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The Late Roman Bridge at Cuijk

CONTENTS

Teacher told us,
The Romans built this place,
They built their houses and temples and garrison towns
but all that was left were the stones the workmen found

All this time,
the river flows,
endlessly to the sea.

(Sting)

1 HISTORY OF THE FIND, RESEARCH QUESTION AND STRATEGY

1.1 *History of the find*

1.1.1 Cuijk in the Roman Period

In 1989 local divers discovered piles and stones in the river Meuse at Cuijk which could be interpreted as the remains of a Late Roman bridge (fig. 1).[1] The underwater finds were near the old Roman settlement of present-day Cuijk, so that it was a matter of course to link them with previous archaeological investigation above water.

Research by A.E. van Giffen, J. Willems and J.E. Bogaers in the centre of Cuijk in 1937–38, 1948 and between 1964 and 1966 resulted in the discovery of settlements from the Mesolithic, the Bronze and Iron Age, the Roman Period and the Early and Late Middle Ages. Unfortunately, these excavations were only summarily published.[2] The emphasis of the excavations lay on the Roman remains around the Roman fortification in the centre of the town (fig. 2). The main structures of the excavations have been reproduced as a reference on the general plan in this publication. It may be assumed on the basis of the investigation, that the toponym Cuijk and its location correspond to the name 'Ceuclum' on the Tabula Peutingeriana (fig. 3).[3]

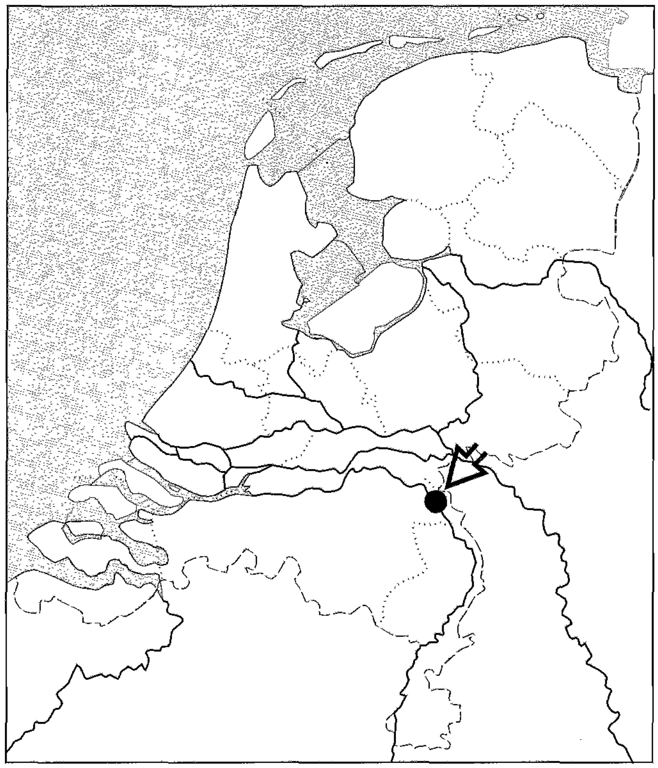


Figure 1 Location of Cuijk in the Netherlands.

The town of Cuijk is situated on the west bank of the Meuse on the remains of a high Pleistocene river terrace. Several kilometres downstream, the river turns sharply westward and flows through the Rhine and Meuse delta to the North Sea. The high position of Cuijk gives it a strategic advantage behind the barrier of the Meuse which has a more or less fixed bed here. Cuijk is also the most northerly location at which the Meuse can be crossed in the direction of the rivers Waal or Rhine (see chapter 4). The arrival of the Romans at Cuijk is connected with the construction of a fort in the first half of the first century. This implies a direct link with the building of the *limes*.[4] The fort is the

1 The geographical position of the centre of the findspot is 51°43'52"N lat/5°53'07" E long. In the Dutch national grid, based on the Dutch National Geodetic Network, the so-called State triangulation system, it is 189.427/415.793. In this study the Dutch national grid is used, also for the section of Germany which is included in the study area. For the Dutch rivers there is a separate method of localizing a place, the 'transect'. This is the distance on the longitudinal axis of a river. The distance is measured from the point at which it crosses the Dutch border. The bridge is situated at transect 162.150.

2 Bogaers 1966 and 1967; Bogaers & Rüger 1974; Willems 1937. For a good survey of the investigation see Van Enckevort & Thijssen 1998.

3 Bogaers 1966, 68 and 1967, fig. 7; Stolte 1938, 705.

4 Willems 1984, 98.

Figure 2 Plan of Cuijk (scale 1:10 000) with a projection of the former castellum (1), castellum wall (2) and the former Late Roman bridge (3).

northernmost fortification on the Meuse. It was rebuilt in stone in about AD 70, but in about AD 100 it fell into disuse.

Because of its position on a through north-south road, Cuijk retained its military function probably even in the Middle Roman Period in the form of a *statio* to control the river crossing. The presence of military roof-tile stamps from the second century may be evidence of this. However, the fact that remains of a road were also found near Katwijk, slightly north of Cuijk, may indicate a(nother) crossing there (see 6.4.2). Van Es suggests that Cuijk also played a part in the east-west connection with Rossum, situated more to the west.[5]

After the fort was abandoned as part of the demilitarization of the border zone, a vicus was left in Cuijk which expanded over the old castellum site.[6]

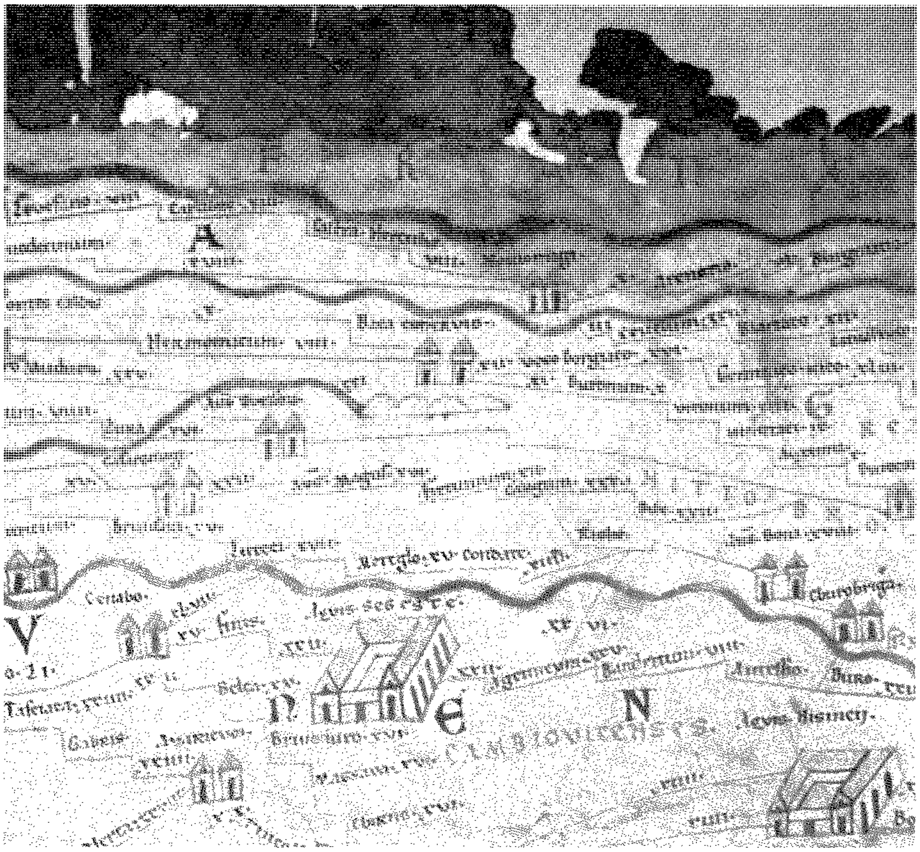
Cuijk was now a regional centre. The remains on the bank of the Meuse which have been interpreted as temples have given rise to the assumption that Cuijk was also important in the religious sphere (see fig. 6).[7]

In the fourth century AD under Constantine II (306–337), a new fortification surrounded by an earth and timber rampart was constructed on more or less the same spot as the first-century fort. In his analysis of coin finds in the river area, Willems suggests that there was also great activity in Cuijk in the period after Constantine I, particularly under Constans (337–350) and Constantius II (337–361).[8]

Under Valentinian I (364–375) the fort was built of stone and provided with heavy semicircular towers. Around it, two relatively narrow V-shaped ditches two metres in width were dug. Since it was impossible to trace how and where the east side of the castellum ended and the Meuse began, the dimensions from west to east have not been reconstructed. Perhaps part of the castellum was eroded by the Meuse, or perhaps the river functioned as the fourth castellum wall.[9] In the fourth century Cuijk must have been one of the most important forts in the eastern river area of the Netherlands.[10]

Based on the inventory of the finds around Cuijk, the vicus would at first sight appear to be restricted to the immediate vicinity of the fort.[11] Strangely enough, another cluster of settlement traces is to be found outside this area, on the west side of the built-up area which can be dated to the Late Roman Period and Early Middle Ages. Possibly the vicus extended uninterrupted as far as this boundary. The Roman

5 Van Es 1972, 110.
6 Van Es 1972, 116; Willems 1984, 110.
7 Willems 1984, 111.
8 Willems 1984, 287.
9 The discovery of the bridge in the Meuse makes it clear that this distance can have been no more than *c.* 150 m (see 5.4 and 7.1).
10 Willems 1984, 148.
11 Koeling & Elbers 1989; Van Enckevort & Thijssen 1998, 158 and fig. 1. Thanks to J. Koeling (Cuijk) and H. Verscharen (Middelaar), among others.



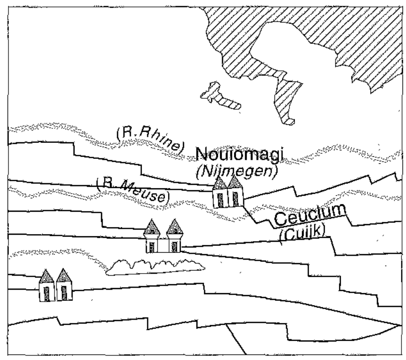


Figure 3 Fragment of the *Tabula Peutingeriana*. A Meuse crossing is indicated between Cuijk (Ceuclum) and Nijmegen (Nouiomagi).

occupation ends roughly at the beginning of the fifth century.[12] Scarce traces of Early Medieval settlement may indicate continuity of settlement. In the eleventh century the Lords of Cuijk settled on the former castellum site.

Cuijk has two excavated cemetery sites. The first is close to the fort and extends along the Grotestraat to the south. The graves are frequently at right angles to the road which was of Roman origin. On the north side, close to the fort, are the oldest graves dating to around the first quarter of the first century, and becoming gradually younger towards the south. The final date of the cemetery is about AD 270. Only part of the material has been published, but the cemetery most probably remained in use until into the Late Roman Period or even the Early Middle Ages. A second cemetery is situated northwest of the military fortification on the so-called Heeswijkse Kampen and dates until AD 270 at the latest.

Cemeteries from the Late Roman Period or the Early Middle Ages are still lacking, although more evidence for them is constantly emerging.[13]

12 Willems 1984, 148–9 and note 294: the latest coin dates from AD 402.

13 Proos 1988 (catalogue numbers 011.015 and 011-16) mentions a number from the Late Roman Period and the Early Middle Ages from the area around the castellum and the Grotestraat. Willems (1984, site 502; *JRMO* 1970, 264) supposes an Early Medieval cemetery on the bank of the Meuse. See also De Boone 1956, 11–13, in which he describes a Late Roman burial find made in 1845/47 in the Haagsestraat which is also included in the unpublished material dissertation of Van Hoek (1968). In 1914 a possible Late Roman grave was also discovered at 21 Veldweg, the glass from which has been published by Isings (1964, 174–9). With thanks to W.A.M. Hessing (ROB).

1.1.2 The history of the discovery

The discovery of the bridge in 1989 was the last of a long series of reports dating back at least as far as the eighteenth century. As early as 1752 river fishermen from Grave and the County of Cuijk mention the presence of building materials in the Meuse.[14] In 1845 the findspot comes up again: 'Below the church old tuff foundations have been found in the Meuse at a low water level'.[15] In 1891 coin finds from the fourth century AD are reported in the Meuse, and a quarter of a century later, new finds are again discovered on the same spot: 'At Cuijk, in 1921, at a very low water level, in the Meuse, behind the old church: Roman piles and coins from the late imperial period'.[16] Between 1930 and 1940 a great deal of work was done to make the Meuse navigable as far as the coal mines in the province of Zuid-Limburg. As a result of regulation, extremely low water levels no longer occurred and the find reports were forgotten. Not until 1964 and 1969 are informal underwater surveys carried out in the Meuse as part of the current land excavations and – as it later turned out – a wood sample was taken for ^{14}C analysis.[17] The survey by local divers in 1989 again confirmed the presence of piles and rubble near the landing quay and resulted in a preliminary rough survey of the outcropping parts, as a basis for the research by the Department of Underwater Archaeology (AAO) of the State Service for Archaeological Investigations (ROB).[18]

1.1.3 Pilot study

In 1989 a small group of divers from the County of Cuijk under the direction of J. van den Besselaar began an investigation into the exact site of the bridge remains at the landing quay of Cuijk.[19] This was followed in 1990 by an additional pilot study by the Department of Underwater Archaeology of the ROB in collaboration with the finders. The objective was to gain insight into the nature, preservation and date of the findspot.
The findspot measures *c.* 25 x 100 m and extends right across the Meuse. This is exclusive of the bank structures mentioned later (see 2.1.7). The river has a constant maximum depth of *c.* 7 m. Because it was impossible to survey the findspot quickly due to limited visibility (*c.* 50 cm), a sonar recording of the riverbed was made. With this so-called side-scan sonar recording it was possible to determine the limits of the site in a short time (fig. 4). The sonar picture, together with a visual underwater inspection, indicated an imaginary straight line right across the river, along which the remains of piles and stones were concentrated.[20] Within the find area, concentrations of dressed stone and oak piles could be observed. Although during the survey it was uncertain whether the course of the present-day Meuse was the same as in Roman times it seemed likely that the remains would continue underneath the present levee deposits. An electric conductivity survey and magnetometer analysis of the east bank did not however produce any results due to the great thickness of the post-Roman sedimentation layer.[21] Later borings

14 Hermans 1937–1940, 43 where he bases himself on Paringet 1752. Hermans writes here: He (*i.e.* the author Paringet) was told by fishermen that when they touch the ground with a hook at low water below the church, where now the Meuse flows, they here and there felt something hard as if it were a brick floor and in between suddenly fathom a great depth, as if they were reaching into a cellarlike cavity'. Paringet adds : *en heeft men voor deesen ook veel duyfsteen uytgehaald* ... (and much tuff was taken out).
15 Reuvens, Leemans & Janssen 1845, 46.
16 Byvanck 1947, 71–2. The town clerk of Cuijk makes detailed mention of the 1921 find to the RMO.
17 Willems 1984, 47. The exact spot where samples were taken can unfortunately no longer be traced, but this sample probably comes from area 4000 (see 2.1). According to the age analysis, a Late Roman date is quite possible. See table 3 for a survey of the dates from Cuijk.
18 Apart from the above-mentioned written reports, there are countless verbal accounts in Cuijk of finding wood and stone in the Meuse. Mrs Thijssen-Ariaens, for example, reports that, as a girl of 11 in about 1920, she walked along long beams on the banks of the Meuse near the bridge, and was told off by the parish priest for lifting her skirts up too high. A resident of Rotterdam born in Cuijk in 1869 states that wood and stone were found in the Meuse which were linked with the Castle of the lords of Cuijk. He speaks of 'hard foundations under water and a row of oak posts 75 cm apart which curved slightly downstream'. The site description, however, would fit the present area 6000 (see 2.1 for the area divisions) (Van Hulten, 1953). Mr Heiltjes senior from Cuijk mentions the hoisting up out of the Meuse in about 1950 of an extremely heavy beam at least 10 m long near the landing quay.
19 To simplify matters, the findspot and remains will henceforth be referred to as 'the bridge'.
20 Thanks are due to the Geometrical Service of the department of Marine Geodesy of the Department of Works (*Rijkswaterstaat*) in Delft (Dhr. N. Wiegman, B.J. Valstar and L. Kamminga) and Rijkswaterstaat District Nijmegen (see afterword). The most easterly area could not be reached with the side-scan sonar because the water was too shallow. From the diving inspection it appeared that this area was actually richest in finds.
21 Anderson 1991. With thanks to K. Anderson (RAAP/NWO).

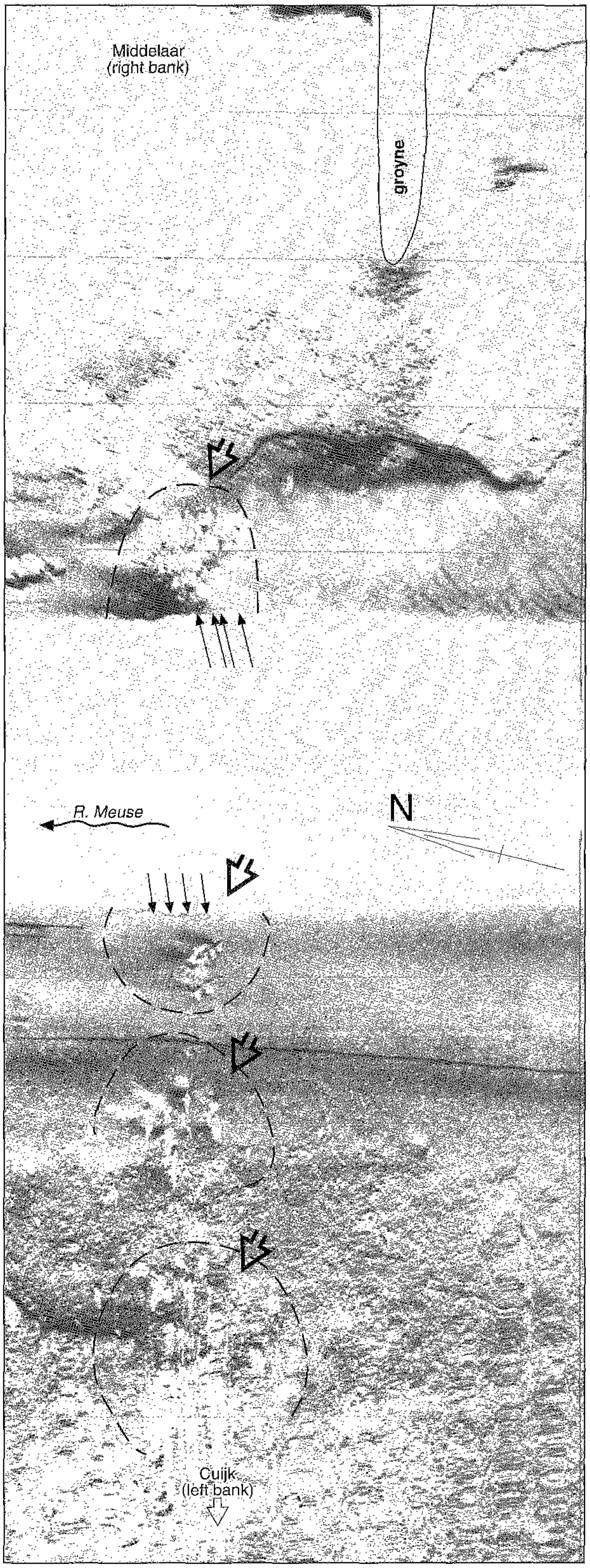


Figure 4 Side-scan sonar recording of the river bed at the site. The arrows point to the various find areas. The white central zone is the area which was not measured by the laterally focused sonar. Differences in height in the topography of the soil (caused, for example, by piles or stones) are visible as a difference in contrast.

gave more information (see also chapter 4).[22]
Prior to the pilot study there was no certainty as to the nature and age of the findspot. The traces there could have been from the eastern part of the castellum which had been eroded by the Meuse or they could be medieval. The straight line of finds across the river would suggest a river crossing. The literature too refers to a river crossing near Cuijk.[23] The longitudinal axis of the findspot ends almost in the centre of the fourth-century fortification, so that a link with the castellum is likely. The groups of heavy piles in the bed of the Meuse were therefore interpreted after the survey as foundation piles of Late Roman bridge piers.

1.1.4 The river Meuse

As a result of human intervention, the Meuse near Cuijk now has a completely different character from the natural river encountered by the Romans. Originally the Meuse was a rain river with sharply fluctuating water levels and a riverbed morphology to go with it. The Romans built the bridge in the natural bed. The present Meuse is a busy shipping route in which the water level is kept constant as far as possible and whose river bed is becoming more like a canal bed. In order to understand the building conditions then and the preservation conditions now we shall take a closer look at the main river characteristics in both cases.
The course of the Meuse between Cuijk and the North Sea has been influenced by human intervention since the eleventh century. Upstream from Cuijk the Meuse remained relatively untouched by radical action by man into the first quarter of the twentieth century. Intervention is therefore relatively recent, which is why there are many historical sources and maps showing the natural character of the river. Until the beginning of this century, the Meuse from Cuijk to Venlo was only navigable in the winter months for small boats, and upstream from Venlo it was considered completely

22 With thanks to J. Broertjes of the RGD in Nuenen (prov. of Noord-Brabant).
23 Willems 1984, 64; Van Es 1972, 110.

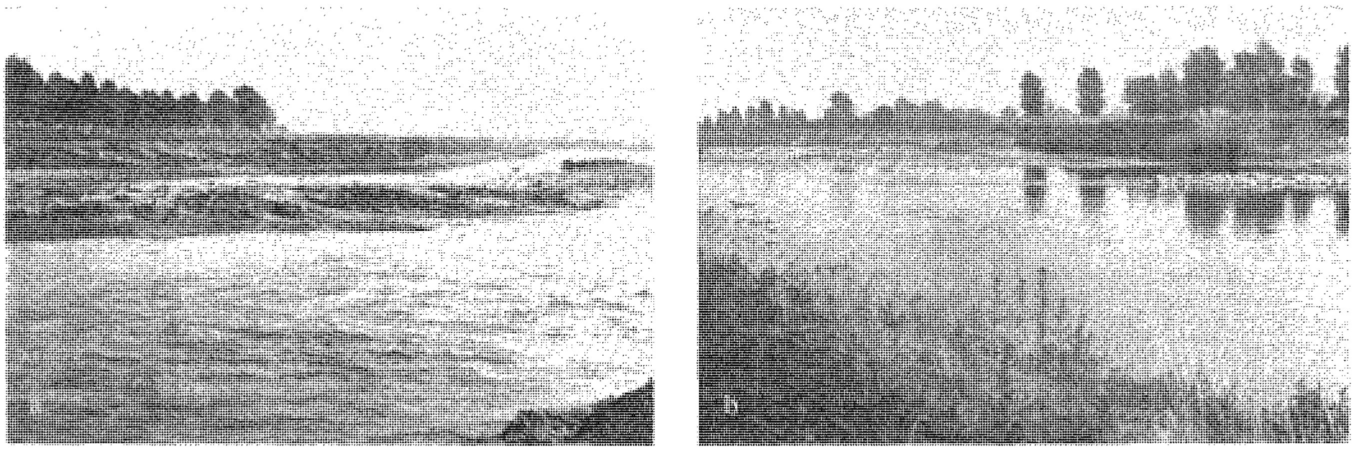


Figure 5 The 'natural' Meuse is a so-called island river full of sand and gravel banks. The photographs were taken in 1956 near Mechelen on the Meuse (from Paulissen, 1973). They give an idea of the shape of the river prior to the regulation of the water level. Photo 'a' shows a meander bend; between the main and subsidiary channel is a gravel bank in which active flooding channels have been eroded. Photo 'b' shows a straight section of the river, the gravel banks in the river have a relatively stable position and some sporadic vegetation is visible as island formation begins.

unnavigable for boats needing more depth.[24] Because of the rising economic importance of coal-mining in the Dutch and Belgian provinces of Limburg at the beginning of this century, the navigability of the Meuse needed considerable improvement. For the transportation of coal canals were dug which were dependent on water from the Meuse. So countless measures were undertaken to normalize the river. In Dutch Limburg the Meuse was divided into five river sections by means of weirs and locks. The course of the Meuse at Cuijk is in the most northerly section, in which a water level of 7.5 m NAP is aimed at. With this target level, the Meuse at Cuijk is *c.* 7 m deep. The findspot stretches right across the bed of the Meuse. The river here is approximately 110 m wide from bank to bank; the flowing part is narrowed to 90 m as a result of groynes. A concave bank of the Meuse bending northward ends at Cuijk. About one kilometre past Cuijk a meander of the Meuse begins which curves westward. On the concave bank of this lies Mook. The main current of a river (the imaginary line in the river connecting the points with the greatest rates of flow) always runs along the concave bank. At Cuijk, therefore, the main current is against the Cuijk bank and past Cuijk the main current crosses the river to the Mook bank. The morphology of the river bed is largely dependent on the course of the main current where the river is naturally deepest. The bed here has a steep slope towards the concave bank and a gradual slope toward the convex bank. Sand or gravel banks may be formed on the slope towards the convex bank. At low water the tops of these banks become visible. Some of them are almost always above the surface of the water and become overgrown. At such islands the Meuse splits into two branches: a main river flowing along the concave bank and a tributary flowing along the convex bank.

The natural Meuse was a river full of islands and sandbanks (fig. 5). Because the Meuse is a rain river, its flow is dependent on the rainwater surplus in the catchment area and on the speed at which this surplus water reaches the river. Upstream from Cuijk, the Meuse has a catchment area of *c.* 25 000 km^2. Nowadays, the average annual flow at Cuijk is 300 m^3s^{-1}. In the summer months (1 May – 31 October) the average flow is 160 m^3s^{-1} and in the winter 440 m^3s^{-1}. The lowest daily flow this century was 5 m^3s^{-1} in the summer of 1947. High daily flows at Cuijk were registered in the winters of 1926, 1993 and 1995 when 3200 m^3s^{-1} was recorded. With such flows, the Meuse at Cuijk attains a water level of *c.* 11 m NAP.

