-BB (Figs 16 and 21). Its meaning is unclear, but based on the dendrochronological research the plank has a Southern Baltic provenance and is likely to have been a later repair. Due to the hole in the original plank, the arcs must have been visible on the inside of the ship, therefore they could have been drawn by a shipwright, someone working on the wharf, or by a sailor during the later use of the ship.

On several original planks irregular crosses are inscribed near treenail holes. These can be related to the construction phase of the ship to indicate the location of a treenail hole. Inscribed lines have been seen also on the side of the futtocks, which appear to indicate the location of the joggles. Such marks can be seen as the hand of the shipbuilder marking the exact location where holes, joggles and so on needed to be made.

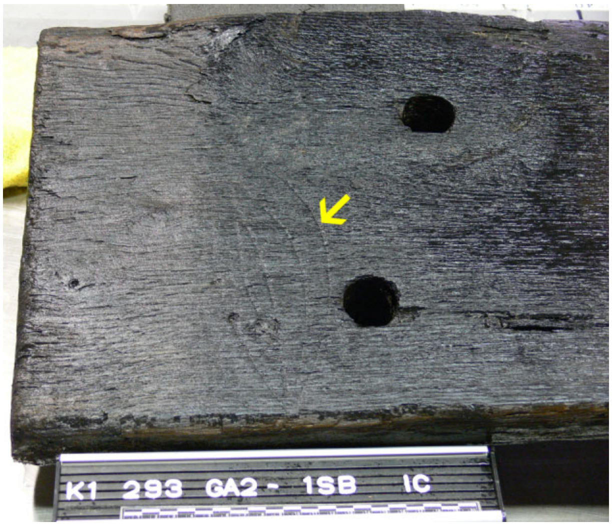

Figure 20. The inscribed figure situated on the starboard garboard strake GA2-SB that lay partly under frame S23. (FHA)

Traces of disassembly?

Several important parts of the ship are missing, in particular the mast and rigging, and also the bulkheads, longitudinal beams or knees which would have been connected to the through-beams by the vertically placed treenails noted. It also seems that part of the outer stempost was sawn off, as is visible by the fragment recovered. The fact that these parts were missing when the ship was discovered but had once been strongly attached with multiple treenails might be an indication that they were removed before the ship was inverted.

Signs of disassembly are also noted on other parts of the ship. Several irregular and deep axe marks have been noted on the ceiling, planking and framing. On the aft part of GC1-BB a large roughly cut hole, *c.*0.275 x 0.12 m, also has many visible axe marks (Fig. 22). No similar traces of this kind are present on the starboard side. The reason for the presence of this hole remains unclear.

The outer sternpost and the rudder are missing. The removal of the outer sternpost would have necessitated the dissassembly of the gudgeons which are also missing. Unfortunately, due to the poor state of preservation of the inner sternpost, few construction details related to the rudder have survived.

Discussion

The find of the late medieval vessel Doel 1 enabled the start of a large interdisciplinary research project, which was unique for Flanders, even though many very interesting shipwrecks have been found both on land (Van de Moortel, 2006 and 2011) and in the Belgian part of the North Sea (for example Zeebroek *et al.*, 2010). Doel 1 shares many constructional similarities with the Bremen and other cogs. Today at least 30 ships are identified as cogs (for example Van de Moortel, 2011: table 6), including Doel 1.

Figure 21. Two concentric circular arcs on the inboard face of the repair plank used on GN3-BB. (FHA)

Two more recent and nearly complete finds from Bohuslän (Sweden) and Kampen (the Netherlands) have been identified as cogs (Von Arbin, *pers. comm.* and Waldus *et al.*, 2012), though further research on them is needed. Furthermore, the fragmentary remains of the bottom part of a 14th-century cog near the town of Kraggenburg in Flevoland, referred to as NT25, has also been researched during a field school in 2010 coordinated by André Van Holk and the first author (Van Holk, 2011: 8–9).