24 This does not mean that no transport was possible over the river in Roman times, but the vessels had to be shallow and had to wait for a favourable water level. Particularly in the upper reaches of the Meuse (the Ardennes) river transport will mainly have been in a downstream direction and on rafts.

The extremely high flows are, among other things, the result of the high speed at which the rainwater surplus is discharged into the Meuse via sewers, canals and pumping engines. In the Roman Period, the rainwater surplus reached the Meuse via the groundwater and natural watercourses. These are relatively slow processes which have a suppressive effect on the development of drainage peaks in the river. Measured over the seasons, the drainage characteristics would have been roughly the same. In winter two and a half times as much water is discharged as in summer.
The rate of flow is greatest along the concave bank and it is there that the most extensive lateral erosion may be expected. With a high rate of discharge, erosion of the river bed increases, not the lateral erosion. The river carries sediment over the whole of its surface of contact with the bed (including both the slopes towards the concave and convex banks). The river becomes temporarily deeper during high discharge. Once the discharge returns to its normal rate, clastic sediments are deposited on the bed and the river reverts to its normal depth and morphology. This process is called scour and fill.[25]

1.1.5 Threat to the findspot
Since the Industrial Revolution (nineteenth century) a large-scale process has been underway to make rivers more navigable (normalization). The main alterations are making the river straighter (canalization) and controlling the water level and the depth of the navigation channel in rivers (regulation). These changes have generally had far-reaching effects on the riverbed. A large number of historical bridge remains in Europe have probably been lost as a result, without receiving any archaeological attention. In the Dutch section of the Meuse, normalization did not start until the beginning of the 1930s. The physical intervention at Cuijk has remained limited. On the right bank, groynes were constructed to narrow the river, a landing quay was built on the left bank and the navigation channel has been dredged several times. The most important change was that a through shipping route came to lie along Cuijk. Shipping is still steadily increasing in the number of ships, tonnage and engine capacity. This causes erosion of the riverbed which is the greatest threat to the findspot. The threat is most acute in the navigation channel and on the landing quay, *i.e.* in the middle of the Meuse and on the left bank. On the right bank the threat is far less acute because of the presence of the groynes. The groynes narrow the channel of the Meuse causing an increase in vertical erosion (scour and fill) with great rates of flow. During the pilot study it was established that the archaeological remains on and in the bed of the navigation channel and on the landing quay side could not be preserved and had to be excavated (see fig. 6).
During the excavation another find area was discovered beyond the axis of the bridge. The finds from this area are about the same age as the bridge (area 6000, see 2.1.7). This area is situated against the south corner of the present landing quay of Cuijk. During the pilot study it was estimated that this area was not under threat.[26]

1.2 *Research question*

The presence of Late Roman bridge remains at the bottom of the Meuse at Cuijk has resulted in many questions which can be narrowed down to four main issues.
1 What was the technical construction of the bridge like?
2 How did the bridge fit into the landscape of the time?
3 What was the function of the bridge in the regional infrastructure?
4 What was the function of the bridge in the Late Roman society?

Possible answers to these questions are obtained by:
1 reconstruction of the bridge;
2 reconstruction of the landscape;
3 reconstruction of the infrastructure;
4 fitting the bridge into Late Roman society.
In the present research the following strategy has been followed:

25 Paulissen 1973, 55.
26 Since the field survey, the Meuse has again displayed its capricious behaviour as an unpredictable rain river. In the winters of 1993 and 1995, great floods occurred and in the winter of 1996–97 there was a lengthy period of frost which caused the water level to drop considerably. The floods led to decisions being made at a political level to take extra measures (to deepen and widen the Meuse and to raise its banks). The extremely low water level made it possible for new observations to be made as to the preservation of the findspot. All this resulted in 1997 in a new assessment of the threat: all the outcropping find areas are threatened.

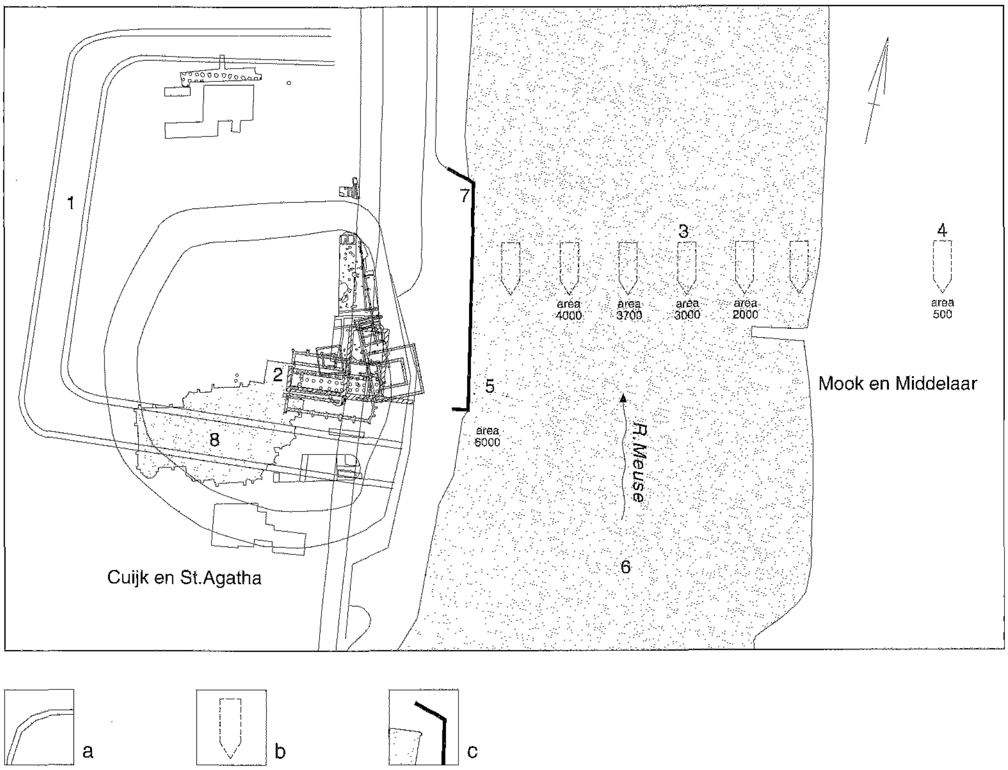


Figure 6 The spatial relation between castellum, bridge and a find area in the bed of the Meuse which does not belong to the bridge. The Roman bridge is visualized by the outline of a pier in each find area. To facilitate general orientation some elements of the present topography have been indicated (scale: 1:2500). Legend: a the Late Roman castellum with the double V-shaped ditches (1) and a wall foundation (2); b the Late Roman bridge with the underwater find areas (3) and the (possible) find areas in the bank (4), and the find area unrelated to the bridge structure with find area (5) in the continuation of the wall foundation (2); c present topography with the Meuse (6), the landing quay (7) and the church (8).

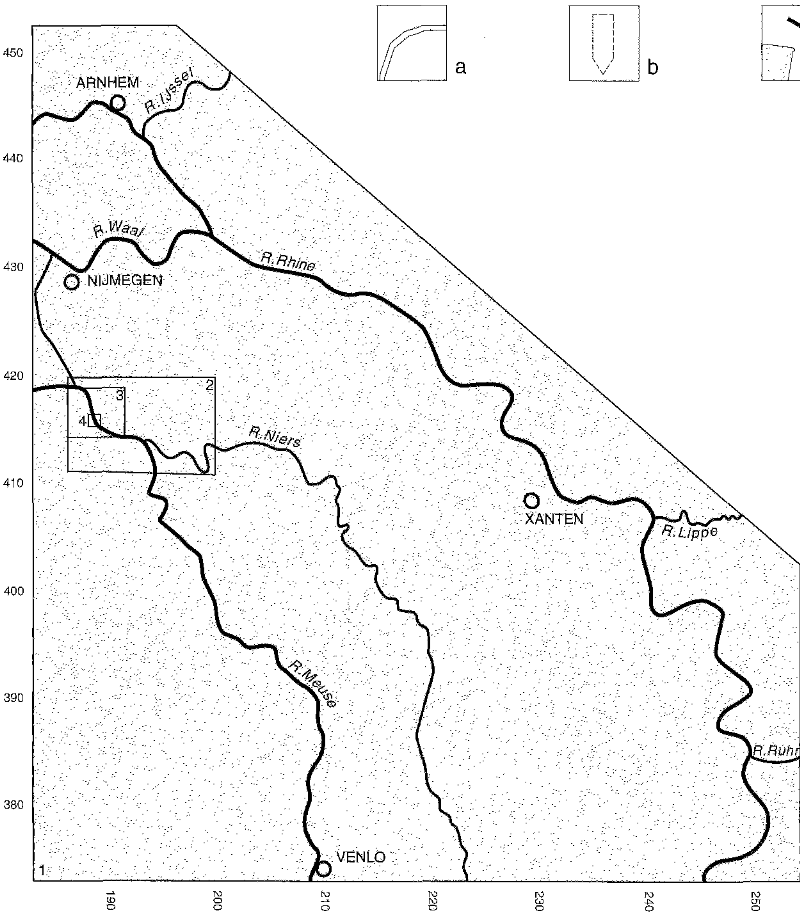


Figure 7 Location of the four study areas (scale 1: 250 000).
Legend: 1 macroregion regional, the area to which the historical analysis relates; 2 macroregion local, the area within which an inventory of archaeological find reports was made; 3 mesoregion, the area for which a palaeogeographical reconstruction has been made; 4 microregion, the excavation site of the Late Roman bridge.

study level	area	object of study	research question
A micro level	50 x 450 m	reconstruction of bridge	construction method, building time, use of material, and decay of construction comparison of this bridge with present knowledge of Roman bridge building
B meso level	4.5 x 5.5 km	geological context	reconstruction of the landscape in Roman times, fitting the bridge and the reconstructed infrastructure into the landscape
C macro level, local	7 x 13 km	local archaeological and historical context	inventory of relevant findspots
D macro level, regional	*c.* 75 x 50 km	regional archaeological and historical context	inventory of relevant findspots and historical events in the region; creating a regional archaeological/historical framework for the bridge

Table 1 The four study levels. Each level has its own study area, research question and method.

1 reconstruction of the bridge on the basis of the archaeological fieldwork, supplemented by archaeological parallels and structural mechanics;
2 reconstruction of the landscape on the basis of physical-geographical fieldwork, supplemented by a literature search for the regional origin of the landscape;
3 reconstruction of the infrastructure on the basis of an analysis of find reports in the vicinity of Cuijk, supplemented by a search near the bridge;
4 fitting the bridge into Late Roman society on the basis of a literature search of the Late Roman Period in Northwest Europe.

To each of the four main research questions belongs a specific research strategy with its own spatial scale (table 1). For this reason four scale levels have been defined. Each research level has its own geographical definition (fig. 7).

1.3 *Levels of research*

1.3.1 Research level A: the reconstruction of the bridge (microregion)

The aim of the research at this level is a reconstruction of the bridge by means of mapping the entire findspot and excavating the threatened section, together with a literature search. The dimensions of the research area above and under water are 58 x 450 m, excluding the bank structures found.

The bridge at Cuijk dates from the Late Roman Period and is founded on wooden piles with piers built of stone. This type of foundation is frequently found. The variant encountered at Cuijk is, however, only comparable to the foundations discovered in Maastricht and Mainz. Unfortunately, these have hardly been investigated.
At research level A the following specific questions were asked.
1 How was the Cuijk bridge constructed and what techniques were used? Were there any previously observed techniques or were as yet undocumented techniques used, and can the bridge be classified typologically?
2 Is it possible to distinguish building phases and were there any repairs or maintenance? Where are repairs located in the foundation and why there?
3 Is it possible on the basis of the excavation data to say anything about the system of measures used and about the nature of the design?
4 Is reconstruction possible on the basis of a wider investigation, and what conditions must be used?
5 Can anything be said about the amount of time it took to build the bridge and the use of materials?
6 What post-depositional processes were involved between the building and the excavation of the bridge?

1.3.2 Research level B: the geographical context (mesoregion)

There is a close relation between landscape and bridge.

The bridge, after all, was built to fit the landscape. The builders of the bridge chose the best location and took into consideration the water level, the behaviour of the river, the width of the bed and the height of the banks. Consequently, the construction of the bridge provides information for the reconstruction of the landscape at that time. On the other hand, the reconstruction of the landscape contributes to our knowledge about the bridge. For the research of the local landscape context an area was selected measuring 4.5 x 5.5 km. The bridge is situated approximately in the middle of this area.
The find of the Roman bridge in the present course of the river Meuse is surprising from a geological point of view. The normal pattern is that a meandering river gradually shifts its bed and builds up a point bar on the site of its former bed. The bridge remains on and in the present bed of the Meuse at Cuijk show that the Meuse is still in more or less the same position as in the Roman Period. If the Meuse has not shifted since Roman times, the landscape will hardly have been affected by fluvial erosion. This offers good prospects for a palaeogeographical reconstruction of the landscape in the Roman Period.
The bridge was obviously the central point in the local infrastructure. The Roman road network was determined by the position of the bridge and the landscape possibilities. This common ground between landscape and bridge leads to the following questions.
1 What did the a-biotic and biotic landscape around Cuijk look like?
2 Why is the crossing at Cuijk?
3 Does the reconstruction of the landscape contribute to the reconstruction of the bridge and *vice versa*?
4 Where did the roads and routes run in the immediate vicinity of the bridge?

These questions can only be answered when the genesis of the landscape is known. Because the existing information about the area around the bridge was insufficient, a geological field survey was carried out.

1.3.3 Research levels C and D: local and regional archaeological inventory of the area (macroregion)
A bridge is a labour-intensive and costly structure. The building and upkeep in a Late Roman context are at least unusual and deserve to be considered in a wider historical and spatial frame. Pressure on the borders of the Roman empire must have been perceptible in all aspects of Late Roman society. Nevertheless a structure like this was built. There must have been well-founded reasons for doing so. The research of the archaeological context covers an area of 13 x 7 km around the bridge. In this area findspots from the period in question were examined. For practical reasons use was only made of the ROB's database, and only the Dutch section of the study area was mapped.
For the research into the regional archaeological context, a second area of 75 x 50 km was selected in which the most important findspots were investigated and marked. The emphasis lay on the military findspots and the infrastructure in the Roman border zone. The area includes the then border zone between Cuijk, Xanten, Nijmegen and Arnhem, and is enclosed by the Meuse and Rhine. The local and regional inventory is aimed at setting the findspot in an archaeological-historical context. The focus is on the military infrastructure and the underlying system of organization in the fourth century. The following questions are central.
1 What function did the Cuijk bridge have in the fourth-century network of communications?
2 What military function did the bridge have in the organization of border defence, and specifically the method of the defence in depth.

For levels B, C and D the research is focused especially on the Roman border area east of Cuijk.

1.4 *Method of the underwater research*

1.4.1 Administrative classification of the findspot
During the fieldwork the entire find area was divided into nine administrative find areas (fig. 8). Eight of these are in a row across the river. It is assumed that in each of these find areas there was one bridge pier. These eight find areas are each *c.* 20 m wide (at right angles to the river) and 25 m long. From east to west they are numbered: area 500, 1000 (not shown in fig. 8, see fig. 6), 1500, 2000, 3000, 3700, 4000 and 5000. In areas 1000 and 5000 no finds were discovered so they will not be discussed further. Area 500 is situated on the right bank of the Meuse and area 1500 is half on the bank and half in the river. The remaining find areas are situated in the Meuse. Find area 6000 against the landing quay of Cuijk is also about 20 m wide and 25 m long.
During the surveys (see 1.1.3) it appeared that the large

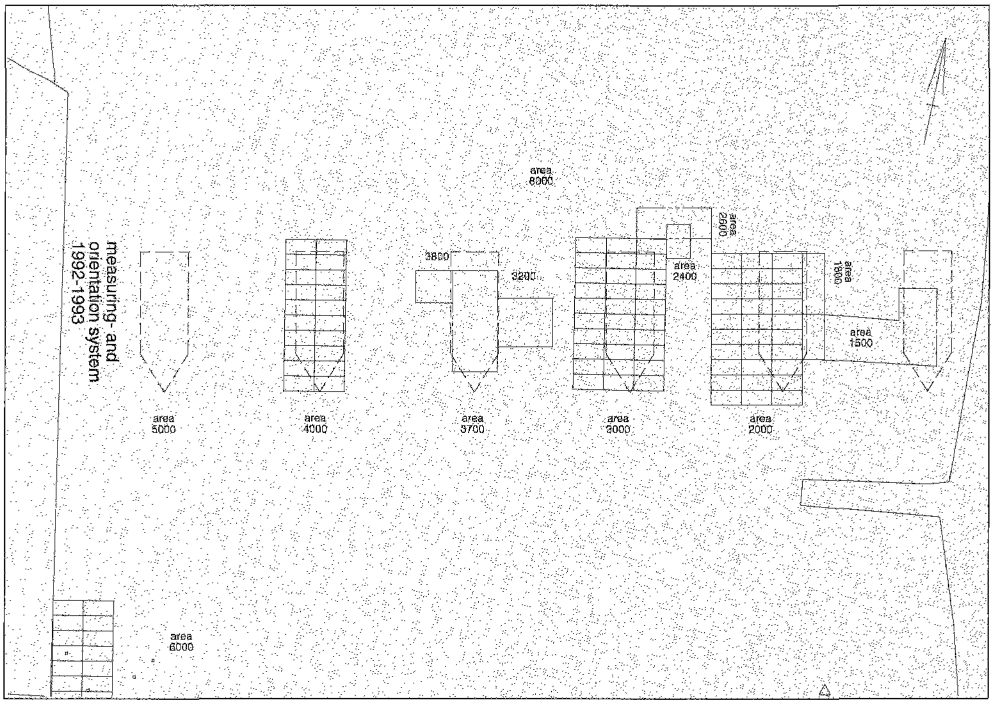


Figure 8 Division of the excavation site into find areas (scale 1:1000).

find material at the bottom of the Meuse was concentrated in a number of find groups. In three of these upright piles were observed in the river bed. These three groups of piles were interpreted as the remains of bridge piers *in situ*. From east to west they are referred to as area 2000, area 3000 and area 4000. Allowance was made for the discovery of a pier east of area 2000, and find number 1000 was reserved for it. During the digging of a trial trench in the river east of area 2000, another group of piles *in situ* was in fact found. During a trial boring on the east bank of the Meuse a vertical pile was struck. This pile represented area 500. The upright piles found during the trial trench investigation make up area 1500. When the position of five piers was known the spatial pattern became more obvious. There was room for one more pier between piers 500 and 1500 as well as between piers 3000 and 4000. The deepest point of the navigation channel is between areas 3000 and 4000. Stones and piles lying flat were discovered at the bottom of the channel; this concentration of finds was called area 3700. No finds were encountered west of area 4000. At first allowance was made for the fact that pier 4000 was the furthest west and that the Meuse had moved in a westerly direction after the Roman Period. In the final stage of the field survey a new find area (area 6000) with upright piles was found southwest of area 4000 and against the west bank of the Meuse. This area does not belong to the bridge structure but is probably connected with bank or harbour works. Part of the piles in area 6000 form a kind of embankment or jetty. From the position of this structure it appears that the left bank of the Meuse was virtually in the same place in the Roman Period as the present landing quay of Cuijk. This means that there may have been another pier (or bridgehead) west of area 4000. On the overall plan number 5000 has been reserved for it.

1.4.2 Working conditions

The Meuse is *c.* 7 m deep and this depth does not impose any restrictions on the time a diver can stay under water. Nor are the rates of flow in the Meuse so high that they would restrict divers. Only after periods of heavy rainfall is the water drainage and therefore also the flow temporarily too great. There are two problems which do affect underwater work: shipping and visibility. Busy shipping makes it necessary for all diving activities to be supervised. Visibility under water is 50 cm at the most so that stiff requirements are made of measuring techniques and of the orientation systems for the divers. Under these conditions it is difficult to map any possible soil features.

1.4.3 Fieldwork plan
The fieldwork plan is a derivative of the working conditions, the strategy and the research questions. It comprises the following activities:
– making an inventory and mapping the outcropping parts of the entire findspot;
– establishing which part of the findspot is not threatened and carrying out a limited survey of that part in order to discover the building method, date and dimensions of the bridge;
– excavating the threatened part of the findspot.

For safety reasons only one find area at a time was excavated. The separate find areas were later combined above water on the drawing-board to form one findspot.

1.4.4 Inventory
Around the centre of each find area a rectangular orientation system of 12 x 20 m was installed, which consisted of metal tubes and nylon cords. This rectangle was subdivided into smaller sections of 2 x 4 m. Each of these sections had a logical letter/number combination at a fixed place, so that this grid could serve as an orientation system when visibility was poor. The non-archaeological material was subsequently removed per section and the stones and piles were given a label with a number. The piles were provided with one fixed measuring point (a nail) so that it was clear where a pile had to be measured. Next a rough sketch was made per find area. The measuring details were recorded on a cassette recorder specially adapted for use under water.[27] On the basis of these sketches, a measuring plan was drawn up. These sketches also served as a first map for the iterative software package WEBIT discussed below.

1.4.5 Mapping
In order to determine the exact position (the x-, y-, and z-coordinates) of the finds, a measuring strategy was developed which makes use of the position of the piles *in situ*. Per find area these piles are first measured in relation to each other and the height of each pile is established. Next the large finds are measured in relation to the piles and the position of a few piles in each group is determined in the Netherlands National Grid coordinates. There are also groups of finds with piles not *in situ*. These finds are measured with the help of the upright piles in neighbouring find areas.
To measure the piles and stones in relation to each other a so-called non-parametric static method was chosen. Although the method shows strong similarities to triangulation, it has the advantage that no fixed measuring points are required in advance. In practice, the distances from the measuring point on a pile to at least four other measuring points on piles in the vicinity are determined with a tape measure. On the basis of the algorithm known as multidimensional scaling, the spatial distribution of the measuring points corresponding best to the measurements taken can be calculated from a large number of such measurements and on the basis of a rough sketch. As is now usual in statistical methods of approach, the margins of error are also calculated. The computer programme WEBIT used at this excavation was developed on the basis of experience in other excavations in Dutch waters and can calculate other data as well as linear measurements.[28] An important aid is the fact that the programme also shows the successive types of approach graphically, so that incorrect measurements can be traced quickly. In WEBIT a margin of error is given in advance. If a line has a green colour on the screen the difference between the estimated distance and the distance measured is within the margin of error. A red or blue colour indicates that the difference is above or below the margin of error. As a check, these distances are then measured again (fig. 9).
The diameter of all the piles is also measured and, in the case of slanting piles, the compass point and the angle of obliqueness. Two height measurements were taken of each upright pile: the top of the pile and the point at which the pile and the riverbed make contact. These heights are also put into WEBIT and used in triangulation calculations. To establish the height under water a special apparatus has been developed by the AAO together with TNO (Dutch Organization for Applied Scientific Research).[29] This apparatus is an extremely sensitive depth gauge which gives a reading in millimetres and is reliable in centimetres. In connection with the fluctuating water level, measurements are taken in relation to a point of reference under water. The point of reference is converted into NAP.
From the piles *in situ* all the stones were measured

27 Maarleveld 1984.
28 Rule 1995.
29 Botma & Maarleveld 1987.

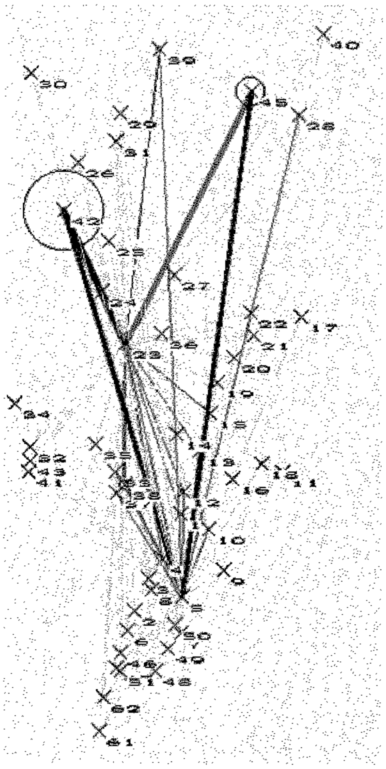


Figure 9 Example (in black and white) of the measurements of a find area as computed with the programme WEBIT.

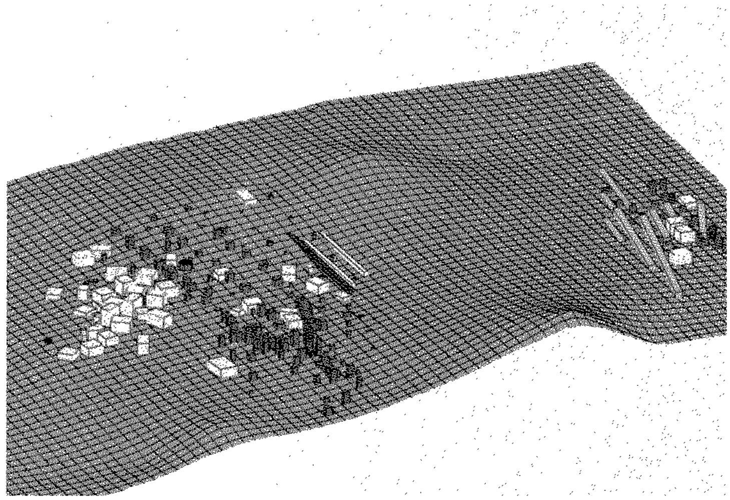


Figure 10 Perspectival representation of the underwater topography and the large find material from areas 2000 (left) and 1500 (right). The grid consists of squares with sides of half a metre.

three-dimensionally and input to WEBIT. All measurements concerning the dimensions, direction and geographical position of the large finds were put into the programme AUTOCAD. As a result it was possible to view the find area in two as well as three dimensions (fig. 10).