As Grille (2002: 83–5) pointed out, the construction of cogs in the 14th century becomes more standardized, in terms of the main constructional characteristics which, when combined, results in a readily recognizable tradition of construction. Therefore, when comparing contemporary cogs (*c.* AD 1275–1400) of similar size, several can be seen as very similar in construction to Doel 1. However, when the timber provenance is added as a characteristic, the list is reduced to only the Bremen cog. Potentially Dronten OM61 could be considered for further comparison. However, the dendrochronological analysis for this ship, with a felling date after AD 1290, is based on two samples only and provenance analysis based on the tree-ring pattern of these timbers was inconclusive. Relatively high *t*-values were found with chronologies from both NW Germany, which would point to a similar provenance as Doel 1, but also with chronologies from western coastal Poland and Middle Sweden (Daly, 2007: 102). The wood of the Bremen cog has a dendrochronological date of AD 1378, based on two samples, with a provenance in the Weser region (Daly, 2007: 115). The ship was under construction in Bremen, which is most probably within the region where Doel 1 was constructed, as demonstrated by dendrochronology (Haneca and Daly, 2014: 92–4).

One of the most typical features shared by most cogs is the combination of a keelplank with knee-shaped hooks and straight posts at each end, which serve as the backbone of the ship. Exceptions with a keel instead of a keelplank include the Oskarshamn wreck (Adams and Rönnby, 2002: 177), the Mollö cog (Von Arbin and Daly, 2012: 6), Kronholmen, Helgeandsholmen

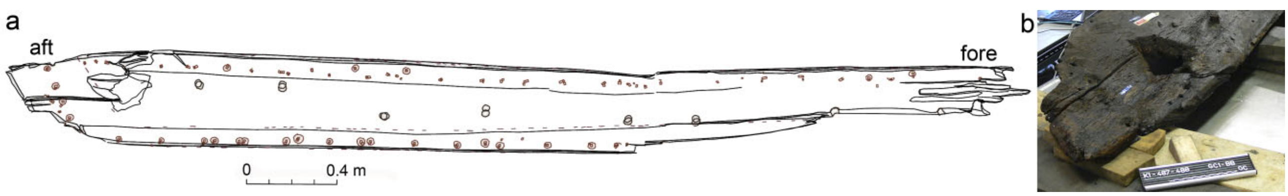

Figure 22. *a)* Simplified 3D-drawing of the outboard face of plank GC1-BB with the hole cut near its connection onto the inner stempost; *b)* detail of the hole in GC1-BB. (FHA)

2 and Skanör (Grille, 2002: 24). The keelplank of the Bremen cog measures 8.30 x 0.47 x 0.10 m (Lahn, 1992: 27). The keel of Doel 1 is about a metre longer (*c*.9.27 estimated original length), but somewhat more slender at 0.33 x 0.13 m. The total keel length, including the hooks, in the Bremen cog measures 15.6 m, while in Doel 1 the total horizontal length is *c*.14.17 m; thus the keelplanks represent 65% and 53% respectively of the total keel lengths. Whether these varying proportions (also seen on other cogs, see Van de Moortel, 2011: table 6) were a conscious decision taken by the shipbuilder is doubtful. It is more likely related to the available timber at the time of construction.

Dendrochronological research has shown that the keel of Doel 1 most probably has an earlier felling date than the other ship timbers, AD 1325/1326. This would imply that the keel was stored for an undetermined period of time.

The carvel-built bottom was constructed according to bottom-based assembly, which, in the case of Doel 1 and almost all other cogs, is recognizable by the presence of so-called *spijkerpennen*.