For a bank-to-bank survey, the drawings of the separate find areas were combined. Per find area three piles were measured in the national grid, the RD-system. For this it was necessary that the position of these piles could be measured above water. The device used for this was a tube longer than the depth of the Meuse. One end of the tube was held by a diver on the measuring point of the pile in question. Above water the tube was held upright by assistants in a boat. A prisma reflector was attached to the end and the position of the reflector was measured with a theodolite set up on the bank. Because the length of the tube is known, the measurement also produces a height for the measuring point.

The relief of the river bed was measured with the underwater altimeter in a grid of 5 x 5 m. All the height information of the bed of the Meuse was processed in the programme SURFER, which shows the relief as a grid. This picture was combined with the three-dimensional AUTOCAD drawing of the large finds. In this way a three-dimensional field drawing developed of the outcropping finds in the underwater landscape.[30] What could not be seen under water was thus made visible on the screen.

1.4.6 Investigation of the unthreatened areas

On the basis of the survey it was established that the section of the findspot under the east bank of the Meuse (area 500) and that on the east half of the bed of the Meuse (areas 1500 and 2000) were not threatened, nor was the section situated against the landing quay of Cuijk (area 6000).[31] The section in the middle of the Meuse (the navigation channel, areas 3000, 3700 and 4000) was, however, threatened and has been excavated.

30 With thanks to Kramers Automatisering Rotterdam, which supplied both the soft- and the hardware for computerization and provided support.

31 Since the field survey erosion has taken place here. Possibly the increase of shipping has something to do with it.

Figure 11 Impression of the excavation in 1992: stones and piles on the east bank of the Meuse (photo: B. Goudswaard).

Of the unthreatened section of the findspot, area 500 was investigated by means of an electric conductivity survey and extensive trial boring. The areas 1500 and 2000 can easily be kept free of shipping and are best suited for testing research and excavation techniques. In these areas trial trenches were dug, an estimate of the density of finds was made, piles were sampled for tree-ring analysis and salvage techniques for the stones and piles were tried out. The trial trenches served to collect the small find material. Two techniques were used: the dirty-water pump and the so-called airlift. The dirty-water pump sucks up water, unconsolidated sediment and small objects from the river bed. The sucked-up material is passed over a sieve above water which collects the finds. The airlift consists of a flexible pipe, one end of which is held under water just above the river bed while the other lies above water in the sieve. Compressed air is blown into the pipe from below. The air bubbles rise and gradually increase in volume due to the decreasing water pressure. This causes a suction in the pipe which draws in water and loose material from the bottom of the river. Because the suction is dependent on the difference in pressure between the atmosphere and the water pressure at the bottom, the airlift only works if the depth is sufficient. The airlift has been shown to be usable from circa five metres depth of water. For shallower water the dirty-water pump is a better option, although it can only process less heavy material.
When digging the trial trenches, the two by four-metre grid system was used. This is the same grid as described in the inventory (see 1.4.4). With a view to possible future research, steel pickets were driven into the soil at the corner points of the orientation systems and given durable labels. Area 6000 was discovered in the final stage of the fieldwork period. The limited time that could be spared for this area was used to survey the outcropping finds, collect large quantities of small find material and take samples for tree-ring analysis.

1.4.7 Excavation of the threatened areas

The objective was to excavate the threatened areas completely. The excavations were carried out in the part of the Meuse where there is a lot of shipping (fig. 11). The river police and the river authority temporarily directed water traffic past the locations where work was being done under water. The large finds were brought up by a crane ship. The piles *in situ* were tied in a noose and pulled out of the river bed. Because most of the piles were still firmly embedded in the bed of the Meuse, the noose sometimes caused slight damage to the pile. From the nail holes in the points of five piles it can be concluded that the iron pile-shoes of these piles remained stuck in the bed.
The piles and stones were then transported over land to a neighbouring storage place where there were also facilities for processing and documenting the finds. The wooden piles were laid in temporary water basins to protect them from drying out. After the investigation, the piles were preserved in three different ways to keep them available for future research. The majority of the piles were buried under groundwater level at an archaeological depot for long term storage, a few were very slowly dried under controlled circumstances and

25 piles have been preserved in PEG (polyethyleneglycol). In the areas that were cleared, steel pickets were also placed at the corners of the orientation systems so that it remains possible to trace these locations.

2 THE FIND COMPLEX

2.1 *The features*

2.1.1 Find area 500

The position of the find areas under water was roughly known on the basis of the pilot study. In a continued line from this position, trial boring was carried out on the east bank of the Meuse to find out whether the find areas continue in the bank. One of the borings ended in the heartwood of a vertical pile (at 3.8 m NAP). The ^{14}C age of this wood sample was determined (see 2.3.1.2 and table 3) and this showed that the pile could be considered part of the bridge structure. This borehole is the centre of area 500. The boring survey was also useful for the reconstruction of the post-Roman process of sedimentation (see chapter 4). Despite an extensive follow-up investigation it was not able to establish either the size of area 500 nor the configuration in which the piles stood.

2.1.2 Find area 1500

Area 1500 is partially situated in the right bank. The depth of the water is no more than 4 m. In the area the find material is covered with river bed- and/or levee sediments. The pier foundation was discovered here in a 9 x 4 m trial trench which was dug to confirm the presence of a pier and to acquire more information about the space the builders left between the piers. Because of its protected position, there was a possibility that the existing pier would be well preserved. The effects of currents and shipping on the right bank are far less than elsewhere in the river and the remains of the pier do not crop out. Nevertheless, erosion was serious here too. The top half metre of the piles had probably jutted out above the sedimentary layer for some time. This corresponds with the observation that the present sediment which covers them contains recent material and Medieval pottery.[32]

In area 1500, 35 vertical piles were found *in situ* and eight horizontal beams *ex situ* (fig. 12, area 1500 and appendix I). The heavy piles are 25–30 cm thick, the light ones between 12 and 19 cm. The top of the highest vertical pile measures 3.63 m NAP. The excavated section of area 1500 is too small for anything to be said about the pile-driving pattern of the piles. The distance between the piles varies, but is often around 1.5 m. Important finds in this area are the long beams which were possibly used as a frame or as a supporting structure for the foundation. These beams lie *ex situ* and are up to 7.5 m long and 30 x 30 cm wide. One of the beams, on examination, turned out to be a pile with a pile-shoe, that had apparently never been rammed in. This pile was 7.5 m long. This is interesting, because from the rammed-in piles removed in other areas it was evident that piles with pile-shoes were never longer than 5 m (see 5.1.4). None of the piles in area 1500 were removed, so there is no information available about the length of the piles or the presence of pile-shoes. Two piles from this area have been dendrochronologically analysed (see 2.3).

In the excavated section of this area there are five building stones of a white quartz sandstone *ex situ* (fig. 12, area 1500, and appendix II).

2.1.3 Find area 2000

Find area 2000 is situated 20.4 m from the right bank of the river. The riverbed in this area slopes gradually upwards in the direction of the bank. The area measures *c.* 25 x 15 m at a water depth of 3 to 6 m. Compared with the other find areas, the preservation of the piles is good. During the investigation, none of the piles in this area were removed, so there is no information about the length of the piles and the presence of pile-shoes.

In the area 139 piles were discovered, 126 of which were *in situ* (fig. 12, area 2000, and appendix I). No other find area in the river had more piles. The heavy piles are 25–30 cm thick and the light ones between 12 and 19 cm. The highest pile-top reaches 3.37 m NAP. This well-preserved group of piles is situated in the convex bend of the river, the piles hardly crop out and are still deeply set in the bed of the Meuse. The west side of the group of piles borders the navigation route. There, several smaller piles are missing from the otherwise virtually complete foundation pile pattern. The pile-driving pattern consists of two basic shapes: a rectangle and a triangle. Together they form a foundation in the form of a pier with the pointed end facing upstream. In the rectangular part of the foundation the piles are placed

32 Among which a complete stoneware jug; see 2.2.3.

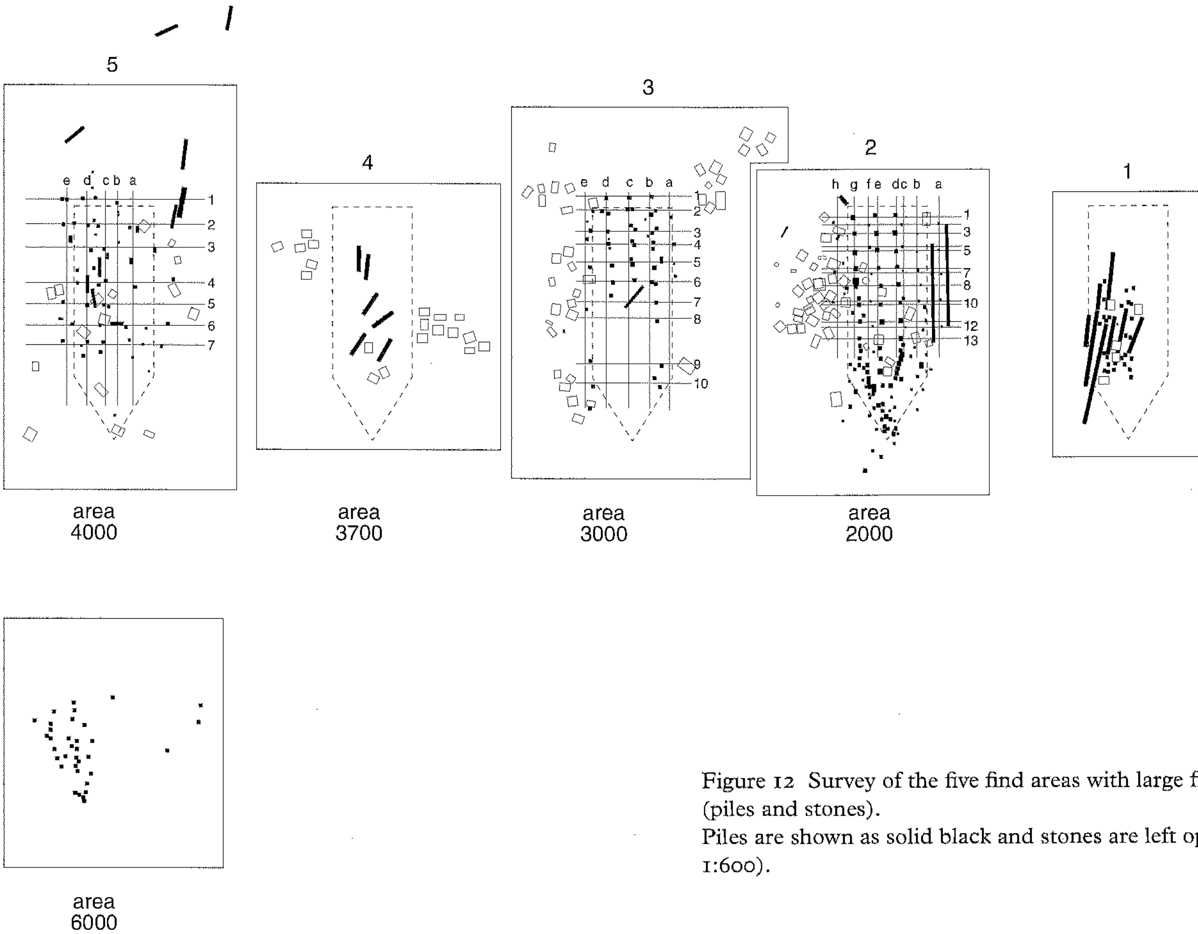


Figure 12 Survey of the five find areas with large find material (piles and stones).
Piles are shown as solid black and stones are left open (scale 1:600).

in rows both in the direction of the current as well as at right angles to it (fig. 12: rows A to H in the direction of the current and rows 1 to 13 at right angles to it). The rows of heavy piles are alternated with rows of light ones. The symmetry of the pile-driving pattern is also visible in the centre of the group of piles between rows G and D.

The cutwater of the foundation consists of an isosceles triangle with a base angle of *c.* 65° (see 2.2.2). The point of the cutwater facing upstream is therefore *c.* 50°. In the cutwater the piles are set close together, sometimes even touching. Within the cutwater it is difficult to recognize a pattern in the way the piles are placed. The established length of the foundation (that is the distance along the longitudinal axis of the rectangular part of the pier between the first and last pile *in situ*) is more than 11 m.

In this area 41 stones were found lying *ex situ* as a pile of rubble on the slope on the navigation channel side which appear to have come from the pier foundation. Under some of the building stones very recent finds were discovered, indicating that the stones are still moving. A limited number of stones were salvaged. The majority of the stones consists of dressed building stones of white quartz-sandstone. Some of the stones had been angled. As in area 3000 which has still to be discussed, the majority of stones have processing and jointing elements such as dowel, clamp sockets and Lewis holes.[33] Four column drums and a plinthstone were also found.

A remarkable find is a coarse ware pot without a lid, almost in the centre of the pier (see 2.2.3.2). The pot contained only washed-in sediment. Several lumps of tuff were also found. These lumps are irregular in shape and have a diameter of 1 to 30 cm.

For the date and phasing of this find area, five samples were taken for tree-ring analysis. Three samples are from vertical piles and two from foundation beams (see 2.3.1.1).

33 These terms are explained in chapter 2.2.2.

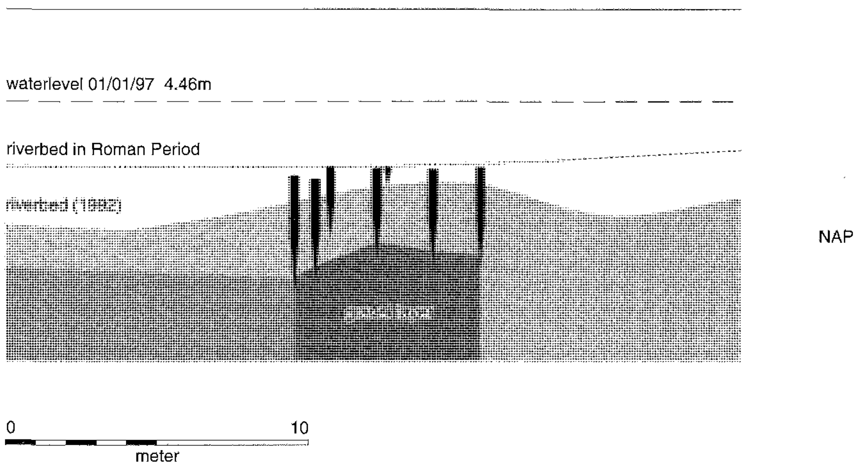
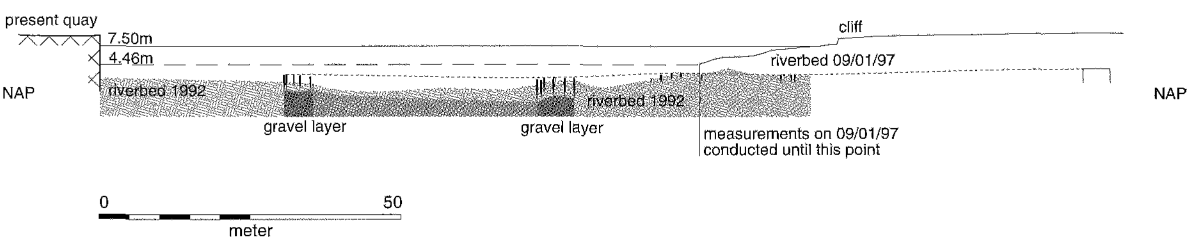


Figure 13 Reconstruction of the underwater topography in the Late Roman Period based on the depths to which the piles were driven in. Also shown is the present topography of th Meuse bed and the banks.



2.1.4 Find area 3000

The centre of find area 3000 is situated 40 m from the right bank on a firm and very local elevated part of the bed of the Meuse to 2.25 m NAP. The rise in the river bed consists of a sandy layer of river bed and below it a layer of very heavy clay resting on a gravelly sand layer. The maximum difference in height between the top of the mound and an erosion channel between areas 2000 and 3000 is *c.* 2.5 m (fig. 13). The upstream part of the elevation has disappeared. The navigation channel side of the area has also been eroded and covered with a thick layer of sand and gravel. The depth of the water is *c.* 5 m.

After measuring, all piles and stones were removed so that, in addition to dating evidence, information is also available about the depth to which the piles were driven in and the presence of pile-shoes. It is remarkable that the group of piles on the downstream side of the pier extended *c.* 2 m further downstream compared with area 2000.

Area 3000 contains 57 piles, 51 of which are *in situ* (fig. 12, area 3000, and appendix 1). The top of the piles is a 2.75 m NAP. The heavy piles are 25–30 cm thick, the light ones 12–19 cm. On the downstream side of the elevation the piles have remained very well preserved. Due to erosion on the upstream side, probably only hal have been preserved. The majority stands on the moun over a width of *c.* 8 m. At the top of this elevation the piles protrude *c.* 10–30 cm from the soil, while on the right and left sides and upstream of the elevation this can be as much as 1.8 m. Although the pattern of piles is less well preserved than in area 2000, at least five rows of piles are evident in the direction of the current (fig. 12, rows A to E). At right angles to the current, ten rows can be distinguished with some difficulty, because little is left of the original structure on the upstream side of the area (fig. 12, rows 1 to 10). The distance between the longitudinal rows is extremely regular and varies between 1.8 and 2.0 m. The two central rows B, C and D are regularly spaced. A number of combinations are present of a heavy, deeply-founded pile *c.* 30 cm thick and a smaller, shorter pile. In this area 26 piles were sampled for tree-ring analysis (see 2.3.1.1). Of the 51 piles *in situ* almost half (22 specimens) had a pile-shoe. It is striking that the piles with pile-shoes were found exclusively in the central part of the pier (rows B, C and D). Moreover, dated piles with pile-shoes tend to be older than dated piles without.

The heavier piles vary in length between *c.* 3 and 5 m. The pile-heads of one foundation were naturally driven in or chopped off or sawn off to the same level, otherwise they would not serve to support the stone part of the pier. The piles salvaged vary in length so the points of the piles reached different depths. The deepest point went down to 2.04 m -NAP and the highest to 0.96 m NAP. The median of the foundation depth in area 3000 is *c.* 0.34 m -NAP. The differences in the depth to which the pile points were driven in are not random. A pattern can be distinguished in the depths. A longitudinal section of the foundation indicates that the pile points at the upstream side were driven *c.* 2 m deeper into the river bed than the pile points at the back of the pier. A cross section of the foundation shows that the pile points in the two outermost rows (and especially the row closest to the middle of the river) project about two metres deeper into the soil than those in the three middle rows (fig. 13). The clay layer through which the piles were driven is much thinner in the three middle rows than in the outer rows. The clay layer rests on a layer of gravelly sand. Nearly all pile points end in this sandy layer. The pile points of the three middle rows are driven even deeper into the sand than those of the two outer rows. This is perhaps why only the piles in the three middle rows have pile-shoes. The penetration of clay requires force, but no pile-shoe. However, to drive a pile into a stony and/or sandy layer, a reinforcement of the point of the pile is called for. The Roman bridge-builders therefore either had previous knowledge of the substratum before piles were driven in or they drove the piles in as far as the sand and sawed or cut them off at foundation level.

To the west of the group of piles in area 3000 there were 27 stones and to the east were 15 stones (fig. 12, area 3000, and appendix II). Most of the material consists of block- or cube-shaped sandstone building stones. In four cases the stones have an angled side. These angled stones which belonged to the construction of the cutwater all lie on the upstream side of the area. The stones have the familiar working and jointing elements such as clamp sockets, Lewis holes and dowel holes. Also parts of a votive altar and a stone with an inscription were found.

2.1.5 Find area 3700

This area lies in the middle of the present river Meuse about 50 m from the right bank and is heavily eroded by currents and shipping. The *ex situ* finds are between 0.5 -NAP and 0.5 m NAP. The depth of the water is *c.* 7.5 m. Due to busy river traffic, the find material was only cursorily examined. The area consists of two concentrations of stones. This find area is *c.* 30–40 cm higher that the surrounding bed. During a short investigation in and on this elevation six piles *ex situ* were also discovered in addition to stone material. The distance between the centre of area 2000 and that of area 3000 is *c.* 19 m. The distance between areas 3000 and 3700, and areas 3700 and 4000 is also *c.* 19 m. In area 3700 there are 16 building stones (fig. 12, 3700, and appendix II). The stones are of sandstone. Ten building stones and all six piles were removed from area 3700.

2.1.6 Find area 4000

Area 4000 is situated *c.* 80 m from the right bank and *c.* 26 m from the Cuijk bank, on the left side of the navigational channel. The surface area is 13.50 x 22 m. The area has been heavily eroded by mooring ships and the current in the concave bend of the river. It is remarkable that the downstream side of the group of piles in this area extends *c.* 4.5 m further northward compared with area 2000. The relief of the bed is regular and the top layer consists of very coarse sand. On the navigation channel side there is an eroded clay edge at *c.* 1.5 m NAP which continues in a downstream direction. This clay layer probably belongs to the same sedimentary layer as that on the right side of the navigation channel and is only absent inside the channel (area 3700). The ground level in the centre of find concentration 4000 is about 1 m higher than outside it. This area had 64 piles, 54 of which were *in situ* (fig. 12, area 4000) The highest pile top was measured at 3.07 m NAP. At some places, the piles project more than

2 m above the river bed, making it probable that the present ground level is *c.* 2 m lower than in the Roman Period. There is no clear pattern in the arrangement of piles. On the navigation channel and front side of the area the pile pattern appears to be greatly depleted and many of the remaining piles protrude from the soil obliquely or have been broken off. In a longitudinal direction, five rows of piles can be discerned with difficulty (fig. 12, rows A to E). At right angles to the direction of the current, the rows have been numbered 1 to 8. The length of the rectangular part of the pier (that is between piles 51 and 41) is 11.2 m, and this length corresponds well with that in area 2000. The distance measured between the piles is often either *c.* 145 cm or 200–210 cm. The heavy piles are 25–30 cm thick, and the light ones 12–19 cm. Small piles standing against larger ones (as observed in areas 2000 and 3000) can occasionally be seen in area 4000. Heavy piles with a pile-shoe are mainly found in 'rows' B and C, which are for this reason regarded as central rows. In contrast to other areas, light piles also have pile-shoes. The pile point driven in deepest in area 4000 was at -1.32 m NAP, and the highest pile point 0.96 m NAP. The median of the foundation depth is 0.11 m NAP. Studying the foundation depth did not yield much information so it will not be discussed further. However, this foundation was slightly less deep than foundation 3000. In the area 25 *in situ* and five *ex situ* piles were sampled for tree-ring analysis (see 2.3.1).
There are relatively few stones in this area (see 2.2.2). All the stones are, of course, in a secondary position, eroded and worn. Only 16 stones were found, 15 of which are building stones, two with an angled side. One stone is a spolium of limestone. Compared with the other areas, the stones here are very scattered.

2.1.7 Find area 6000[34]

Area 6000 is situated on the left bank of the Meuse, about 35 m upstream from the bridge, and has a surface area of *c.* 8 x 14 m. The area borders the south corner of the present landing quay. The Meuse bank here consists of a steep slope of loose basalt blocks. Driven-in oak piles crop out among the blocks (fig. 12, area 6000). More piles are most probably hidden underneath. The outcropping piles project several decimetres above the stone blocks. The level of the tops of the piles follows the topography of the slope. The piles can be divided into three rough groups according to their height: below 4.5 m NAP; between 4.5 and 5.4 m NAP; and higher than 5.4 m NAP. The highest pile top in one of the other groups of finds is 3.63 m NAP. Area 6000 is therefore considerably higher than the foundations of the bridge. Area 6000 is also clearly situated away from the axis of the bridge and for this reason cannot be part of the bridge structure. Its function is not immediately obvious from the total configuration of piles. The piles with tops between 4.5 and 5.4 m NAP do form a partially regular pattern; they stand in a straight row parallel to the bank.[35] This row of piles is interpreted as a river bank protection.
Between the bank and the row of piles peat seemed to have developed. Approximately 1 m in front of the the bank protection there is another group of piles with tops at the same level as the first. Here too peat was found. Samples were taken of this peat and of the charcoal in it for ^{14}C analysis (see 2.3.1.2). In the peat layer, a large quantity of Roman pottery was found (see 2.2.3.1). Four beams lay hidden in the peat, jutting out from the bank horizontally and at an angle of about 45 degrees with the rows of piles.
In the area 36 vertical piles crop out. In cross section the piles have a square shape with sides between 25 and 30 cm. No piles were removed in this area, so there is no information about the length of piles and the presence of pile-shoes. Samples for tree-ring analysis were taken from four piles (see 2.3.2).
The presence of piles here had already been observed in 1978 at a very low water level. Then it was assumed that they were rather recent remains.[36] Not until the final stage of the excavation of the bridge was it discovered that this find material was roughly as old as the remains of the bridge. The estimate was that this find area was not under threat and that the large find material did not require salvaging. The large finds were mapped under water. Due to a period of extreme frost the water level of the Meuse was again very low in January 1997.

34 Only in the final stage of the fieldwork it was discovered that area 6000 was the same age as the bridge. By then a detailed investigation was no longer possible. After the fieldwork period, a local working group undertook to inventory this site further.
35 Small piles of a more recent date (impregnated rough timber with a diameter of 10 to 15 cm) were set between the Roman piles (square-cut oak with sides of 25 to 30 cm). Maybe it was once the intention to repair the Roman structure. The date of this operation is unknown. The recent piles have not been marked as finds and have not been included in the general survey.
36 In 1978 photographs were made by the municipality of Cuijk of the remains of the piles (verbal communication Bogaers).

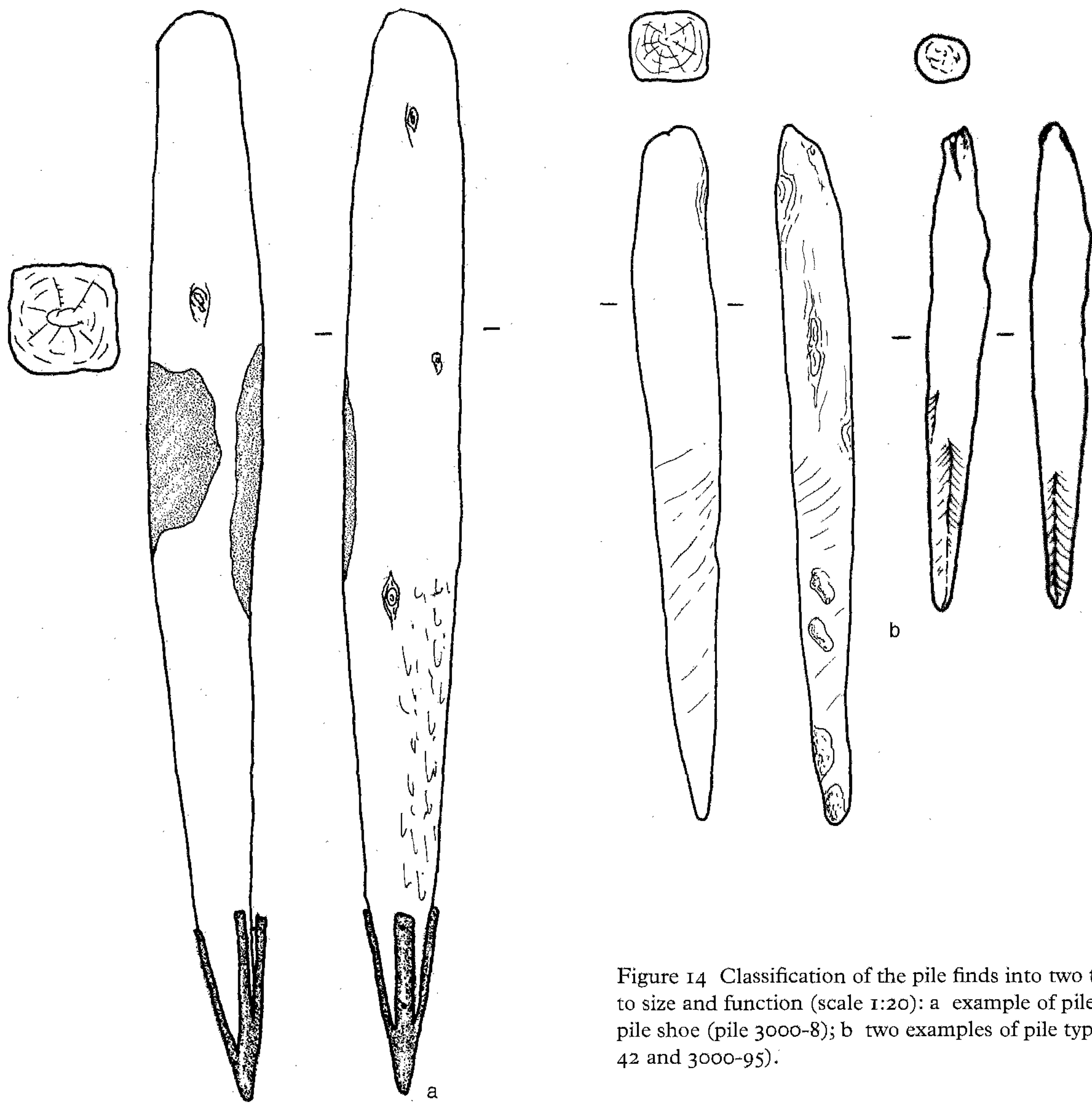


Figure 14 Classification of the pile finds into two types according to size and function (scale 1:20): a example of pile type 2 with pile shoe (pile 3000-8); b two examples of pile type 1 (piles 3000-42 and 3000-95).

A large section of area 6000 lay dry. Advantage was taken of the low water level of 4.46 m NAP to photograph and draw the find area and take extra peat samples (see 5.4).[37]

37 Five piles proved to have been knocked over by ships mooring at the landing quay. Three of these piles belong to the group with tops higher than 5.4 m NAP, two other knocked down piles belong to the group with tops lower than 4.5 m NAP. The piles included in the main structure do not have any collision damage.

2.2 *The finds*

2.2.1 The piles

At the findspot of the bridge and the bank structures, 337 piles were found. During the excavation, the length and width of 123 piles which had been removed was established and they were examined for pile-shoes. From these 123 piles, a selection was made of 93 characteristic foundation/construction piles. The piles of the bank structures were not examined, apart from a dating sample. Finally, 13 more horizontal beams were found *ex situ*, spread over areas 1500 and 2000.

2.2.1.1 *Use of wood and provenance* The piles are of oak (*quercus*). The similarity between the dendrochronological curves of the three building or repair phases of the bridge is so great that we may assume that the wood came from the same forest. The area of origin must be sought in the northern basin of the Meuse.

2.2.1.2 *Dimensions* On the basis of their size, the foundation piles can roughly be divided into two types (fig. 14). The division between both types may appear arbitrary, but the position in the foundation pattern and therefore the probable function of the piles supports a division into two types. This will be discussed in more detail in chapter 5.
For the analysis of the length, the piles from areas 3000 and 4000 were used. For the analysis of the thickness, use was made of areas 2000, 3000 and 4000. Pile type 1 is a small pile *c.* 17 cm thick and *c.* 135 cm long. Type 2 is a heavy pile *c.* 30 cm thick and *c.* 290 cm long. However, the longest pile in this group is 440 cm. In order to prevent rotting, the head of the piles will have stood under the lowest low water, and of course at the same height within one foundation. The foundations have, in the course of time, been eroded by the river and by shipping, causing differences of between 16 and 217 cm between the highest and lowest pile-heads. The greatest differences from the original length have been caused by piles breaking off. Judging from the top ends of the piles that seem fairly intact, there appears to have been little loss of length since the Roman Period, apart from breaking. These pile-heads are still reasonably square. The original length of the piles cannot therefore be stated exactly, but will have been around 3 m on average.
Far fewer piles were found of type 1 than of type 2; in areas 2000, 3000 and 4000, the quantities of piles of type 1 and 2 are in the ratio of about 1:3 to 1:4.

2.2.1.3 *Traces of processing* In contrast to a number of other Roman bridges both types of pile at Cuijk are squared, *i.e.* levelled on four sides by means of an adze and/or axe to obtain a square cross section. In other bridges, this kind of labour-intensive working was sometimes omitted and the pile retained its natural round shape. Traces of adzing are easily recognizable on the surfaces and are 7–10 cm in width (fig. 15).[38]

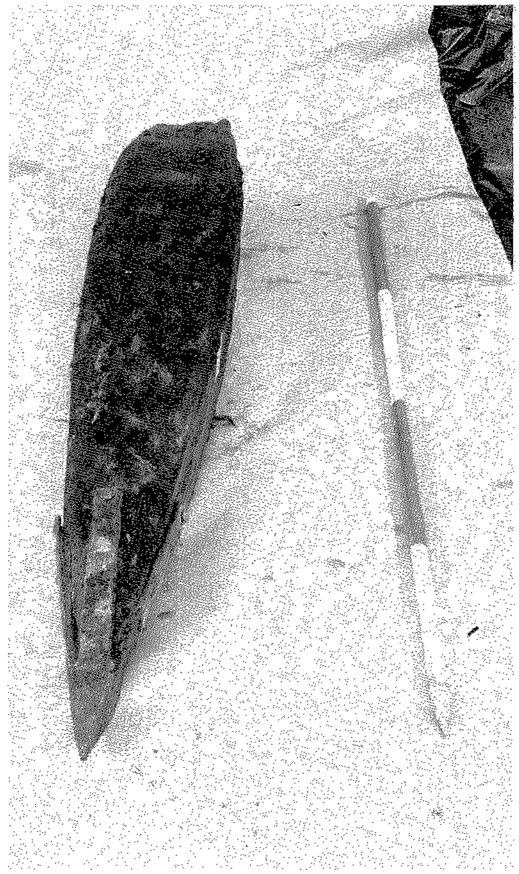


Figure 15 Traces of adzing on a pile (photo: P. Bersch).

The piles are pointed. Type 1 is pointed over a length of 60 cm and type 2 over a length of 120–150 cm (see fig. 14). The type 2 piles have been squared in such a way that the heartwood or centre of the tree-trunk is located in the heart of the foundation pile. It is clear that trees of a certain thickness were selected, because this would contribute to the strength of the pile. Sapwood is still present on many piles indicating that during squaring only little wood from the original trunk was removed to achieve the desired thickness. In places where the trunk was not thick enough, the sapwood and sometimes even the bark was left. This is extremely

38 Axes were found on the site with a width varying between 8.4 and 7.1 cm. An adze fragment is 8.9 cm wide (see 2.2.4, and fig. 30).

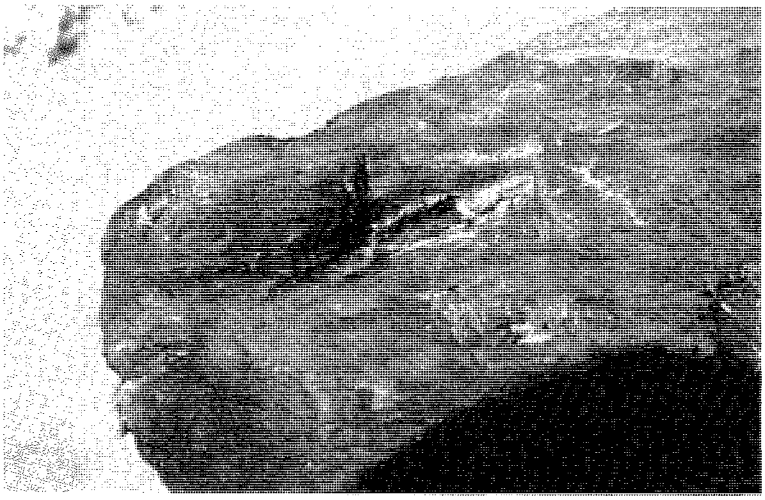


Figure 16 Pile head with probable attachment broken off. Only on this pile were traces of possible processing found which were connected with the pile structure (photo: R. Kroes).

valuable for tree-ring analysis. The presence of bark also shows that the piles were used almost immediately after felling; when the trunk is exposed to the air after the tree has died, the bark quickly comes loose.

How the head of the pile was processed is uncertain due to the wear of the pile-heads. Where erosion is less serious, one can see that the piles were lopped off squarely. No sawing traces were observed.

The piles must have been attached in some way to the foundation elements above by means of metal or wood joints. It is unclear from the material how these connections were made, but it seems likely that a framework of beams lay on top of the pile-heads and was fixed to them with iron nails or pegs.[39] In area 2000 possible remains have been found in a pile-head of a mortice for a tenon joint with the framework above. Traces of rust were still present in the hole (fig. 16). Many piles have a well worn hollow on the upper side which may have contained a peg or pin, but which may also be due to natural erosion. Judging from the degree of erosion, traces of joints may have been erased, particularly in the case of wood joints.

2.2.1.4 *Function* Both types of pile are pointed which indicates that they were driven in. The orientation of the knots, that is the beginning of the branches, shows that the piles were driven in with the top of the original tree facing downward. Because a trunk is always narrower at the top, a pile naturally has a pointed shape so that cutting is kept to a minimum. The heartwood at the root end of the tree is also thicker, making the pile-head stronger.

Pile-type 2 is the largest and forms the basis of the pile-driving plan and foundations. These piles gave the foundation its strength and played a part in counterbalancing both the vertical and the horizontal pressure.

Pile-type 1 clearly has a different function. Although the piles are much less heavy, they still have an unusual position in the foundation. They are almost always set *c.* 30 cm from a type 2 pile, forming octagons of alternating type 1 and type 2 piles (see chapter 5).

Of the beams from which the probable pier framework was constructed, remains were only found in areas 1500 and 2000. They are beams measuring 20 x 20 to 30 x 30 cm with a maximum length of 5 m. None of the beams, however, lay *in situ*. An important find was a beam with a cross lap joint set at an angle of *c.* 50 degrees, which is similar to the angle in the cutwater of the foundation and very probably formed part of the framework (fig. 17). Two other beams also showed possible traces of joints.

2.2.1.5 *Pile-shoes* Of the total number of 123 piles removed, 32 (*c.* 26%) had a wrought-iron pile-shoe. A pile-shoe is fitted around the point of the pile to protect it from irregularities in the soil during pile-driving. The pile-shoes at Cuijk are built up of four wings, two of which are spade-shaped and two flat bars. The cross-section of the point is square (fig. 18). Each wing is

39 Cüppers (1969, 49) speaks of large iron nails hammered into the heads of the piles so that the timber framework is firmly connected to the foundation.

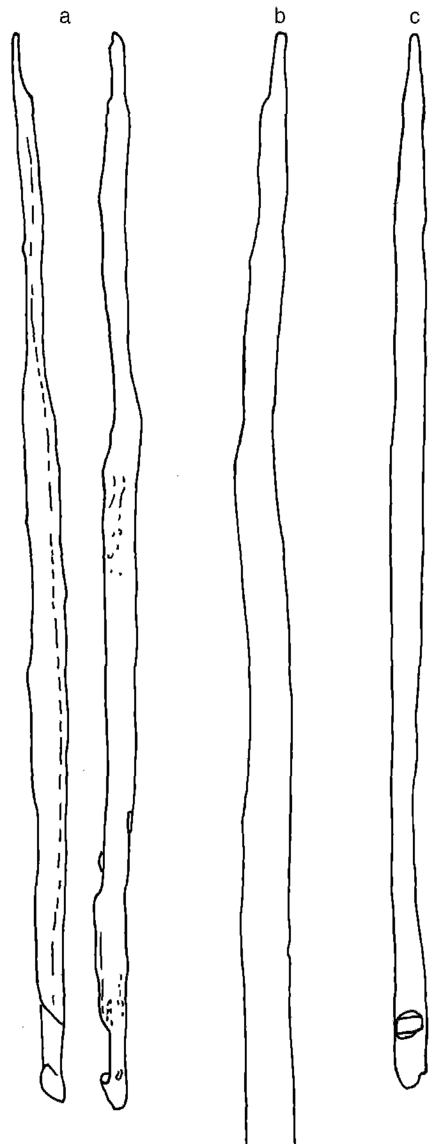


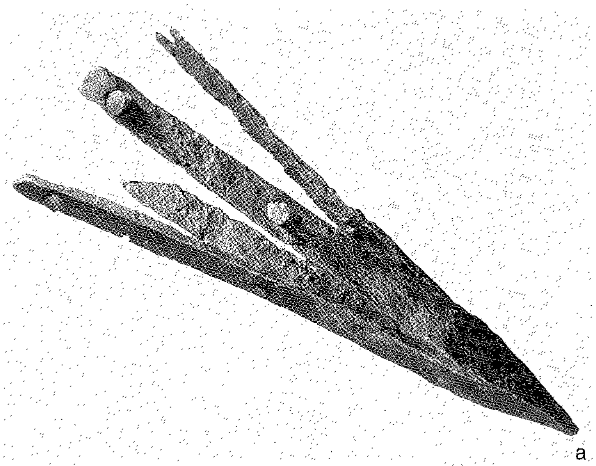
Figure 17 Three beams with traces of joining (scale 1:20): a beam with cross-lap joint at an angle (*c.* 50 degrees); b beam with slot; c beam with square cross-lap joint.

attached to the pile with two nails 6.5 cm long on average. The nails have flat heads. The length of the shoe varies between 58 and 61 cm (*c.* 2 feet) and the weight between 6 and 7 kg. The pile-shoes from Cuijk correspond roughly to the type characterized by Mesqui as Roman, although this type only has three wings.[40] A similar type has been observed at Trier and Frankfurt. Several pile-shoes from Maastricht are also similar to those found at Cuijk, as are the finds from the rivers Jeker, Oude Rijn and Waal near Nijmegen.[41] The pile-shoes from Cuijk therefore fit the collection regarded as Roman. Nevertheless a typochronology is far from reliable, since even nowadays the same types of shoes are used as in the Roman Period. Clearly their shape is not subject to whims of fashion.

The pile-shoes are made of material with an unusually high iron oxide content.[42] The wings are forged together by a process known as welding, in other words, heating and beating. Per shoe three welds had to be made for the four wings. The wings attached last lay in the fire longest and therefore absorbed most carbon. As a result, it was possible to determine the order of welding (fig. 18).

2.2.1.6 *Epigraphy* On one pile of type 2 a partially eroded inscription can be seen on the top side. The text consists of five letters which were very roughly carved over a length of 81 cm with a gouge or adze (fig. 19). The lines that make up the letters are 18–20 cm tall and 2–3 cm wide. Read from the point of the pile, from left to right, the letters could be read as E T E R N A . The sixth letter (A) is especially uncertain, because this part of the pile projected from the soil and is worn. On the left side the beginning of the text is unclear. Before the inscription was carved in, the inscribed side of the pile was made extra smooth. The pile is dated in the second building phase (see 2.3.1.1). Although many letters and numbers have been found on piles, in Mainz among other places, a text like this with a meaning is unique. One can only guess as to the reason it was inscribed, but it was undoubtedly connected with the wish for the bridge's eternal existence.

40 Mesqui 1986, 229; the type *sabot à trois languettes*.
41 Cüppers 1969, 47 and 49, type a; Gundel 1922, 71, type a; Koppert 1969, 120. Bogaers 1969, 56; Van Enckevort & Thijssen 1996, 70.
42 Thanks to Mr Colijn of the Technical University, Delft. Horssen 1994, 217–20.



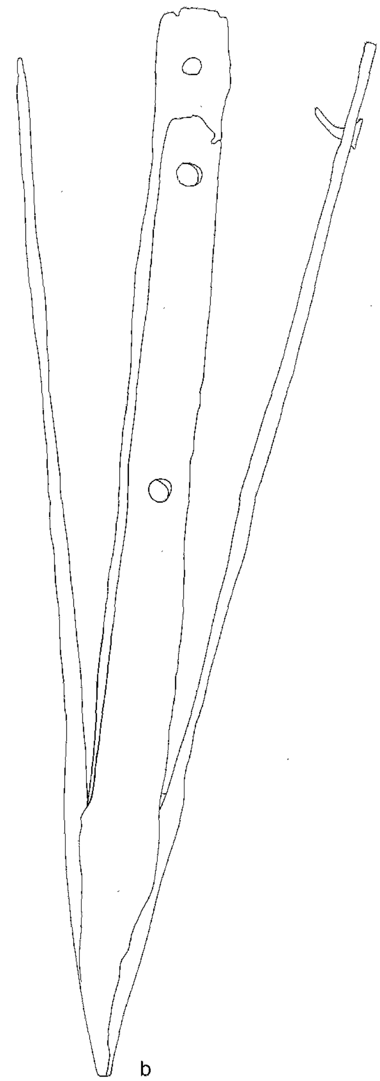


Figure 18 Wrought iron pile shoe:
a photo; b technical drawing (scale 1:4);
c macro-shot of a section through three wings welded together of the tip of a pile shoe (magnified 6.3 times). Visible are the welding seams between the wings. The darker the iron, the more carbon it contains.
Legend: 1 high carbon content;
2 intermediate carbon content;
3 low carbon content (photo: TU, Delft).

2.2.2 The stones

A total of 116 stones were found under water, including 108 building stones. The term building stone refers to a dressed, block-shaped stone, intended for the construction of the pier. Of these 77 were removed. In areas 2000 and 4000, 40 stones were left. Only six characteristic stones including plinthstones and fragments of pillars were salvaged.
During the analysis, attention was focused mainly on the primary and secondary traces of processing left on the stones, such as the shape and construction elements and the provenance of the stones. On the basis of the provenance and processing, a classification was made into two groups:
- building stones for the bridge pier;
- non-building stones or decorative elements (further described as spolia).

The objective of the research was to reconstruct the position of the stones in the bridge pier. Only the first group, the building stones, has been analysed for this

Figure 19 Pile inscription, photograph and drawing (photo: P. Bersch).

purpose. It proved possible to determine the position of a number of stones in the pier from the shape and traces of processing. A processing model was also made from the quarrying of the stone to the secondary usage in the bridge at Cuijk. The second group of non-building stones will be discussed at the end of the chapter and only in the case of unusual specimens. Because stone material is only sporadically found in large quantities in an archaeological context in the Netherlands and technical studies of classical and Medieval building practice are few, knowledge of this subject is limited.

2.2.2.1 *Type of stone and area of origin* The stone material can be divided into four groups on the basis of stone type and area of origin. Thin sections were made of the various groups.[43]
The first group consists of white quartz-sandstone possibly from the Alsace or the Ardennes. This group comprises 64 stones and therefore represents the greater part of the stone material. Almost all the stones in this group are building stones and have characteristic dressing and construction features.[44] This group of building stones was used as a basis for the model of secondary usage which is discussed in more detail in chapter 2.2.2.6.
The second group consists of only one stone (no. 328) of rotliegender sandstone, also possibly from the Alsace or the Ardennes. The stone is a fragment of a pillar and belongs to the spolia category.
The third group consists of two stones of grey tertiary limestone and carboniferous rock possibly from the Ardennes or the Geuldal (prov. of Zuid-Limburg). Both stones have a deviant shape and probably belong to the group of spolia.
The fourth group consists of seven stones of marine (tertiary) limestone. This is a soft white limestone, possibly from the Ardennes, but it is also found in Zuid-Limburg. The stones, which include a column drum, an altar volute, two plinth stones, a fragment bearing an

43 Thanks to Mr G.H. Ouwekerk of the Department of Physical Geography of the RUG for making the thin sections and analysing the results.

44 With the exception of a column drum.

inscription and a possible building stone[45] belong to the spolia group.

2.2.2.2 *Dimensions and system of measuring* Among the building stones, which are the largest group with some degree of regularity in size, and apart from a group of straight-sided blocks, 13 angled stones were found which are thought to have had a function in the cutwater or back of the pier. In appendix II, the stones are arranged according to length, width and thickness. An attempt was made to discover some regularity in the dimensions.

The average length of the stones is 80 cm, not including the two extreme values of 39 and 146 cm. About 50% of the stones is between 70 and 90 cm long.

The average width is 64 cm, not including the two extreme values of 26 and 96 cm. More than 50% of the stones is between 60 and 80 cm wide.

Almost 70% of the stones is between 40 and 50 cm thick. The minimum thickness of the building stones is 18 cm. The maximum thickness is 74 cm. The average thickness is 44 cm, not including the two extreme values.

The longitudinal measurements vary most (variance 207). The width varies slightly less (variance 137), whereas there is very little variation in thickness (variance 63) (table 9). In piling the stones, a fixed length and width was apparently not very important. However, the thickness of the stones is extremely regular. For building, a measurement of *c.* 44 cm was decisive. This corresponds to 1.5 *pes monetalis* or 1 *cubitus* or cubit.

Furthermore, it can be concluded from the above figures that the *average* building stone in Cuijk must have been *c.* 0.8 x 0.6 x 0.4 m in size.

2.2.2.3 *Form and function* The rectangular and square stones could have had any place in the pier except at corners or at rounded parts. The angled stones must have had a place in the cutwater where a hydrodynamic design of the body of the pier is essential. The angling of the stones varies from 55 to 75 degrees (fig. 20). The average angle is *c.* 65 degrees. It is striking that this angle corresponds very well with the angle formed by the piles in the cutwater of the foundation plan of the pier (see 2.1.3 and fig. 12). On the basis of the stones and the foundation plan, it may be assumed that the cutwater of the pier made an angle with the body of the pier of *c.* 65 degrees, and the point of the cutwater measured 50 degrees.

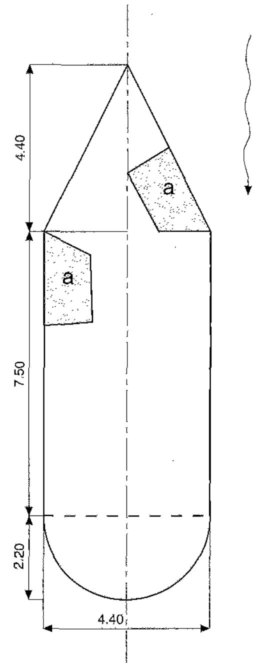


Figure 20 Reconstruction of the cutwater showing the two possible positions of angled stones (a).

2.2.2.4 *Stone working in general*

Processing marks

The stones show traces of surface finishing, processing marks and secondary usage. These features can be classified as follows (see fig. 22):

- processing marks received during the quarrying of the raw material, such as drill holes and cutting grooves;
- dressing of the surfaces of the blocks to obtain the correct form;
- features added to facilitate transport, such as Lewis holes;
- processing to aid the positioning of the stone such as crowbar slots;
- construction features for joints between stones such as clamps or dowels;

45 This stone is of a very hard type and has a most unusual form.

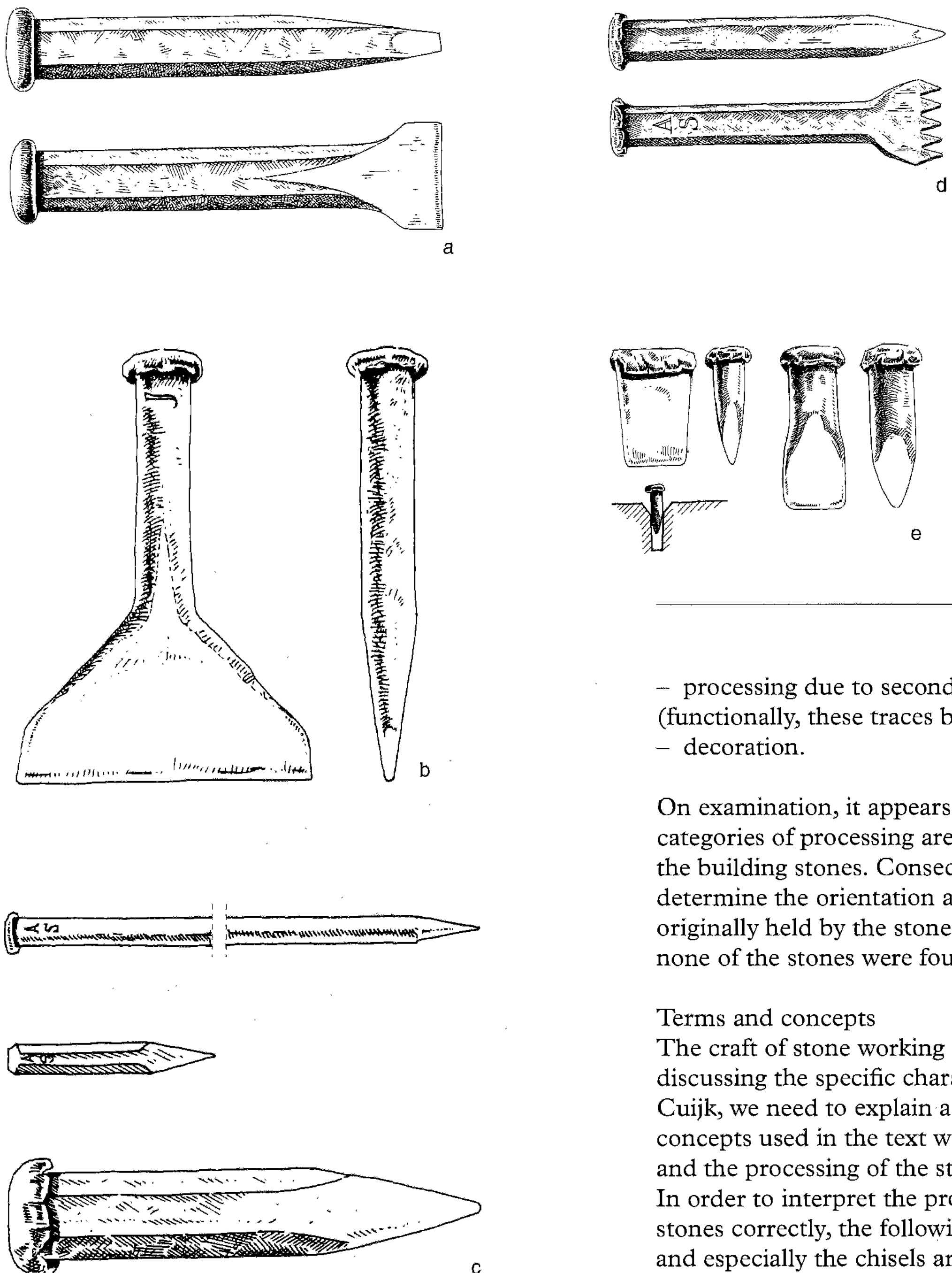


Figure 21 Various stone-working tools (from: Crevecoeur *et al.* 1990).
Legend: a pitching tool; b flat chisel; c point chisel; d tooth chissel or 'claw'; e keel.