In some later cogs, a symmetrical layout of the bottom planks has been attested including Doel 1, OZ36 (Haneca and Daly, 2014: 95–6), the Bremen cog (Lahn, 1991: blatt 8), and the early 15th-century cogs NZ43 (Van de Moortel, 1991: fig. 43) and Almere Wijk 13 (Hocker and Vlierman, 1996: enclosure 2). A similar arrangement has also been attested on the earlier cog of Kolding as well (Hocker pers. comm., 2014). Most likely other cogs would have been constructed in a similar manner. The importance of this part of the ship is shown through the apparent conscious selection of the timber by the shipbuilder in order to obtain a high level of symmetry, thus for strakes on opposite sides of the keel, the same trees have been used.

The 14 completely lapstrake-built strakes are clearly tangentially sawn, probably on two trestles with a frame saw, and have a maximum width of 0.35–0.40 m and a length of *c*.5–7 m, with extremes of over 10 m. The Bremen cog, which is slightly larger, has six strakes less but a larger plank width (of over 0.60 m in some cases) and long planks of over 10 m were also used.

Regarding the framing, a combination of centrally placed horizontal and V-shaped floor timbers has been used, the former covering the entire carvel-built floor. The scarfs of the floor timbers are alternately positioned to port and starboard. The horizontal floor timbers had aligned limber holes situated on the seams between the keel plank and the garboard strakes and also on the seams between strakes D and E. The limber holes on strakes B and C are positioned over the middle of these strakes. The frame arrangement to the fore of the ship, where in two cases a horizontal timber sits atop a V-shaped floor (S26 and S28), is not typical in known cogs, although a similar arrangement has been noted on cogs OZ43 (1275–1300/unknown provenance), Darss (1298–1313/Baltic provenance), Lille Kregme (1358/Southern Baltic provenance) and Vejby (winter 1372/Southern Baltic provenance) (Reinders, 1985: 14; Grille, 2002: 50–1, Thomsen, 2002: 32; Wessman, 2005: 53 and Belasus, 2013, pers. comm.). This structure has been interpreted by Grille (2002) as a technological remnant or transfer of the feature known as a 'biti-knee' (or crossbeam-knee), used in Scandinavian vessels from the 9th until the 12th/13th centuries (Bill, 1997: 135–6; Crumlin-Pedersen and Olsen, 2002: 114–16, Grille, 2002: 50–1), but this cannot be attested with certainty.

In the case of Doel 1, frame S27 is absent and seems likely to have been the location of a pump system. Similarly on the Bremen cog just before (frame 9) and also abaft (frame 34) the keelson, a V-shaped frame is absent (Lahn, 1991: blatt 8 and 11). In the Almere cog (*c*.1410), a variation on this theme is noted: at frames 4 and 27, the V-shaped floor timber is absent and two futtocks meet in the middle, thus avoiding a gap (Hocker and Vlierman, 1996: 29). This arrangement has also been noted on the Vejby cog at frames 9F and 10F. In the Vejby cog, it is said to be related to timber availability (Thomsen, 2002: 32). No such arrangement was noted on the aft frames of Doel 1.

The keelson, with an estimated length of 10.14 m, is placed on top of the horizontal floor timbers. Just fore the centre of the ship, the keelson has a central segment in which the rectangular mast-step is positioned. In the centre of the mast-step, a drilled hole is present which served as drain for water. The mast-step is supported by three chocks on either side. This configuration has been noted on all larger, contemporary cogs, such as Darss (Förster, 2003: 13) OZ36, NA 57, OZ 43 and the Bremen cog (Reinders, 1985: 20).

The sides of Doel 1 are supported by futtocks which are joggled over the lapstrake planks. The position of the joggles were first indicated by an inscribed line on the sides of the futtocks before they were cut, according to their location in the ship. There, they were first nailed into position before holes were drilled with a spoon auger and treenails inserted. The futtocks also supported the through-beams, of which four were preserved: two in the centre and two in the forward part of the ship. A similar construction has been noted on the Bremen cog. The protruding heads were protected by hemi-conical fairings made of alder, a configuration also attested on the 15th-century Aber Wrac'h wreck where the fairings are said to be made of elm or alder (L'Hour and Veyrat 1989: 288). Unfortunately, the stern on Doel 1 was damaged too much to state whether one or two beams were originally present or to give indications of the deck or castle structure.