– processing due to secondary usage of the material (functionally, these traces belong to the first group);
– decoration.

On examination, it appears that these functional categories of processing are found on fixed places on the building stones. Consequently, it is possible to determine the orientation and sometimes the position originally held by the stone in the pier, even though none of the stones were found *in situ.*

Terms and concepts

The craft of stone working has its own jargon. Before discussing the specific characteristics of the stones in Cuijk, we need to explain a number of terms and concepts used in the text with regard to the tools used and the processing of the stone.
In order to interpret the processing marks on the Cuijk stones correctly, the following stonemason's equipment and especially the chisels are of importance (fig. 21).[46]
First of all the *pointed chisel* (fig. 21: c) and the *pitching tool* (simple blunt wedge-shaped chisel) (fig. 21: a). With these tools a so-called 'pointed' surface is achieved, *i.e.* a surface with closely-set grooves. Pointing is a rough

46 Crevecoeur *et al.*, chapters 5 and 6.

dressing, in which large lumps of surplus stone are knocked off. When the stone is the correct size it can also be used as a finish or decoration
Traces of dressing with a *flat chisel* (fig. 21: b) were observed. A flat chisel is a flat wedge-shaped chisel which is used to produce a smooth straight surface. A bolster resembles a flat chisel but is broader, up to 12 cm. A *toothed chisel* is similar to a flat chisel or bolster but has teeth, which produce a parallel pattern of lines on the stone (fig. 21: d).
For quarrying, but especially for splitting stones in secondary usage, a wedge is used. A channelling tool is a chisel with a cutting edge slightly broader than the chisel itself, which is used to make narrow and deep grooves or channels in a stone. With this chisel, cutting grooves can be made, into which iron wedges can be placed for splitting (fig. 21: e).
Surface dressing with various chisels produces different results. The following processes of stone dressing can be distinguished.
– Making a ledge: this is a narrow strip around the surface of a stone, which is carefully levelled.[47] Ledges are used as a guide for levelling the rest of the surface of the stone. This is usually done with a point chisel. Sometimes the inner part of the surface is not levelled (fig. 22: 12).
– Flat chiselling: this is the ultimate finishing of a levelled surface. With a flat chisel a smooth flat surface is created.
– Tooth chiselling: this is a different finish for an already levelled surface. With a toothed chisel or claw parallel lines are inscribed. The toothed chisel can also be used as an intermediate tool between point and flat chisel.

Finally, the stonemason needs a number of instruments and standard processes for jointing and moving stones. For jointing, there are the *clamp* and the *dowel*. The clamp is used to connect various construction parts horizontally, and is shaped like a barclamp or dovetail. For a clamp, a channel is made in the upper surface of the stone which allows one half of a bar with short hooks to be let in. The other half fits into a similar channel in an adjoining stone. The channel is filled with molten lead and the stones are joined. In two dovetails opposite each other, a butterfly-shaped clamp of wood or metal can be inserted so that the stones are then held together (fig. 22: 6 and 7).

47 Rockwell 1993, 81–2.

The dowel is placed in a hole measuring *c.* 6 x 6 cm in the top surface of the stone. The projecting part of the dowel fits into a similar hole in the underside of the stone placed on top of it. A dowel must be fixed with molten lead in the top as well as the bottom stone. To do so, the top stone is first turned over so that the dowel can be fixed with lead. After that, the stone is turned over again and placed on top of the bottom stone. At that moment the bottom dowel hole is filled with molten lead via a pouring channel. Both dowels and clamps can be of wood, bronze or wrought iron.
For moving stones, *Lewis holes, crowbar slots* and *positioning holes* are used. The Lewis hole is a rectangular cavity 2 to 5 cm wide, 10 to 14 cm long and 8 to 16 cm deep, in the top of the stone. The hole becomes wider towards the bottom so that a Lewis can be fixed in it with which the stone can be hoisted up. The advantage of the Lewis is that one can hoist up a stone without anything being attached to the outside, like a rope or forceps (fig. 22: 8). This can be particularly useful when positoning the last block in a layer of stones. There are two types of Lewis hole: with two outward tapering sides, and with one tapering side. Because of balance, the Lewis hole must always be in the middle of the stone.
Crowbar slots are holes at the top of the stone into which a lever or crowbar can be put with which the blocks can be moved to their correct position (fig 22: 9). Hookshaped positioning holes are holes in the bottom of the stone which continue to one side like a horizontal L-shape. It is assumed that hooks, used to guide the stone to its correct position during hoisting were put into these (fig. 22: 10).
The position of a superimposed stone was indicated by L-shaped incisions in the upper surface. These marks generally coincide with the border between two separately dressed surfaces. Because of the varying lengths and widths of the stones, these marks will have been connected with planning the position of the stones of the next layer.
In order to cleave a stone, a *cutting groove*, a V-shaped channel, is cut, preferably along three sides, but sometimes only along the top. By placing the stone on an iron bar at the intended line of fracture and by carefully tapping the bottom of the groove with a chisel one can split stones which are not too thick. The remaining half of the original groove is recognizable along the edge of a fractured surface. Cleaving can also be done by cutting holes in the groove for iron wedges,

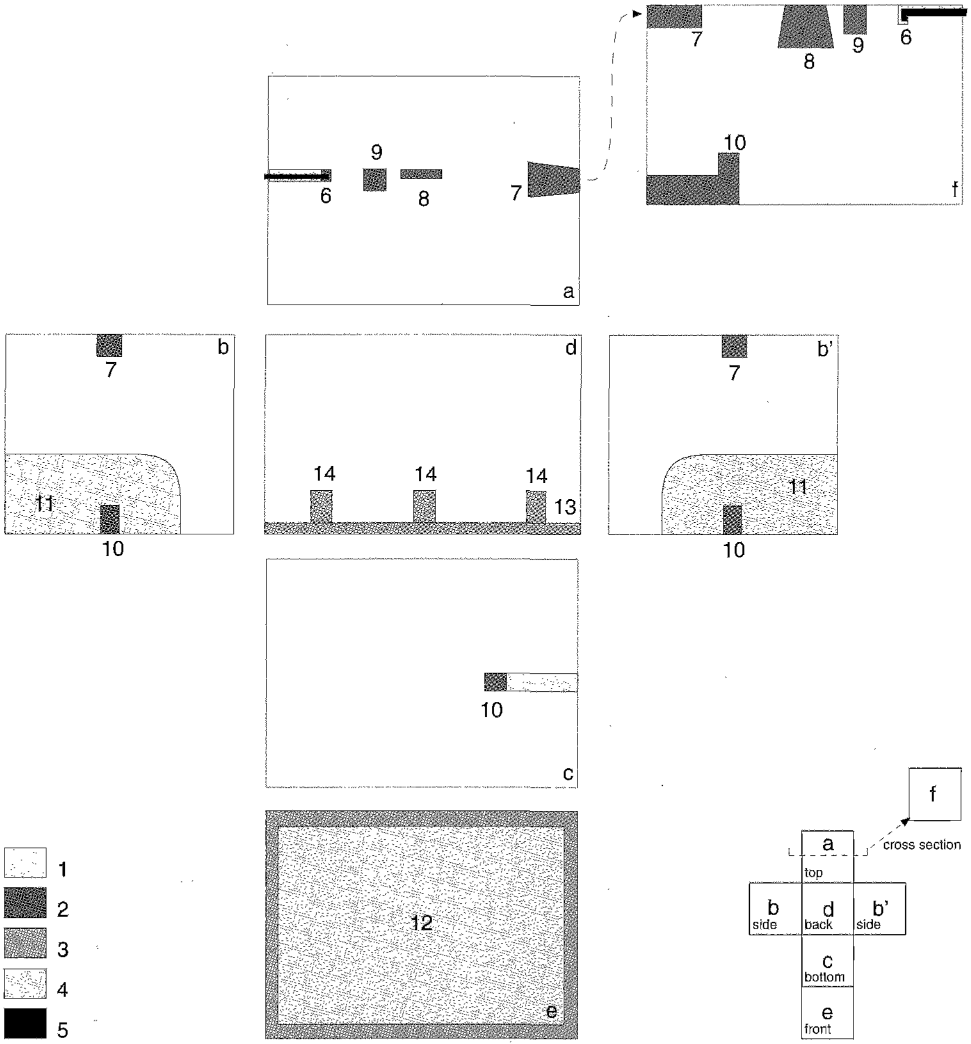


Figure 22 Survey of types of stone processing.
Legend: 1–2 shallow and deep holes; 3 traces of processing; 4 surface processing; 5 iron (means of attachment); 6 bar clamp socket; 7 dovetail clamp socket; 8 Lewis hole; 9 crowbar slot; 10 L-shaped positioning hole; 11 anathyrosis; 12 outside surface; 13 cutting groove; 14 keel marks.

'keels', which are then carefully hit until the stone breaks (fig. 22: 13 and 14). These holes are called keelmarks.

2.2.2.5 *Stone working at Cuijk*

2.2.2.5.1 Surface dressing Each building stone has six surfaces. Each surface has a characteristic dressing related to its place and function in the pier. The processes have been recorded on technical drawings (fig. 25). By analyzing the processing traces information can be gained about the position of the stone in the piers of the bridge and therefore about the method of building. The surface dressing of the stones is discussed per surface.

The outer side The outer side is the side of the stone which was visible on the outside of the pier. This side is characterized by a flat, often 4 cm wide border. This border was finished by a point or toothed chisel. Within the border, the stone was roughly dressed with a point chisel. The pointing was occasionally done in a rough herringbone pattern. The dressing of both border and inside surface was clearly created for its decorative effect. A distinctive outer side was found on 18 building stones (fig. 23: a).

The top and bottom sides These sides are similarly dressed but can be distinguished by the transport and construction features on them, *e.g.* a Lewis hole is at the top, as is a clamp socket which has to be filled with lead. The top and bottom sides are very smoothly

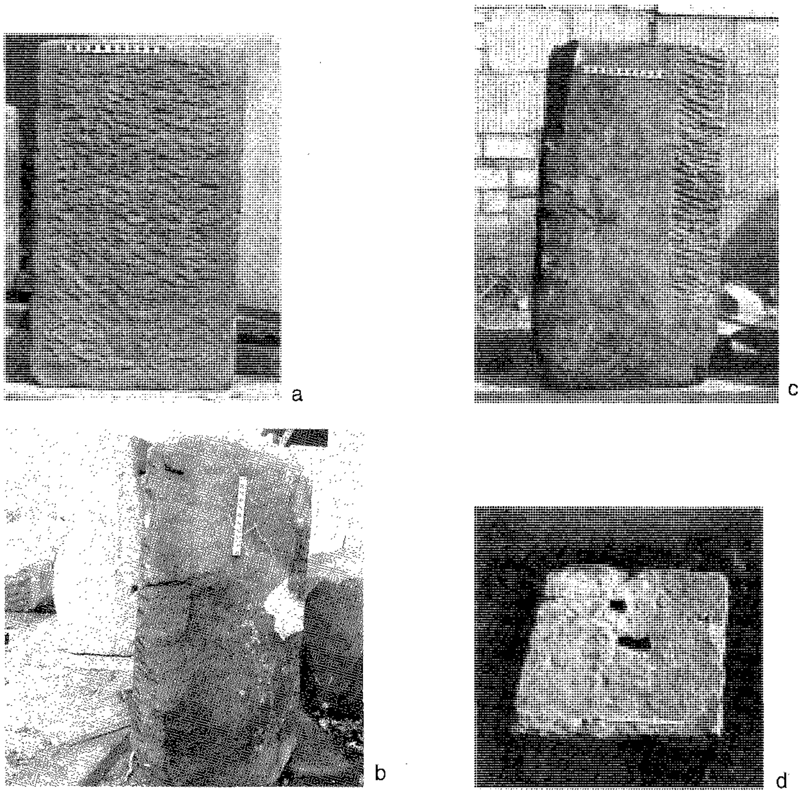


Figure 23 Four characteristic sides of a building stone. a side forming part of the outer side of the pier; b split side (typical for re-used stone); c side; d original upper surface (photos: P. Bersch).

chiselled with a flat chisel. The surfaces were first worked with a point chisel and no care was taken to remove all traces, therefore they have a rather pitted appearance. Because of this, top and bottom sides are clearly different from all other sides. Not all top and bottom sides are worked as described. Bottom sides in particular are sometimes unworked or only roughly dressed with a point chisel or perhaps a pitching tool (fig. 23: d, top side).

The butt side A typical butt side is very smoothly dressed with a flat chisel or a bolster so that all previous traces of dressing have been removed. This produces a surface which is so smooth that it was originally thought to have been sawn. This was not the case. Possibly it was rubbed with a harder type of stone, but no research has been done into this. In a section or corner of the surface a shallow (2 cm) hollow has been made with a point chisel, a so-called 'anathyrosis'.[48] The smooth surface permits a perfect fit with the adjoining stone. The anathyrosis has a labour-saving function: by making the stones connect only along the edges it is not necessary to level a large surface, yet an almost jointless fit is obtained which is necessary for keeping out water (fig. 23: c).

Ideally, an anathyrosis is made in the centre of the side, so that a more or less seamless connection is made along all four sides of the stone. This form was not encountered in Cuijk. More often, an anathyrosis is at the bottom of the side, leaving three smooth edges, or sometimes at the corner of the inner side of the stone, leaving only two. Surprisingly, among the Cuijk stones only small parts of the anathyrosis are present, giving the impression that the stones were re-used and split. The original anathyrosis may then have been up to four times as large, as might the original stone.

In Cuijk, an anathyrosis was found on 41 stones. Stones with smoothed butt sides were also part of the outer rows of pier stones, because they usually occur on the

48 The use of this term is not altogether correct; 'anathyrosis' does not actually refer to the hollow cut in, but to the border around it which remains. However, because the cut appears to be the 'true' process, many are inclined to call this the anathyrosis. See Coulton 1977, 46–8 and fig. 12 (c).

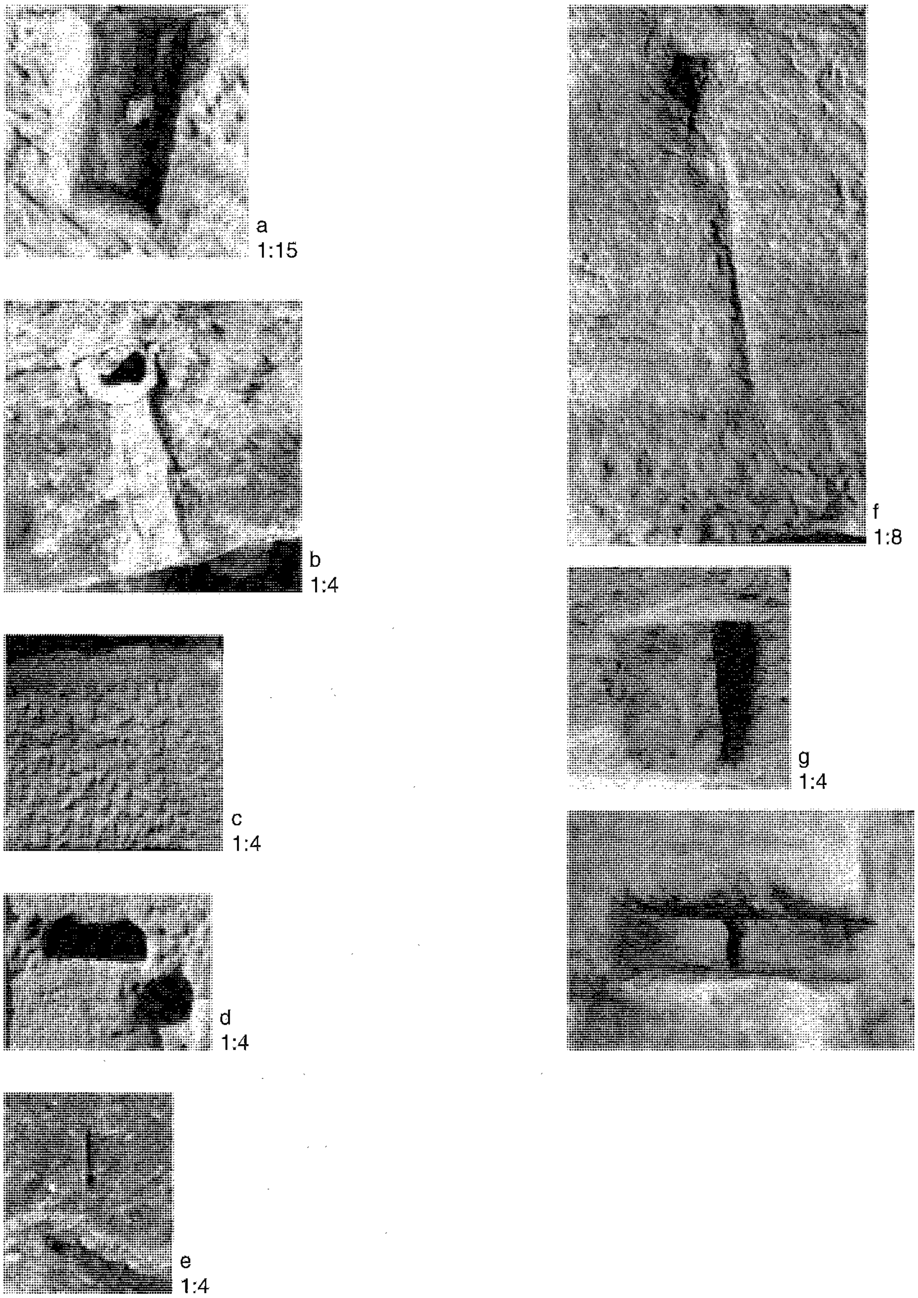


Figure 24 Frequently found stone processing marks: a deepened clamp socket (reused crowbar slot); b bar clam socket with remains of lead; c pointed ledge; d Lewis hole and crow bar slot; e incision; f dowel and pour channel; g dovetail clamp socket; h L-shaped positioning hole.

vertical surfaces which are at right angles to an outer side.

A primary anathyrosis would never cover the full length of the butt side; at the place where the butt side borders the outer side of the pier the hollow may not continue because water could penetrate. In Cuijk 23 stones with a functional anathyrosis were found, mostly in combination with a typical outer side. Twelve stones have an anathyrosis over the entire length of an edge. In these stones the processing is no longer functional. In 28 stones the anathyrosis is on the bottom surface and in five stones along the upper edge. These reverse and/or no longer functional anathyroses indicate secondary usage.

The inner side The side of a stone has all the characteristics of a roughly cleaved fracture which has sometimes been superficially reworked with a pitching tool or point chisel. The opposite side is usually an outer side. On 23 stones traces of keels and cutting grooves can be found on the inner side (fig. 23: b).

2.2.2.5.2 Construction features The stones show all kinds of construction features that indicate both primary and secondary use (fig. 24).
Lewis holes (transport) In Cuijk, 14 stones with an original Lewis hole were found and five with a cleaved Lewis hole. In some stones the hole was clearly not in the centre, which implies that the dimensions of the stone must have changed after primary use.
Positioning holes (positioning) Fourteen stones were found with positioning holes, two of which had two holes. Ideally, positioning holes are used alongside Lewis holes. This was only the case in two stones.
Crowbar slots (positioning) In the top surfaces of stones, points of attachments were found for crowbars used to move the top stones. The crowbar slots are 4 to 6 cm square and 7 to 10 cm deep.
L-shaped incisions (positioning) On the top surface of six stones a positioning mark was found consisting of two short lines 1 to 2 cm deep and 4 to 8 cm long, at right angles to each other.
Bar clamp sockets (horizontal joint) Thirty-three stones had one or more bar clamp sockets. These are usually placed opposite each other and are 10 to 15 cm long, 3 to 5 cm wide and 5 to 8 cm deep. Six stones have only one bar clamp socket. In the bar clamp sockets of eigtheen stones the remains of lead were found. In thirteen of these, the imprints of the original iron clamps had been sufficiently preserved to determine the length, width and/or depth (table 2). It would appear that two types of iron bar were used for the clamps: a wider type *c.* 26 mm in width and *c.* 10 mm thick (ten specimens) and a somewhat squarer type 20 mm wide and 13 mm thick (three specimens). The only metal clamp found belongs to the latter group. This division corresponds more or less to the differences found by Cüppers in Trier, where square and rectangular iron bars were used, 2 x 3 cm to 3 cm square, but also flatter bars only 1 cm thick.[49] In the remaining fifteen stones with bar clamp sockets there was no lead present.
Dovetail clamp sockets (horizontal joint) Dovetail clamp

findnumber	thickness	width	lenght (hook)	group
508	9	23		flat
585	10	28		flat
F	10	28		flat
527	10	32	25	flat
262	12	24		flat
585	13	20	24	square
525	13			square?
A		20		square
596		25		flat
263		25		flat
F		26	36	flat
534		26		flat
H		29		flat

Table 2 Dimensions (in mm) of iron bar clamps taken from the impressions in the lead in bar clamp sockets.

sockets were found on twenty stones. They are 9 to 14 cm long, 7 to 12 cm wide and 4 to 6 cm deep. Since no lead or iron remains were found in any of the dovetails, it is thought that wooden clamps were used. If bronze had been used and later re-used, there would at least have been traces of removal. The dovetails are also usually placed opposite each other. One stone has two dovetails perpendicular to each other on adjoining sides. Only five stones have both bar and dovetail clamp sockets, but no lead was found in the bar clamp sockets. From this, it might be concluded that the bar clamp sockets are of primary origin, while dovetail joints were used secondarily. There is a second indication for this. In almost all cases in which dovetail clamp sockets are found, the primary top sides of the stones have in the second instance become undersides.
Dowel holes (vertical joint) Two stones have a dowel hole, one containing the remains of an iron dowel. Both have a pouring channel. The two stones differ as to shape and origin. No evidence for a vertical joint was found in the normal building stones, which would appear to imply that no dowels were used in the building of the bridge.
Traces of demolition Quite a large number of stones had on the inner side a surface texture which at first was thought to be a roughly dressed surface. On closer examination, these proved to be fracture surfaces with, on the upper side, a strip of 3–5 cm made by a point chisel. This strip is the remains of a V-shaped cutting groove split in two. Once the fractured nature of the surfaces was discovered square impressions were also

49 Cüppers 1969, 49–50.

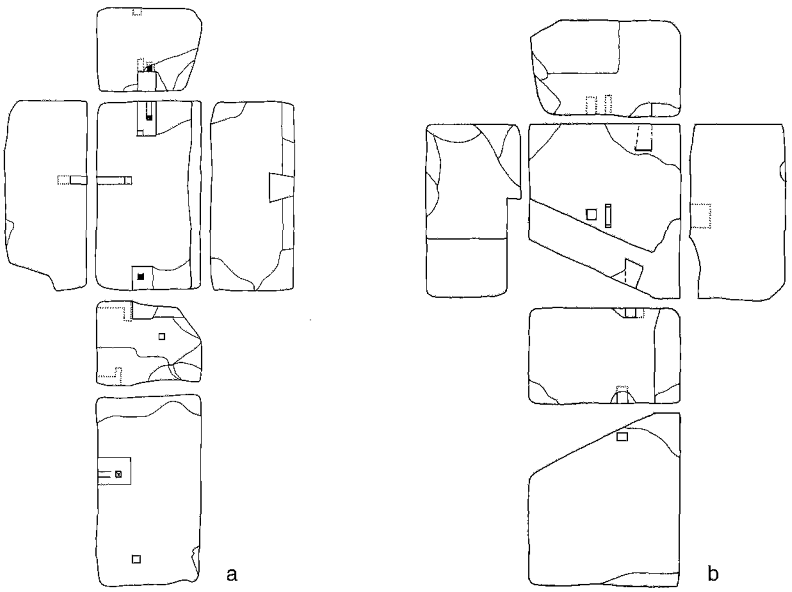


Figure 25 Technical drawings of stone 534 (a) and stone 531 (b) scale 1:40.

recognized of wedges or keels. In addition, a number of the marks appeared to be Lewis holes split lengthways. Bar clamp sockets split lengthways were unmistakably observed as well as Lewis holes split crossways,[50] indicating that the stones had been split and re-used in the construction of the bridge. A total of 32 cutting grooves were found. Ten of these have one or more keel marks.

In the split surface of the stones with a cutting groove, six Lewis holes split length- or crossways were observed. In five of the six stones there were bar clamp sockets which had been smoothed away but were still recognizable as such. Among the stones which had not demonstrably been split, there are two with a Lewis hole which is not directly above the stone's centre of gravity. These stones must therefore have been shortened. In addition there are also at least three stones where clamp sockets have clearly been hacked away. Traces of a point chisel can still be seen in the damaged parts. On the basis of this evidence one can prove that a total of 38 stones were certainly used secondarily. On the basis of other characteristics, it may be asssumed that even more stones were re-used. For example, the clamp sockets in a great number of stones are damaged. Due to the absence of traces of a chisel it is not possible to ascertain whether this was a result of deliberate demolition, but judging from the frequency, this would appear to be the case. Occasionally, hacked away clamp sockets are found in combination with dovetails, which indicates that primary bar clamp sockets were later replaced by dovetails, sometimes even on another surface. In addition, some upper surfaces were clearly not used as such, or stones have obviously been turned because the anathyrosis or the Lewis hole are on the wrong side. All these observations point to secondary usage. This applies to 65 of the total number of 77 analyzed building stones. In twelve cases, it is not possible to say with certainty whether they were re-used. It is therefore possible that new stones were also quarried for the construction of the bridge.

All stones found at Cuijk can be described using the terms and concepts discussed so far (fig. 25).

2.2.2.6 *A transformation model* It is useful to trace the process of transformation from a primary to a secondary stone. In the transformation model, a primary stone is transformed in no more than five steps into a secondary stone as encountered in Cuijk

50 Thanks are due to Mr G. Overeem of the RDMZ (State Service for Heritage Management). We owe not only our recognition of re-used stones to his explanation of stone-working techniques, but also a great deal of the descriptions of stones. Thanks also to T.A.S.M. Panhuysen for contributing to our insight into this group of finds.

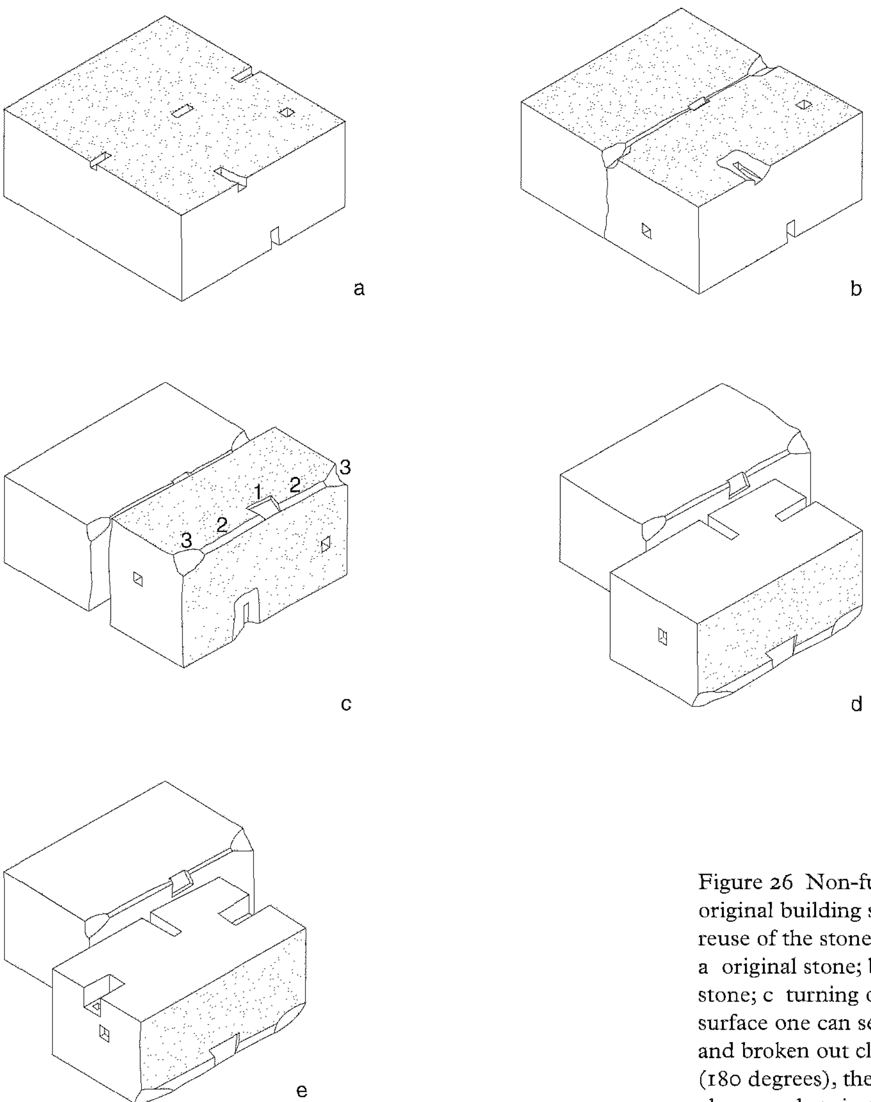


Figure 26 Non-functional processing points to the splitting of the original building stone and new processing marks point to the reuse of the stone halves in the Roman bridge structure. Legend: a original stone; b breaking out of clamp sockets and splitting of stone; c turning of the stone (90 degrees), in the upward facing surface one can see a split Lewis hole (1), a cutting groove (2), and broken out clamp sockets (3); d completely turned stone (180 degrees), the original base is now the top; e making new clamp sockets in the new top surface.

(fig. 26). For that matter, not every stone underwent all five processes. The stone shown in figure 26 is a model based on the one shown in figure 25: a.

1 Breaking the stone out of the original building (fig. 26: a, b): possibly the primary joints were damaged and smoothed away in the course of demolishing the primary building. The remains of clamp sockets remain visible, but are no longer functional in the secondary use. The lead remains in these sockets were recovered. No lead is therefore left in the clamp sockets of re-used stones.

2 Cleaving or splitting the stone (fig. 24: b): a stone can be split once or several times. This can be seen from the unfinished splitting surface or secondary inner side with the remains of keel marks and cutting groove, from halved primary construction features such as the remains of Lewis holes or clamp sockets, from the fragments of the classical anathyrosis or from the presence of an excentric Lewis hole. Theoretically, a stone can be split in three different directions, and it is possible to repeat this process. Splitting a stone in thickness is considerably harder than in the length or

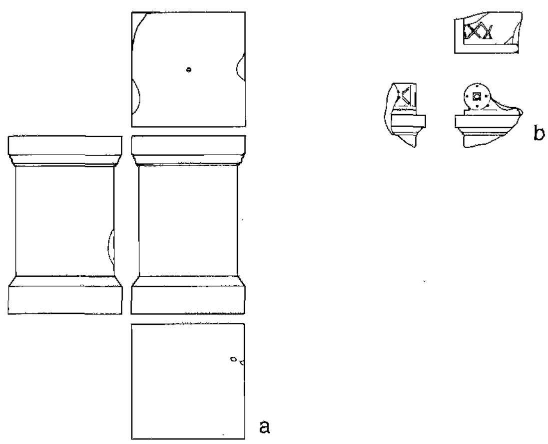


Figure 27 Unusual stone finds: a plinth; b corner of altar (scale 1:40).

width. Assuming a cube-shaped primary stone, it is possible that the stone was split once in thickness, but perhaps several times in the length and width.
A primary stone may have been at least four times as large (1.6 x 1.3 x 0.8 m).
3 Turning the stone 180 degrees (fig. 26: c, d): after breaking out and splitting, the stone is sometimes turned 180 degrees for secondary use. The upper side therefore becomes the underside and *vice versa*. This can be seen from the position of the bar clamp sockets which can only be functional when they are on the upper side of the stone. On secondary stones, however, they are to be found on the bottom side. On the secondary upper side one finds a new Lewis hole and dovetail clamp sockets, or secondary bar clamp sockets filled with lead.
4 New surface dressing (not shown in figure 26): when the stone is given a new position and function in the bridge, the surfaces undergo a dressing process wherever necessary. For example, in some stones a new outside face is made with a tooth chiselled border and a point chiselled inside surface. To move the stone, a new Lewis hole is made in the centre of the stone after splitting. In many stones, this secondary hoisting hole is not dead centre, but *c*. 5 cm off centre. Probably dressing of the outer surface took place after moving the stone into position so the stone has become 5–10 cm narrower on the outside and the Lewis hole is now off centre.
5 Making secondary joints or transport elements (fig. 26: e): in order to transport the stone, new Lewis holes are made. Not until the stone is roughly in place are adjusting holes cut. When the stone is exactly in place, new clamp sockets are cut in the top of the stone. These are mostly dovetail-shaped, but can also be bar-shaped. The dovetail clamp sockets and the bar clamp sockets with lead are both secondary. The dovetails are almost always found on a secondary side or on an original underside of the stone. The bar clamp sockets without lead are always found in combination with a dovetail clamp hole, or on the underside of the stone and were therefore not functional any more when the bridge was built. If the stone was not turned, it sometimes occurs that the bar clamp sockets are made in old crowbar slots or primary clamp sockets which have been broken away, so that the clamp hole has a deeper position.

2.2.2.7 *The remaining stone material and the epigraphy*
In addition to the building stones, a number of decorative elements were found, all spolia. A complete plinth stone probably bore an inscription, but this is no longer visible due to erosion by water. A half plinth stone was also found and an altar volute of soft white limestone (fig. 27). Apart from the epigraphy the other spolia were not studied. The function of this material may have been threefold. The possibility that it was used as rubble around the piers to prevent undermining has also been put forward for other bridge finds.[51] The inner side of the pier may also have been filled up with this material. Finally, the elements may have formed part of the decoration or approach to the bridge. However, no archaeological evidence has been found to support any of these uses.
Among the spolia, there is a fragment of an inscription which is possibly connected with an inscription previously discovered in Cuijk. In 1937, during an excavation by Prof. Dr A.E. van Giffen, two fragments of a building inscription were found on the site of the castellum. Unfortunately, the data were not published.[52]

51 Panhuysen 1996; Cüppers 1969, 124.
52 The inscription consists of two parts, a fragment of 70 x 40 x 28 cm and a fragment of 29 x 20 x 22 cm and is described in a lecture by Joan Willems in 1946 on the occasion of the inaugural meeting of the Cuijk council (Van Giffen & Willems 1946). Bogaers has examined the inscription again and has given a verbal interpretation.

a

Figure 28 Fragment of an inscription found during the excavation of the bridge (a). In this illustration the fragment has been placed next to a reconstruction of an inscription found in the castellum of Cuijk in 1937 (b). The F at the end of the second line and the R at the end of the third line are depicted in the same way as on the fragment found.

b

According to Van Giffen and Bogaers, the text is related to the construction of a fortification at Cuijk under Trajan between AD 97 and 99. The letters are 9–13 cm tall and 4–7 cm wide, and have been interpreted as follows:

[IMP.C]AESAR
[.DIVI. NER]VAE.FNER
[.T]RAIA[NUS.AUG.GER.]
CIV[IUM?][—]

The letters FNER, 'son of Nerva', have clearly been inserted. Because the letters did not fit into the frame: they are smaller and the righthand part of the frame is not at right angles, but set further out.

The inscription from the bridge is similar in format and style to the inscription from the castellum site. The fragment measures 39 x 28 cm and is made of a marine Tertiary limestone. Two letters from two lines can be seen on the stone (fig. 28). The top letter may be the base of an I, P, H, R or F. The bottom letter is an R. The letters are *c.* 14 cm tall and *c.* 8 cm wide and are relatively thick. On the bottom line, to the right of the letter R, a line is visible which can perhaps be interpreted as a text frame. This frame line is, however, very oblique, so that there would have been room for more letters on the top line, whereas the R is certainly at the end of the line. The size and style of the letters makes one suspect that this is an inscription from the first or second century. The text would then have no connection with the bridge.

According to Bogaers, the fragment from the site of the bridge may have been part of the inscription found in 1937. The letters on the bridge inscription can then be interpreted as the base of the F of FNER and the R is the last letter of GER.[53] This would appear to fit the exact position of the letters as well. The Letters FNER are in fact directly above the letters GER in the 1937

53 Thanks to Prof. Dr J.E. Bogaers.

inscription (fig. 28). The very slanting line of the profiled edge in the bridge inscription also fits this picture.

2.2.3 The pottery

During the investigation, over a hundred pottery sherds and several complete pots were found. These finds are discussed in two groups according to their find location (figs. 29–31). Most of the pottery comes from the peat layer encountered between the piles of the bank structure (area 6000). This pottery was collected during excavations in several small test trenches, together with countless fragments of Roman building material. The second group of pottery was salvaged during the investigation of the bridge remains themselves in the Meuse. In this case there are only a few more or less complete items.

2.2.3.1 *The pottery from the bank* A total of 101 Roman and 29 post-Roman sherds were found in the peat layer against the left bank of the Meuse. Because they come from the peat layer they are highly discoloured (brown). Of the Roman sherds, 3% could be dated to between AD 50 and 150. Among other things dating from this period is a fragment of a coarse ware pot with inverted raised rim (fig. 29: 1), which on the basis of its shape may be included among the wheelthrown variants of so-called cork ware, dated around AD 100.

Of the Roman pottery, 23% dates from AD 150–250. It includes two rim fragments of Niederbieber 89 pots with a lid seating (fig. 29: 2–3) and a fragment of the lower part of the wall of a decorated bowl Dragendorff 37 (fig. 30: 1). On this fragment a bird, a goblet and a border of rosettes are visible. Unusual is the mirror-image impression of the graffito present in the mould which can be observed among these decorations. The graffito should probably be read as —]*ulus*. The bowl is from Lavoye and was made by Gesatus between AD 120 and 150.[54] Of the Roman pottery 73% dates from the Late Roman Period. Part of the Roman pottery belongs to the Argonne sigillata (figs. 29: 10–11 and 30: 2–6), of which various forms have been discovered. Most of these occur during the whole of the fourth and the first half of the fifth century. A fragment of a Chenet 325 bowl can be dated more precisely to the first half of the fourth century.[55]

Five fragments of the form Chenet 320, on which roulette decorations have been applied, also belong to the Argonne sigillata. One fragment can be classified as Hübener group 2 on the basis of the decoration (fig. 30: 2). The double-row stamp that was used consisted of at least 21 small blocks. This stamp has been observed previously on finds from Cuijk.[56] The four other fragments can be classified as Hübener group 3. On one specimen there is a decoration which is known from Heerlen and Cuijk (fig. 30: 3).[57]

A decoration on one fragment depicts two small blocks next to each other with hatching in the same direction (fig. 30: 6).[58] In addition, two more fragments with a decoration were found which can no longer be reconstructed (fig. 30: 4–5). Both fragmentary roulette motifs are not found among the decorations shown by Chenet.[59] The motifs from Hübener groups 2 and 3 are mainly found in the first half of the fourth century, although a later date is also possible. Sherds with roulette motifs from the second half of the fourth century are lacking.

A fragment of a terra nigra bowl was also discovered (fig. 29: 8). It is probably an imitation of a Chenet 324 terra sigillata bowl. Similar terra nigra bowls, though different in shape, are often seen in the area between the Rhine, Main and Neckar. In view of the similarities with other such forms in terra sigillata, the terra nigra bowl would appear to date from the first half of the fourth century.[60]

In addition, various fragments of colour coated beakers were found (fig. 29: 9). On the basis of the shape and quality, they may be dated to the first half of the fourth

54 *cf.* Fölzer 1913, Taf. VII, 27, 53 and 57 for the goblet and the rosettes. The identification of the decoration and the reading of the graffito was done by C.A. Kalee, Nijkerk.

55 The identifications are after Chenet 1941. These are forms 314 (1x), 319 (2x, fig. 29.10), 320 (8x, fig. 30.2-6), 324 (1x), 325 (1x), 328-330 (5x), 335 (2x, fig. 29.11) and 345 (1x). *cf.* For the dates Chenet 1941 and particularly Hussong-Cüppers 1972 and Pirling 1966, 1974 and 1979.

56 *cf.* Hübener 1968 and Thijssen 1979, 36, 2–14 and Pl. 27.6.

57 *cf.* Glasbergen 1948, fig. 6.2 and Thijssen 1979, 37, 3-5, Pl. 21.3 and 3-6, 22.2.

58 *cf.* Chenet 1941, 10.

59 *cf.* Chenet 1941.

60 Chenet 1941; Hussong & Cüppers 1972, 8, form 8; Bernhard 1984/1985.

61 These are fragments of eight beakers of the Pirling 59–62 form. See Pirling 1966, 70–1; 1974, 44–5; 1979, 36–7. *cf.* For the date: Unverzagt 1916, 20 and Hussong-Cüppers 1972, 10–11 and 46.

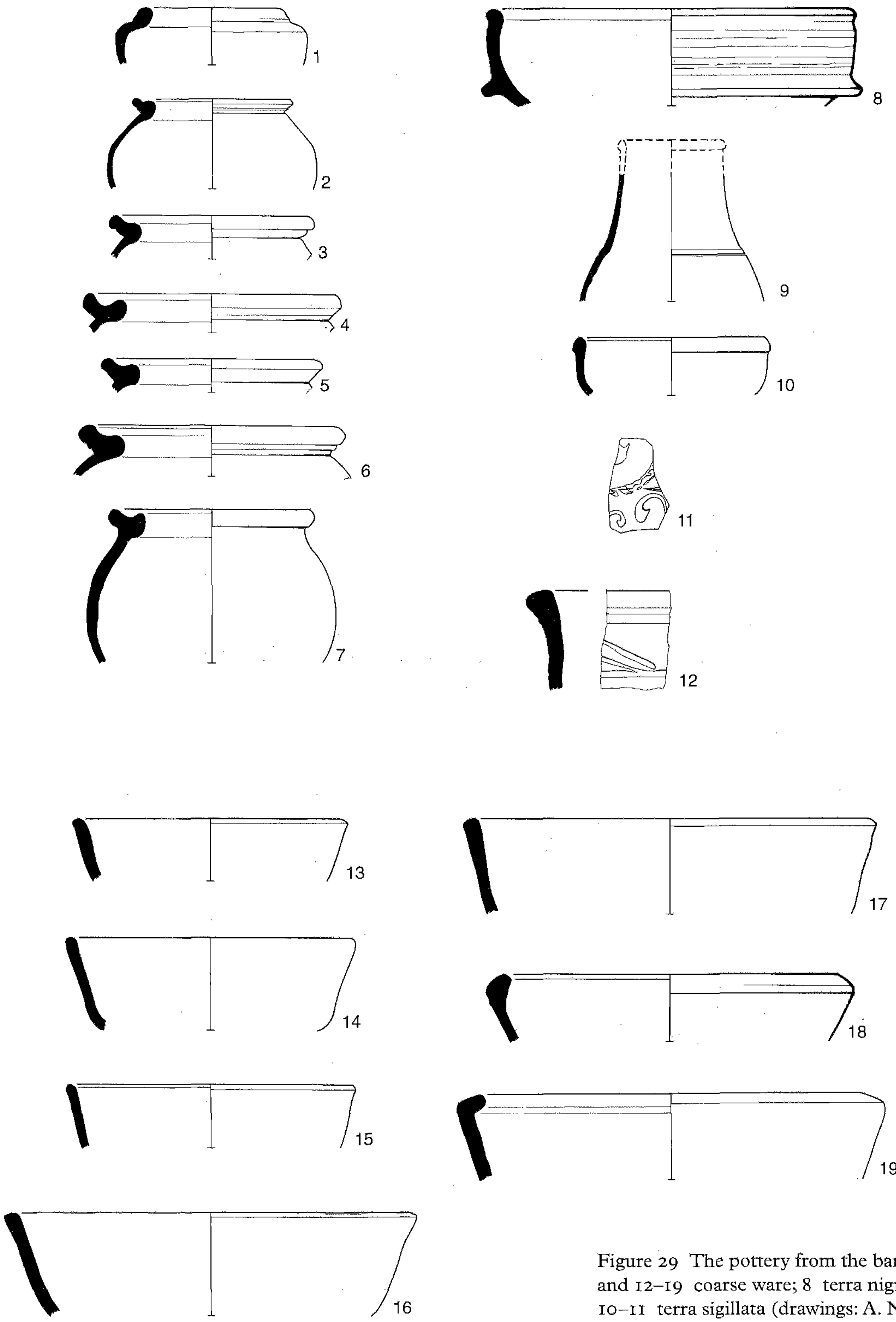


Figure 29 The pottery from the bank (scale 1:4). Legend: 1–7 and 12–19 coarse ware; 8 terra nigra; 9 colour coated ware; 10–11 terra sigillata (drawings: A. Nijs, Nijmegen).

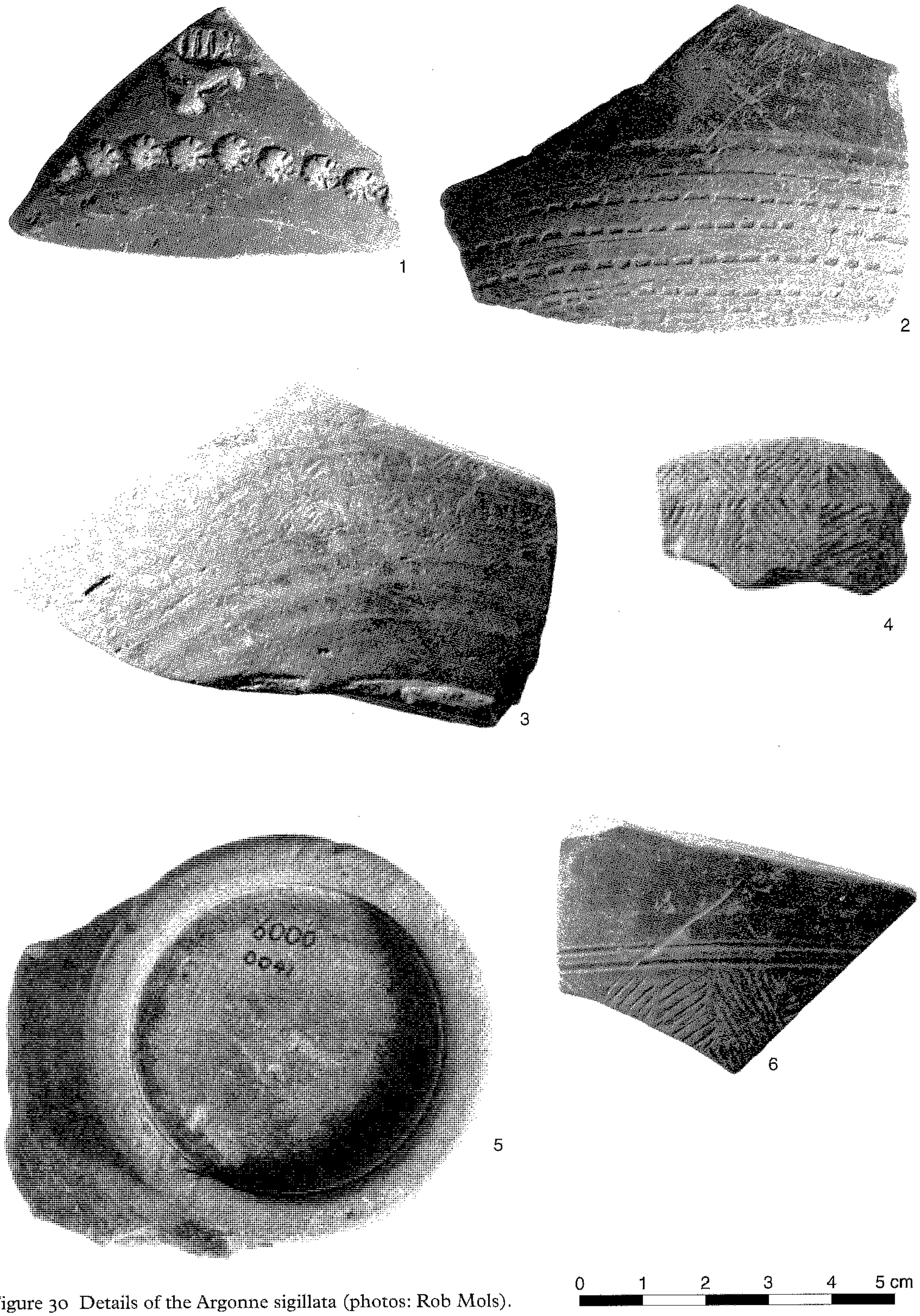


Figure 30 Details of the Argonne sigillata (photos: Rob Mols).

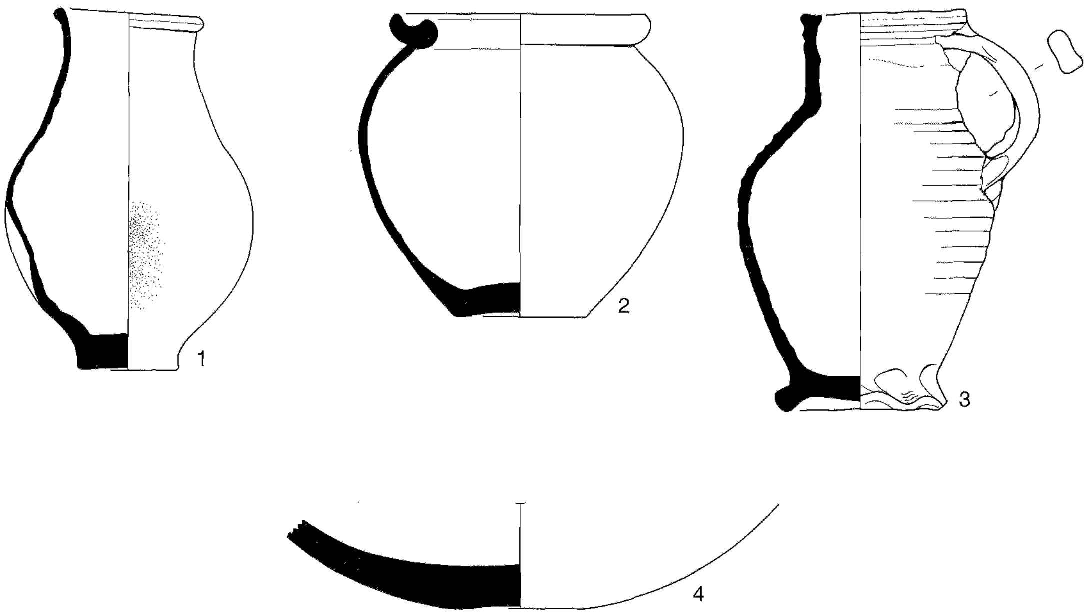


Figure 31 The pottery from the Meuse (scale 1:4). Legend: 1–2 coarse ware; 3 proto stoneware; 4 mortarium (drawings: A. Nijs, Nijmegen).

century.[61] In the second half of the fourth century this type was produced with a rougher surface, and disappears shortly after. The fragments of marbled jars[62] and a smooth ware jar[63] can only roughly be classified. However, marbled jars all date from the first half of the fourth century.