On Doel 1, the sheer-strake is partly preserved towards the bow on the port side. Its upper edge is damaged in two places, one of which has been repaired on both the inner and outer side. It is not clear whether this is linked to the rigging assembly.

Almost all constructional characteristics of Doel 1 correlate to features of cogs as described by Crumlin-Pedersen (2000) and Grille (2002), except from the fact that in Doel 1 the carvel-built bottom was caulked only from the outboard and that the lapstrake planking was caulked both on the inboard and outboard. Only in the case of the Almere cog was all planking caulked from both sides, while carvel-built planking caulked on both sides was noted on the Kolding, Kuggmaren, Vejby and Skanör cogs. For most other cogs caulking of the lapstrake planks was applied only on the inside face, with caulking on the outboard face on the carvel-built plank seams (Grille, 2002: 40). Also the absence of one of the V-shaped frames, and the presence of two beam-knees on the two neighbouring frames is a characteristic which has been seen on only a few cogs.

With the slowly growing number of similarly built vessels, an interdisciplinary approach for their research is essential. A combination of an archaeological investigation with dendrochronology, macro- and microbotanical research of the caulking material results in a better understanding of the construction, date, provenance and area of use.

The felling date of most of the timber in AD 1325/26, combined with the many cracks observed on the hull planks, indicates a construction date of the ship shortly after that winter. Dendrochronological and archaeobotanical research pointed towards a location of construction probably in the area of Northern Germany near the rivers Elbe and Weser. Already during its construction various repairs were needed, especially cracks that emerged while the ship timbers were drying or following the drilling of treenail holes. The original planking and repairs performed on the wharf were all caulked with moss, feathery bog moss being the preferred species. During the ship's life, wainscots from the Southern Baltic were used to repair damage to the hull planks. For the repairs, moss was used as caulking material as well, but besides feathery bog moss other moss taxa are more prominent. In at least one of the later repairs a piece of textile made of sheep wool was used as well.

How Doel 1 met its end is impossible to reconstruct. The ship must have ended up in the Deurganck, a creek on the left bank of the river Scheldt, which was probably still under rule of the count of Flanders. A historical connection with the city of Antwerp on the right bank of the river and under rule of the duke of Brabant is difficult to attest; although, together with Ghent and the harbour towns in Seeland, Antwerp can be seen as one of the main ports along the Scheldt of that time.

The missing parts of the ship and the many axe marks are seen as indications of disassembly while the ship was lying in the gulley. At a later date, the vessel was most probably turned upside-down as a result of one of the many known floods in the area. The fact that all the beams were severely damaged gives an indication of the force of the event which turned the ship over. Moreover, this shows that the missing knees or bulkheads, which were once treenailed to the beams, must have been taken out of the ship before it was inverted.

Despite the damage to the wreck at its discovery and the suggested marks of disassembly, Doel 1 can be seen as one of the most complete cog finds in NW Europe. In size, date and timber origin, it closely resembles the Bremen cog, which it predates by half a century. The slightly smaller size of Doel 1 may suggest it had a cargo capacity of somewhat less than the estimated 80 tonnes of the Bremen cog, but it ranks as one of the larger cogs known to date.

Acknowledgements

The authors would like to thank the following people for their input and suggestions: the members of the scientific committee of De Kogge, Staffan von Arbin, Mike Belasus, Koen Deforce, Damian Goodburn, Fred Hocker, Tinne Jacobs, Glenn Laeveren, Tom Lenaerts, Alice Overmeer, Marnix Pieters, Lore Poelmans, Kris Vandevorst, Aleydis van de Moortel, Nele van Gemert, Johan van Laecke and Daniel Zwick. Last but not least, we are grateful for the comments of the anonymous peer reviewers and the editor which improved the quality of this paper.

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