Most of the Late Roman pottery is coarse ware. Fragments of various forms were found.[64] The Late Roman pots with lid seating of the Alzey 27 form mainly date from the fourth century (fig. 29: 4–6). The plates with inverted rim, Pirling 126, mainly date from the fourth century. The plates with everted rim, Pirling 128, can be more precisely dated to the first half of the fourth century (fig. 29: 13–17).[65] It is striking that these plates are all made of the same hard and sandy fabric. The surface is black and mat. Among the coarse ware material there is also a rim fragment of an Alzey 27 pot which, on the basis of its form may be dated to the fifth century (fig. 29: 7). Further Roman pottery: a neck fragment of an amphora which cannot be more closely identified and several sherds from a hand-made pot. As evidence of more recent settlement activities in Cuijk, there are also 29 post-Roman sherds among the pottery. Most of these (86%) date from the 17–20th centuries. Both the 12–13th and 14–16th centuries are represented by 7%. The material from the Late Middle Ages is undoubtedly connected with the period in which the Lords of Cuijk played a prominent part in Cuijk.

Apart from the pottery from the Early and Middle Roman Period and a fifth-century sherd, most of the Roman pottery dates from the fourth century. In view of the homogeneous composition of this find complex

62 The fragments which can be attributed to a form belong to jars of the Pirling 71-4 form, 261 or 315 (6x). See Pirling 1966, 74–5; 1974, 51; 1979, 38–9.

63 This is possibly a fragment of a jar form Pirling 85b (Pirling 1966, 79).

64 The identifications are after Pirling 1966. There are seven pots with lid seating form 105-106, two plates form 126, seven plates form 128, one plate, one mortarium and six fragments of various pots. The pots with lid seating are known as Alzey 27 (Unverzagt 1916/1976). In addition a rim fragment of a pot was found for which no direct parallels can be given.

65 Pirling 1966, 95–6; 1974, 66–7; 1979, 47–8.

and the well-datable forms, one would be inclined to ascribe this material as a whole to one period – the first half of the fourth century. The date of this find complex can be made more precise. The oldest phase of the Late Roman fortification in Cuijk was probably built under emperor Constantine I.[66] The pottery can then be dated to about 325–330 at the earliest. In view of the homogeneity and virtual lack of later Roman material, a radical change would appear to have caused a break in the pattern of deposition. This break may quite well have been linked with the renovation of the fortification and the bridge under Valentinian I in 368–369. In connection with this, substantial changes took place on the bank of the Meuse, as a result of which no more refuse could be dumped in the river at that point. It is quite possible that the new (second) Roman fortification left more space on the bank of the Meuse, so that a road between the fort and the Meuse could be built.
Two oak piles from the bank structure were dated to the period 320–342. The pottery found appears to be linked with these timber structures. Judging from the absence of visible raised layers, the sherds were not brought in with soil from elsewhere. They were probably among the refuse that was thrown away there.

2.2.3.2 *The pottery from the Meuse* The group of pottery from the Meuse is limited in size. Three specimens appear to date from the last decennia of the fourth century. A surprising item is a complete coarse ware folded beaker (fig. 31: 1). From the presence of volcanic inclusions the beaker probably comes from the Mayen area. Similar beakers are also known from Nijmegen, Krefeld-Gellep, Tongres and from Mayen.[67]
A coarse ware pot with lid seating (form Alzey 27) stood upright in the soil in the centre of area 2000 and might be a building offering (fig. 31: 2, see 2.3.1.3). The fill consisted of washed-in sediment. The pot differs from similar pots from the area under the Cuijk bank in its fabric (olive-green and grey) and its tempering with dark reddish-brown sand. Moreover, there are no similarities in form and tempering with other pots of this kind from Gennep-Stamelberg which are dated there from the end of the fourth century.[68]
A coarse ware base fragment of a mortarium stands out for its round shape which differs from the Late Roman mortaria with flat bases (fig. 31: 4). The inside is roughened with fine, rounded gravel mainly consisting of quartzite-like material. In view of the probable volcanic tempering, its provenance must be sought in the Eifel, in the Mayen area.
The presence of complete pots in the Meuse in the immediate vicinity of the bridge can be explained by the fact that travellers made an offering to the gods during their crossing. For this, they deposited objects in the water.
The flanged jug in proto-stoneware from Siegburg dates from the first half of the thirteenth century and, as previously observed, will have been connected with the activities of the lords of Cuijk on the site of the former Roman castellum (fig. 31: 3).

2.2.4 The metal finds
The metal finds have been seriously eroded by the water of the Meuse. The majority of this group of finds were stray finds on the surface of the river bed. For this reason, the material has not been further analysed and studied (fig. 32).
There are three wrought-iron axes, with, in one specimen, the remains of the handle still present.[69] The three axes are very different in appearance.
One of the axes measures 18.7 x 7.4 x 3.7 cm. The cross-section of the handle hole is oval and 2.9 x 3.9 cm. The axe has a rather slim shape and the top has a regular, more or less convex line.[70] It was found on the surface of the river bed in area 4000. The second axe is very angular in appearance and is 16.9 x 7.1 x 3.8 cm.[71] The diameter of the handle hole is 2.4 x 2.9 cm. The top is virtually straight and rises towards the end. This specimen was found in area 2000. The third axe is much smaller and more compact than the others and measures 14.9 x 8.4 x 3.4 cm. The diameter of the handle hole in which there are still wood remains is 2.2 x 3.9 cm. This axe is also very angular in shape with

66 Bogaers 1967, 111; Bogaers 1974, 84.
67 Nijmegen: four specimens, cf. Brunsting 1937, 157–8, form 28 and Pl.7.28 and Stuart 1977a, 76–7, form 206 and Pl. 20.337. Krefeld-Gellep: two specimens, date after 375, *cf.* Pirling 1966, 90, form 111 and Pirling 1974, 62, form 277. Tongres: one specimen, date between 350–400, cf. Vanvinckenroye, 1991, 128, form 585. Mayen: three specimens, date 350–400, *cf.* Haberey 1942, 266, Abb. 6e; 268, Abb. 8d; 269; 272, Abb. 14d; 273.
68 *cf.* Van Enckevort 1990.
69 Find numbers F400-3, P200-4, and 1800-19.
70 Cüppers 1969, 121, fig. 135, no. 3.
71 Cüppers 1969, 121, fig. 135, no. 2.

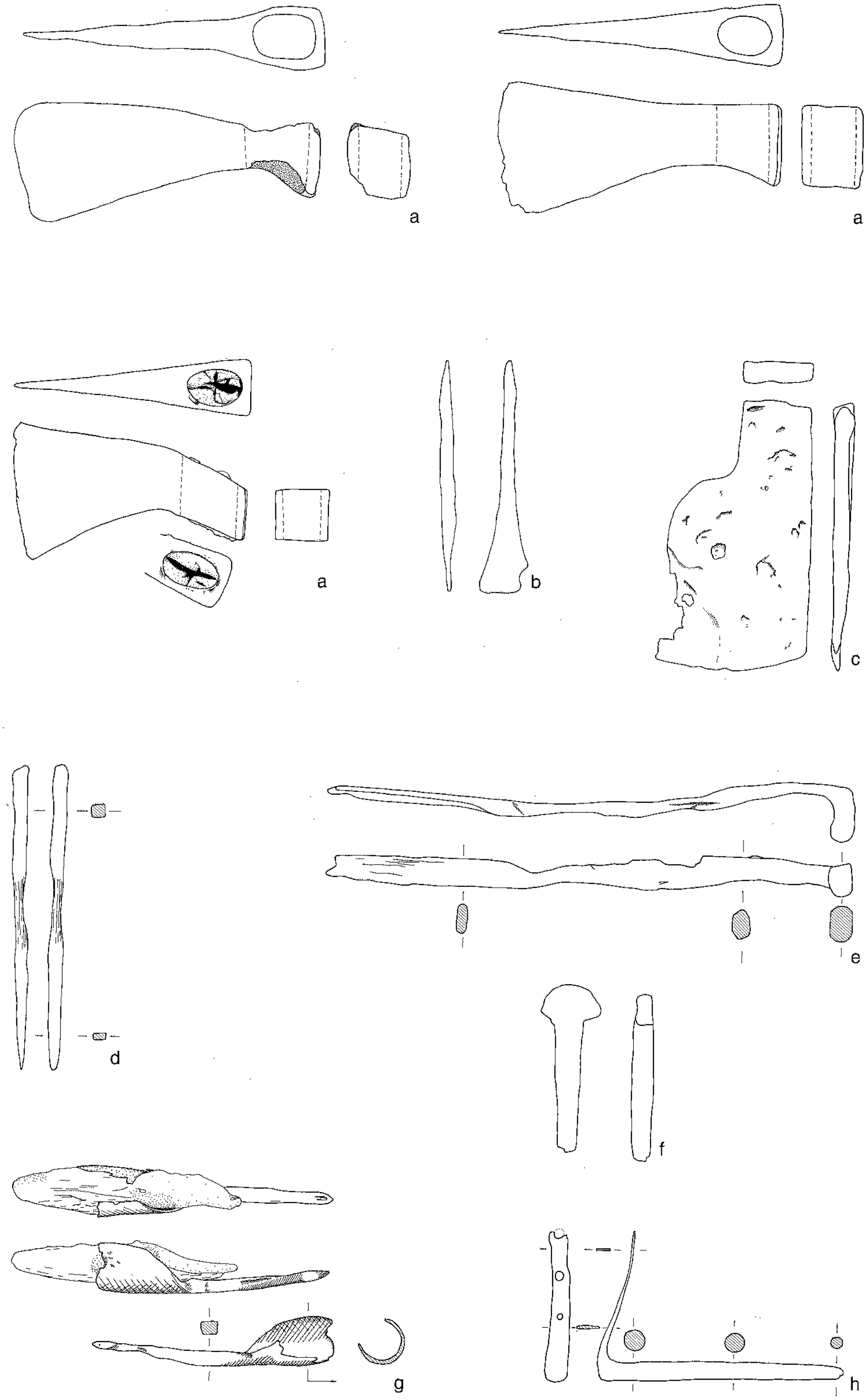


Figure 32 Iron tools (scale 1:4). Legend: a three wrought iron axes; b fragment of a wood chisel or stonemasons flat chisel; c fragment of an adze or axe; d fragment of a marking awl or pointing chisel; e bar clamp; f unknown object; g boathook (?); h unknown object.

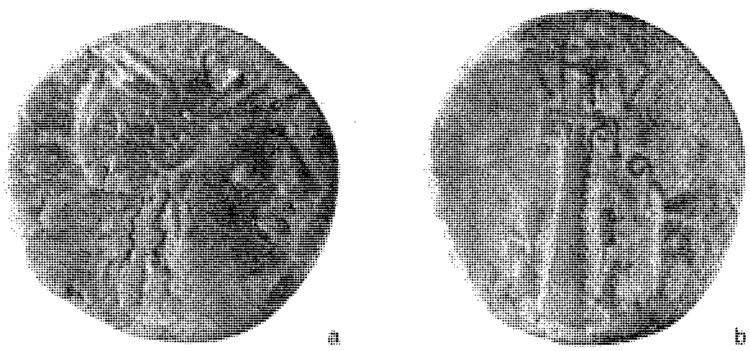


Figure 33 Coin find (Republican): a obverse, with punched mark; b reverse (photo: P. Bersch).

the blade facing sharply downward. It was found *c.* 80 cm below the river bed at 2.50 m NAP. The latter two axes are very probably of Roman origin since they were discovered on and in the cemented Roman pier-foundation layer. The first axe is a stray surface find and, although found in the pier foundation, cannot with any certainty be attributed to a Roman layer.
Another find is a wrought flat piece of iron measuring 16.8 x 8.9 x 1.1 cm with the appearance of an axe. The front has a round, sharpened edge; at the back the blade narrows to 4.7 cm where there was once an attachment, possibly for the handle hole. The axe is very flat and may have been a kind of adze. The relatively large number of axes found is surprising. It leads one to suspect that building and repair activities were partly carried out in the water, making it difficult to retrieve a lost axe.
Two iron fragments are probably the remains of wood- or metalworking tools. The first fragment is 14.2 x 3.1 x 0.8 cm and is possibly part of a flat chisel. Because the handle is rather short for use in stoneworking, it probably once had a wooden handle. This can be the case with stonemasons chisels. On the other hand, it could be a wood chisel. The second fragment is 18.6 x 1.1 x 1.1 cm and may have been a fine point chisel used in stone-dressing, or a tracing tool.[72] A fragment of a boat hook was also discovered which need not be of Roman origin. A final fragment could not be identified. In one of the bar-clamp sockets that still contained lead a coin was found. The coin must have been placed there before the lead was poured in and therefore during the construction of the bridge. It turned out to be a silver denarius struck in 135 BC (fig. 33).[73] This republican coin was therefore almost 500 years old when it was used in the bar-clamp socket. Republican coins were still in circulation in the fourth century and were valued for the purity of their silver. They were however quite rare. It seems difficult to interpret this coin as anything else than a building offering.

2.3 *Dating and phasing of the findspot*

2.3.1 Dating

2.3.1.1 *The dendrochronological phasing*[74] As many as 337 piles and beams were found in the Meuse. Of these, eighty piles were sampled for dendrochronological analysis. Of the eighty samples taken, 58 have been dated, 54 of which came from the foundations of the bridge. Four samples of the foundations of river bank structures have been dated. For phasing, only 36 dates were used because the others could not be attributed to

72 Crevecoeur, Overeem & Schellevis 1990, 49 and 59.
73 Crawford, 1974 vol. I, 242 no. 1 and vol. II plate XXXXVI no. 16. On the obverse side the coin also has a punched mark on the occipital part of the head of Roma in the form of a 'V' turned 225° counter clockwise. The mark was probably of a private character, indicating ownership, or it was used for testing the silver.
74 Thanks to E. Jansma and E. Hanraets of Stichting RING/ROB in Amersfoort.

a phase with enough certainty. Of the wood samples with a sapwood-heartwood border, two object chronologies were prepared. The first object chronology (AD 256–346) gives a felling date between AD 347 and 349. The second object chronology (AD 250–368) gives a felling date in the winter or spring of AD 368/69. The third object chronology (AD 276–387) has an estimated felling date of around AD 393. As a reference chronology in dating, a site chronology of oak samples from two wells in Gennep was used. This curve forms part of the Dutch reference chronology from the period 325 BC–AD 475.[75] The significance level of the dates calculated on the basis of percentage similarity is high.[76]
In the foundation piles of the bridge three building phases can be distinguished on the basis of the dated samples (table 3):
- phase I (5 ex.) is dated between AD 347 and 349;
- phase II (24 ex.) is based on an absolute felling date and dates to the winter or early spring of AD 368/369;[77]
- phase III (6 ex.) is dated between AD 388 and 398, with an estimated felling date of AD 393.

Two phases can possibly be distinguished within the bank structures.[78] Phase A (2 ex.) is uncertain, but dates to between AD 320 and 342. Phase B (2 ex.) is based on an absolute felling date of AD 373.

2.3.1.2 *^{14}C analysis* Seven ^{14}C dates support the tree-ring analysis (table 3). Two dates (nos. 1 and 2) were used in the reconstruction of the abiotic landscape and are discussed there. Three dates (nos. 4–6) concern the age of the peat in area 6000. Two ^{14}C samples (nos. 3 and 7) from the bridge foundations were analysed. Date 7 is a previous dating taken in the 1960s and published by Willems.[79] The calibration of this date produces two datings. The three dendrochronologically determined building phases of the bridge fall within the youngest dating. Date 3 was necessary in order to establish whether the pile in area 500, encountered while boring on the Mook bank may be included with the bridge. Calibration of this ^{14}C analysis produced two datings on the basis of which the pile can be classified in the dendrochronological phases I or II. The dates of the peat in area 6000 are all in the beginning of the fourth century which corresponds well with dendrochronological phase A of this area. After the bank structures are built in phase A, peat starts to develop in the shelter afforded by them. This gives an indication for the site of the Roman bank. The peat level is also an indicator for the level of the lowest low water at the beginning of the fourth century, which is important for the reconstruction of the bridge (see 5.1.1).

2.3.1.3 *The pottery* The pottery from the site of the bridge can be dated in the last decades of the fourth century. The basis for this date is provided by the complete coarse ware folded beaker from the Eifel and the complete coarse ware pot with lid seating (Alzey 27). Apart from the foundation piles, the coarse ware pot is possibly the only *in situ* pottery find at the bridge site. The pottery from the bank structures is more plentiful and has a much wider dating, from AD 50 at the bottom of the peat profile until into the first quarter of the fourth century. The majority of the material from this area dates from the Late Roman Period, and approximately three-quarters of it dates from the first half of the fourth century. Unusual is the virtual absence of even later Roman material, which gives rise to the impression that fewer or different activities took place around this part of the findspot at the end of the fourth and beginning of the fifth century.

2.3.2 Phasing and dating of the foundations

2.3.2.1 *Area 500* Only one ^{14}C date is available from this area (table 3, no. 3). This foundation may have been built in phase I (AD 347–349) or II (AD 368/69).

2.3.2.2 *Area 1500* Area 1500 has been partially excavated and there are only two tree-ring dates in pile row A available, which is why the conclusions are limited.
Both tree-ring dates belong to phase I. This foundation therefore certainly belonged to the first construction of the bridge. These piles are situated, like most of the piles from phase I, in the centre of the foundation, about 3 m from the outermost limit.

75 Jansma 1995.
76 P, being the fraction of 1 that indicates the chance that the value found occured by coincidence, was 0.001.
77 Three piles in this area have an absolute date in 368/69, the remaining twenty must belong to the same phase on the basis of an estimate of the number of sapwood rings.
78 In this area four of the 34 piles have been sampled and dated.
79 Willems 1984, 47. See also 1.1.2.

2.3.2.3 *Area 2000* In area 2000, two piles and a foundation beam have been dendrochronologically dated in phase I (AD 340–47). The piles belong to the innermost foundation plan of the cutwater. There is also a pile and a foundation beam from phase II (AD 368/69). The pile stands on the outer side of the foundation. Unfortunately there are no dates available for the smaller piles. The number of dates is insufficient to underpin the phasing within the foundation, but it may be assumed that this pier was constructed in phase I and later repaired in phase II. The Late Roman coarse ware pot with lid seating was centrally situated under the foundation and may have been a building offering. If this pot is dated to the end of the fourth century and was discovered *in situ*, it could not have been placed there during the first construction but only in a later phase of repair. This implies that the whole pier must have been demolished in the second phase. It would appear more likely that the pot is of an earlier date.[80]

2.3.2.4 *Area 3000* In area 3000 nine piles are dated in phase I (AD 340–347). All the piles from this first phase are to be found in the centre of the foundation, that is the central rows B, C and D. The five piles from phase II (AD 368/69), just as is the case in the other areas, are all without exception more towards the outer side of the foundation in rows A, B and E, and appear to be repairs. Six piles can be put in phase III (around AD 388 and 398). The piles from this phase are all on the outer side of the foundation in rows A, B and E. An important fact is that none of these later piles has a pile-shoe except one pile on the outside of the group that probably belongs to the first repair phase. A good overview of the phasing of the bridge construction is given in figure 43. Phase I is well represented in the centre of the foundation, while repairs and adaptations from phase II are all on the outer side. The final phase, phase III, is also easily recognizable with extensive repairs to the outermost rows of piles.

2.3.2.5 *Area 4000*[81] In the foundation of area 4000, only two piles *in situ* can be attributed to phase I (AD 340–347). The foundation has no clear pattern so it is difficult to attribute the piles to a certain row. There appear to be remains of a large-scale renovation in phase II (AD 368/69). The majority of the piles (20 ex.) in this foundation can be dated with an absolute felling date in the winter or spring of AD 368/69. Only the occasional pile can be attributed to phase III.

nr	code	sample	significance	x (RD)	y (RD)	z (NAP)	y BP	calibrated BC/AD 1s = 68.3%	calibrated BC/AD 2s = 95.4%
1	GrN 17778	peat in residual channel	end phase x-terrace channels, start phase (ante quem) Meuse valley	184530	417470	3.3	8830 ± 55	7962-7884/7810-7720 cal BC	8016-7840/7828-7700 cal BC
2	UtC 2581	humic layer	hight of sedimentation on the east bank	189620	415780	6	3280 ± 100	1670-1650/1640-1440 cal BC	1870-1850/1770-1370/1350-1310 cal BC
3	UtC 2580	pile in bank	does pile belong to bridge; dating area 500	189490	415810	3.8	1840 ± 60	120-250/304-312 cal AD	64-340/366-370 cal AD
4	GrN 21268	peat near pile 20	dating area 6000 and level of low water in Meuse	189342	415731	4.0-4.5	1830 ± 30	142-176/188-236 cal AD	128-252/300-314 cal AD
5	GrN 21269	peat near pile 40	dating area 6000 and level of low water in Meuse	189339	415734	4.0-4.6	1805 ± 35	144-172/204-254/294-320 cal AD	132-264/282-332 cal AD
6	GrN 21363	charcoal in peat	dating area 6000	189341	415732	4.0-4.5	1810 ± 40	142-174/188-196/198-252/298-316 cal AD	124-268/276-334 cal AD
7	GrN 6006	pile in river	prospection of findspot, probably area 4000	189360	415790	?	1715 ± 35	260-284/328-390 cal AD	250-302/314-414 cal AD

Table 3 Results of ^{14}C analyses.

2.3.2.6 *Area 6000* The dates of the bank structures are distinct from that of the bridge. For this reason, the phasing on the basis of tree-ring dating is represented in a phase A (AD 320–342) and a phase B (summer/autumn AD 373, absolute). Phase A has two dated piles, one of which stands in the innermost row of the sheet piling, while the other stands far into the Meuse, *c.* 14 m from the bank. Building phase A may partially overlap the first construction of the bridge (phase AD 340–347). Phase B also consists of two dated piles, one of which again stands far from the bank. One pile has an absolute felling date of AD 373. The peat behind the piles can be dated on the basis of ^{14}C analysis in the first quarter of the fourth century and can be attributed to the effects of building phase A.

3 STATE OF RESEARCH

3.1 *The archaeological investigation of Roman bridges*

3.1.1 Introduction

The investigation at Cuijk is, for the time being, the last in a series of bridge investigations which began at the end of the last century, so it is not the only source that gives us an idea about Roman bridge building.
Three crucial factors are involved during the building of a bridge. First there is the restriction imposed by the available materials and techniques on the maximum possible span between the piers (for an explanation of terms, see fig. 37). This factor determines how far apart the supporting piers can stand. A bridge builder will always attempt to set as few piers as possible in running water, because piers form an obstruction in the current which causes turbulence, particularly *downstream of* the piers. This turbulence causes undermining which can be counteracted by preparing the riverbed on which construction is to take place. A solid foundation, provided it covers a larger surface area than the structure standing on it and provided it is built strongly enough to resist currents and turbulence, will considerably prolong the life of the piers.
Second, the construction is borne by the foundation. Particularly in the case of structures which are set on less firm ground, a good connection between the construction and the supporting layers in the ground becomes an absolute necessity. The weight of the piers makes two demands of foundations: they must spread the weight effectively and be able to withstand it. The most obvious options for achieving this are to build directly on solid ground or if this is not feasible, on piles.
There are three types of foundation piles: the compression pile, the friction pile and the end bearing pile. Compression piles are not really piles in the correct sense of the term. They are often short piles, as many as possible of which are driven into the ground in order to ensure compaction of the soil and therefore increase its supporting power. Technically speaking, this is a method of preparing ground for building. The friction pile is longer and obtains its supporting power from the friction between the surface of the pile and the ground into which it is driven. Compression piles and

80 The reservations about the fabric are given in chapter 2.2.3.

81 No samples were taken in area 3700.

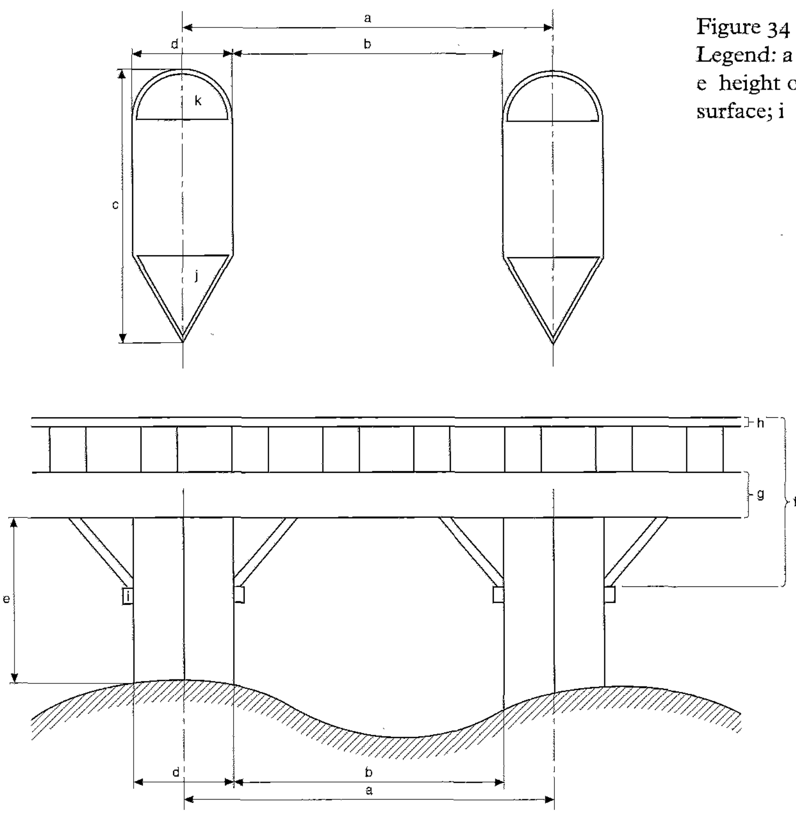


Figure 34 Explanation of terms and concepts in bridge building. Legend: a span; b clear span; c length of pier; d width of pier; e height of pier; f superstructure; g bridge girders; h road surface; i corbels; j cutwater; k rear.

friction piles owe their supporting power to the layer of soil into which they are driven. This is not the case with the end bearing pile. This is driven through one or more layers of soil until it reaches a layer with enough supporting power to build on. From the point of view of statics, the composition of the top layer of soil is of minor importance.
With all type of pile 'downdrag' can occur: the soil adheres to the pile causing it to be drawn further into the ground.
Finally, building in and under water requires a special building process. In order to prepare a planned bridge site for building, cofferdams are indispensable. Cofferdams serve to prevent silt carried by the river being deposited on the site. Cofferdams can also serve as a formwork for poured concrete or some other more or less resistant fill. Cofferdams can be made watertight, or at least watertight enough to be able to create a dry building site in the water. It will later become clear that this is no modern achievement, but that methods of building watertight cofferdams already existed in the Roman Period.

Throughout the world, forty to fifty wooden Roman bridge foundations have been reported. A number of these are no more than find reports of stones and piles or pile-shoes, sometimes in line with a Roman road. With these find reports it is not always clear whether they refer exclusively to a bridge. Quay structures, land-abutments for pontoon bridges and jetties are the most obvious alternatives. Some findspots which certainly include bridge remains may be medieval, but are dated in the Roman Period on the basis of their position in a Roman road system. Particularly bridges investigated by local dignitaries at the end of the last century often appear to be dated to the period in which the investigators themselves were most interested. Of this whole collection approximately twenty bridges have really been investigated. Arguably only about seven of these bridges have been investigated fully and according

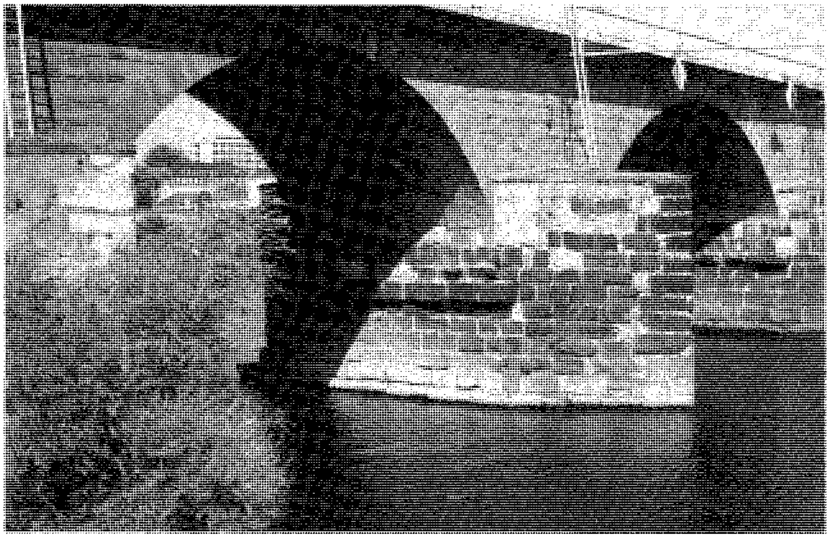


Figure 35 Present bridge at Trier: the pier is Roman (second century), the arch is originally Medieval with later repairs (photo: R. Kroes).

to reasonably modern standards of research.[82] Four of these are built completely of wood and are therefore beyond the scope of this study.[83]

It would be going too far to list all the sites and possible sites here. A number of bridge remains are however important as a reference in the reconstruction of the bridge at Cuijk. A discussion of a relevant selection of bridges follows.

3.1.2 The oldest investigation (Koblenz, Germany)

A good example of the way in which research into bridge foundations was carried out at the end of the last and beginning of this century is the oldest true investigation. This concerned the foundation remains of a stone bridge in the Moselle at Koblenz, which were investigated in 1865. The investigation was restricted to removing several stones and piles, and measuring by feeling for pile remains by hand from small boats. This was done inasfar as the low water level, which was of short duration, permitted.[84]

Although one might question the accuracy of this method of measuring, the plan published in 1867 of the groups of piles does provide a fairly good impression of the foundations. They correspond well with other pile foundations of Roman bridges investigated later.

As it turned out, the bridge has the largest foundations of any of the bridges known so far, with piers of *c.* 10 x 22 m, six of which have been found. On the basis of the stone and coin finds it was thought to be a Roman bridge. This assumption was confirmed by later dendrochronological dating; the bridge was built *c.* AD 131 and repaired *c.* AD 203.[85]

3.1.3 Building method (Trier, Germany)

To gain some insight into the construction of bridge foundations the Trier investigation is indispensable. This is by far the best bridge investigation, carried out by Cüppers in 1963 when the Moselle was canalized, on the two bridges over the Moselle in Trier. The construction of the two bridges began in AD 71 and AD 144 respectively. The latter bridge still exists, with stone arches dating from the Middle Ages (fig. 35).

Cüppers' publication is still the standard work on wooden Roman bridge foundations. Not only have these bridges been well investigated and completely published, but Cüppers also succeeded, despite the difficult conditions – work had to be done under pressure of time to keep ahead of the building activities – in bringing up a very wide range of topics. He was also the first to focus attention on the soil conditions,

82 Cuijk, Trier (2x), Rhine bridge Koblenz, Minturnae, Aldwinckle, Riedstadt-Goddelau. Bridges without wooden foundations are beyond the scope of this article.

83 Koblenz Rhine bridge, Minturnae, Aldwinckle, Riedstadt-Goddelau.

84 Schmidt *et al.* 1867.

85 Hollstein 1980, 72.

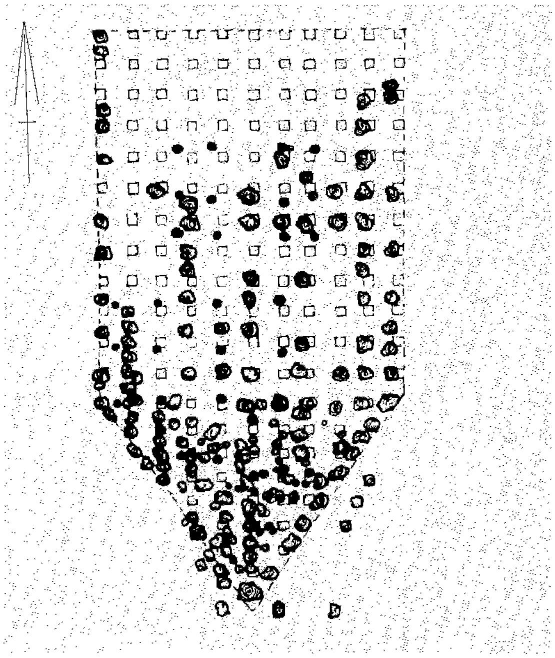


Figure 36 Bridge at Trier: plan of pier 7 of the first-century bridge. (after Hollstein 1980)

and he drew up a typology of pile-shoes. This was only to be equalled 17 years later by the investigation of the wooden Rhine bridge in Koblenz.[86]

Of the bridge from the first century which was founded on piles, seven foundations could still be traced. A number of them were so well preserved that it was possible to reconstruct the building method (fig. 36). The foundations consisted of sheet piling approximately in the shape of the pier. The pier consisted of a rectangular section and a cutwater which faced upstream.[87] The maximum length of the foundations was *c.* 19.5 m, and that of the cutwater was 7.4 m. The greatest width was 10.2 m. The space between the original foundations is set by Cüppers at 19 m.[88] Per pier, therefore, approximately 29.2 m length of bridge was realized. The sheet piling served to keep out soil so that the inner space could be cleaned and levelled without sediment washing in from outside. The sheet piling later enclosed the fill of the foundation. Within the sheet piling piles were driven in at regular intervals about equal to their diameter (20 à 30 cm). A single foundation had an estimated 250 piles.[89] The space between the foundation piles was packed with stone fragments and clay.[90] This stone and clay filling was also observed in the bridges at Mainz, Cologne and Koblenz.[91]

Cüppers assumes that the whole foundation was covered with a layer of beams. The many nails found could be an indication for this.[92] The layer functioned as a cover for the foundations and served to distribute the weight of the stone piers above. Borrmann sees the bridge at Trier as an exception because in other bridges no clear indications were found which might point to a cover.[93]

The piers were built of so-called 'dry' masonry, not with mortar but with clamps and dowels. Apart from a great deal of stone material which probably belonged to the bridge, a lot of iron hook-shaped clamps were found.[94] Iron clamps were also found in combination with the stone material at the bridges in Mainz and Cologne.[95] Mortar could not be used in the wet environment in which the piers stood, because it is not frost-proof. The weight and width of the piers provides the structure with enough stability, even without mortar.

Of the first-century bridge only the foundations were found. Nevertheless it is still possible to say something about the way the bridge was spanned because a few metres upstream from the foundations of the first-century bridge the piers of the second-century bridge are still standing. These piers still contain the corbels and slots on and in which the shores rested which supported the wooden span.[96] At the front and back of these corbels one can see the remains of projecting stones which protected the shores at high water from ice and floating treetrunks.[97]

Cüppers makes a reasonable case for the wooden spans consisting of straight bridge joists and not of a wooden arch as depicted on Trajan's column. The first-century

86 Fehr 1981; Schmidt 1981; Schieferdecker 1981; Mensching 1981.
87 Cüppers 1969, 139.
88 Cüppers 1969, 42–5.
89 Cüppers 1969, 159.
90 Cüppers 1969, 42.
91 Schneider 1880, 110; Cüppers 1969, 185; Schultze & Steuernagel 1895, 140; Schmidt *et al.* 1867, 5.
92 Cüppers 1969, 44, 50.
93 Borrmann n.d. 23–4.
94 Cüppers 1969, 49–50.
95 Kraus 1925, 241, 234.
96 Cüppers 1969, 141.
97 Cüppers 1969, 62, 69, 80, 86, 100.

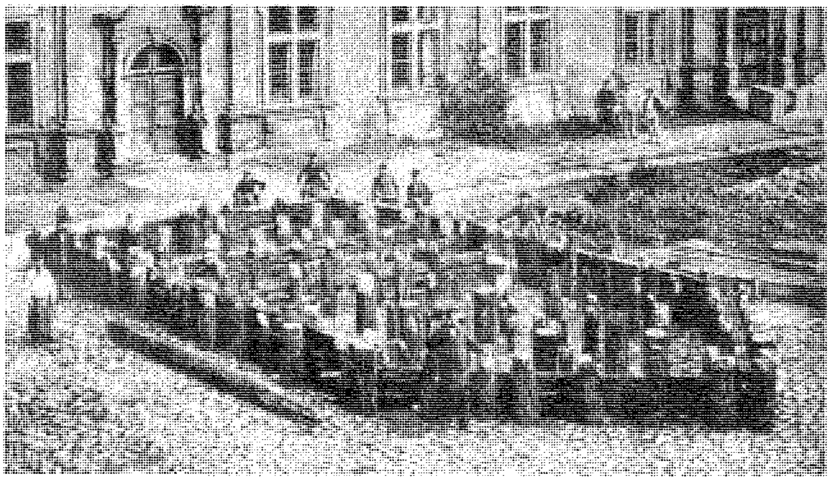


Figure 37 Reconstruction of a pier foundation from the first-century bridge at Mainz assembled from the original find material. The photograph was taken in the inner court of the *Kurfürstliches Schloß* (now the Römisches Germanisches Zentralmuseum, RGZM) in Mainz at the end of the nineteenth century (from: Behrens 1953).

bridge is dendrochronologically dated in AD 71 with a repair in AD 116.[98]

3.1.4 An alternative cofferdam (Mainz, Germany)
In 1885 bridge remains were investigated at Mainz. A total of 26 pier foundations were found over a length of 834 m. Eighteen pier foundations were investigated and at least one foundation was salvaged and reconstructed. Only a photograph remains of the salvaged foundation (fig. 37).[99] It consists of a framework of 24 to 26 cm thick beams lying on top of each other, within which piles have been driven.[100] The foundation measures 18.50 x 7.15 m.[101]
The framework of beams is an alternative for a cofferdam made of sheet piling. Clearly cofferdam and foundation piles were seen as separate components of a bridge foundation. Mainz is the only investigated example of this method of building where the cofferdam was still *in situ*. Only the foundations in Maastricht are though to have a similar cofferdam.[102]
The Mainz bridge was dated on the basis of epigraphical material between AD 71 and 92.[103] Because Domitian began a military campaign against the Chatti in AD 83, the investigators who published the bridge proposed that the bridge at Mainz was built in preparation for this action. This suggestion was adopted by later authors.[104] Dendrochronological dates of a number of piles from the museum in Mainz and of a few piles which were recently dredged up do not appear to contradict this military interpretation: AD 71 (± 8).[105] From other dendrochronological and epigraphical dates it appears that repairs took place in about AD 100, 160 and after 251.[106] Since the foundations discovered are at very different intervals varying from 13 to 25 m, a technique has been considered for the reconstruction of the wooden span which was depicted in scene XCIX of Trajan's column (fig. 38).[107]

3.1.5 A contemporary bridge (Zurzach, Switzerland)
One of the most recent investigations of Roman bridges took place in Zurzach on the river Rhine. Here there are five more or less hectagonal foundations consisting of piles. The bridge has been dendrochronologically dated in AD 368 with a repair to one pier foundation in AD 376. This bridge was therefore built in the same year as the bridge at Cuijk was repaired for the first time.[108]

98 Hollstein 1967, 82; Hollstein 1980, 138–50.
99 Kraus 1925, 241; Cüppers 1969, 185 gives 420 m and 18 piers; Schumacher 1906 and Esser 1972 give 14 piers.
100 Behrens 1953/54, 80.
101 Schumacher 1906, 25; Kraus (1925) gives a width of 7.54 m; Cüppers (1969) rounds down to 7 m.
102 Bogaers 1963,1964, 1965; Bloemers 1973; Panhuysen 1980.
103 Kroes 1990, 99 note 10.
104 Schumacher 1906, 24; Klumbach 1961, 99 note 9; Cüppers 1969, 185; Esser 1972, 216.
105 Hollstein 1967, 82–3; Hollstein 1980, 87–8.
106 Schneider 1880, 110; Esser 1972, 216; Kroes 1990, 99 note 10 for epigraphical material. For the tree-ring dates: Hollstein 1980, 87–8. On 11–09–98 a foundation pile was on exhibit in the *Landesmuseum* in Mainz that had been tree-ring dated to AD 26 after being dredged from the Rhine. No context however was indicated other than the suggestion that it belonged to the bridge.
107 Kraus 1925, 241.
108 Hartmann 1987, 14.

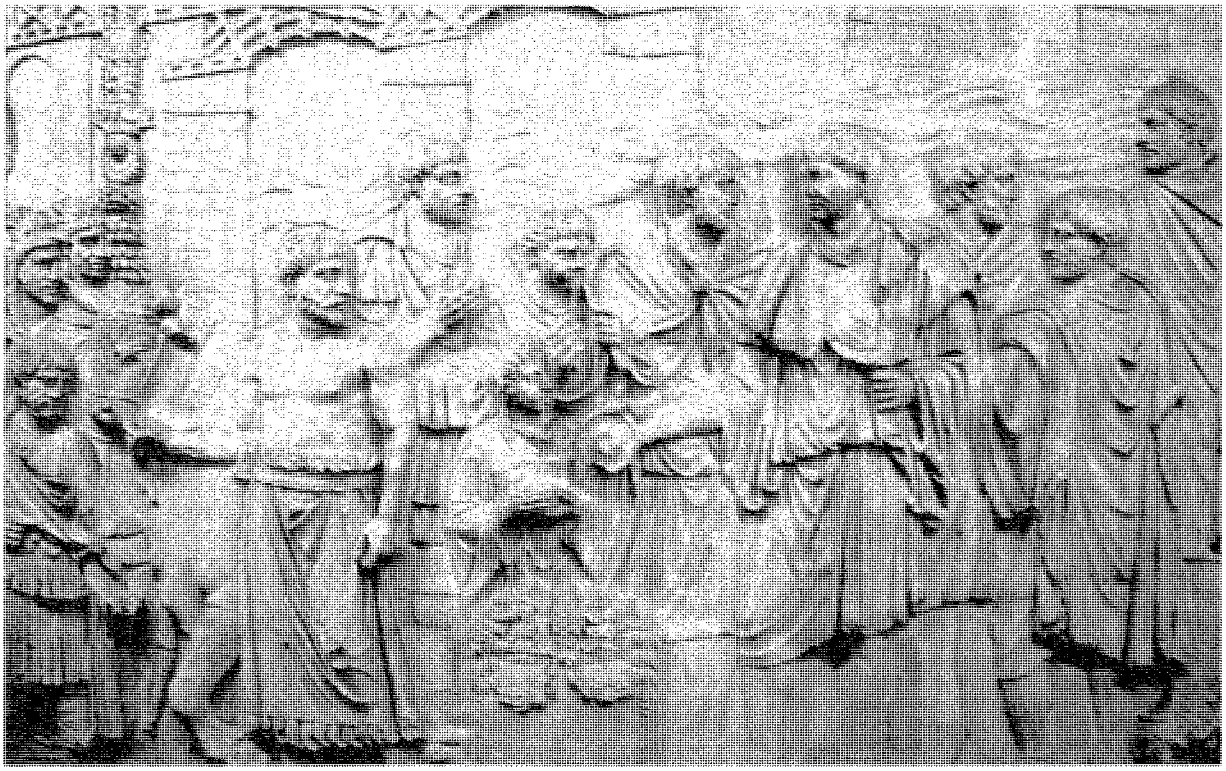


Figure 38 Depiction of Apollodorus' bridge on Trajan's column from Rome (Museo della Civiltá Romana, Rome; photo: J. Lendering).

Hartmann assumes that the building of the Zurzach bridge is directly linked with the fortification of the Rhine border begun by emperor Valentinian I.[109a]

3.1.6 Pitfalls in dating a 'Roman' bridge
In 1963 low water permitted a summary survey of bridge foundations in the river Enns at Ennsdorf (Austria).[109a] Several photographs were processed to form a plan. No date was available, but because the bridge fitted very well into the local Roman road system, it was assumed that it was a Roman structure (fig. 39).[110] The striking thing about the four foundations is that only one is completely founded on piles; the other three only consist of sheet piling inside which a building floor has been levelled. The technique is very similar to the one used for the foundations of the first century bridge in Trier.

However, in 1999 the *Österreichische Gesellschaft für Feuchtboden- und Unterwasserarchäologie* discovered that the foundations belonged to the railway bridge that was built there in 1856–58. The foundations could be matched to the original building plans and dendrochronology firmly dated one of the piles to 1858.[111]
In 1993 and 1995 the southern provinces of the Netherlands were plagued by floods due to prolonged rainfall in the catchment area of the Maas. At Susteren erosion of the river banks brought several piles to light. When the piles turned out to have iron pile shoes, thoughts turned to a Roman bridge. The pile shoes were indeed quite similar to the ones found in Cuijk. In 1995 a preliminary investigation was held at low water. It was noted that some of the piles looked suspiciously unaffected by the passage of time and that the

109 Hartmann 1987, 15.
109a This was no more than a few photographs taken by two chance visitors: H. Cüppers and Mr Von Petrikovitch (verbal communication H. Cüppers, d.d. 17-08-1993).
110 Cüppers 1965, 97 ff.
111 Dworsky & Stradal 1999.

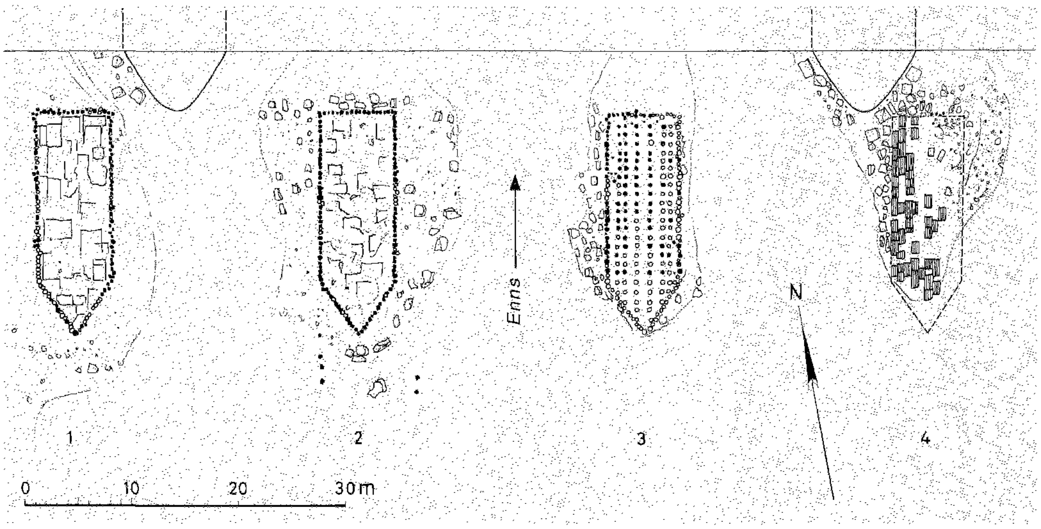


Figure 39 Plan of the four pier foundations of the 1856–1858 bridge at Ennsdorf. Piers 1, 2 and 4 were founded directly on the rocky substratum, pier 3 was founded on piles. All four piers had a cofferdam. The technique is completely comparable to Roman foundations.

limestone building blocks found among the piles were clearly measured out in a metric system, which suggested a post-Napoleonic date. A radiocarbon dating confirmed these suspicions: the structure was built in the 17th or 18th century.[112]

3.1.7 Commissioners of bridges

Building inscriptions on Roman bridges usually only give the name of the emperor or a high official under whose authority the bridge was built or repaired. Those bridges which provide us with more information as to who actually commissioned it or directed the construction, indicate these were either wealthy private individuals or persons in important public positions, whose office was not necessarily connected with public works. Of only five bridges the names are known of officials who were connected with the actual building. They are two architects mentioned by name: Apollodorus of Damascus, who built Trajan's bridge over the Danube, and a certain Auxentius, who built a bridge in Adana (Turkey). In addition, three bridges are known which were built by officials with the title of *curator viarum*.[113] All three date from the republican period and are situated in Italy.[114]

In the northern provinces, it is generally assumed that from the principate onwards public works in the infrastructure were frequently initiated on military grounds and were therefore often carried out under military supervision if not by the military themselves. A slightly duller but more constant use was made of the road system by the *cursus publicus*, the imperial post service. Constantius II entrusted the care for this post service to the *schola agentum in rebus*, a military corps intended for the distribution of imperial letters and decrees and for intelligence services. However, it seems they were only responsible for facilities like *mansiones*, horses and carriages, not for the roads themselves.[115]

One might be inclined to mention Pliny's letters to Trajan, which often deal with building projects, as an indication of the responsibility of both emperor and governor for building projects. However, Pliny wrote his letters when he was in Bithynia on a special imperial mission to straighten out a province in financial crisis.[116]

In a study of building inscriptions from military camps Reuter concludes that larger building projects were initiated by order of the emperor and smaller ones by the governor or, incidentally, by the emperor. It was the governor who was responsible for the care of existing buildings. According to Reuter, the costs, including the procurement of materials, for both large and small building projects were delegated to the governor and administered by the financial *procurator*. Supervision of the actual building was often a task for army *centuriones*.[117]

112 GrN-23319: 230 BP +/- 20, which means 1650-1675 and 1774-1801 cal AD at a 2σ confidence level (Stuiver *et al.* 1993).
113 O'Connor 1993, 38–42.
114 The Pons Minucius, the Pons Fabricius and the Pons Cestius; the latter two are in Rome and are in line.
115 Dvornik 1974, 129–31.
116 Lendering 1998, 61 and 70–1.
117 Reuter 1997, 180.

Supervision by centuriones over the actual building of a bridge is not unknown. Two building inscriptions were found belonging to the bridge in Mainz that mention centuriones by name.[118]

A last observation on organization was made by Borrmann. In his study on Roman, Medieval and pre-modern wooden foundations he notices that foundations for Roman land structures were often insufficient, sometimes unnecessary or even changed ground conditions for the worse. Compared to this, Roman bridge foundations are of superior quality. This difference can be traced during the whole Roman Period. The obvious non-exchange of knowledge is explained by assuming that those who worked on land were a separate group from those working in bridge building and construction in water.[119]

3.2 *Classical authors on bridge building*

3.2.1 Introduction

Classical sources do not appear to be of much assistance as far as technical and constructional matters are concerned. Analysis of texts is far less important than the archaeological record of bridge remains. Our knowledge of bridge building in Roman times, however, is not complete without a study of the texts from this period, in view of several striking parallels between texts and archaeological bridge remains, among other things.

3.2.2 Bridges in a civilian context

When the emperor Trajan decided to connect the province of Dacia to the rest of the Roman empire by bridging the Danube, the engineer Apollodorus of Damascus was commissioned to build the bridge. It is not clear exactly when the construction of this bridge took place, but the most likely date would have been between AD 103 and 105.[120] The comments of classical authors indicate that the bridge was a highly impressive structure and was considered an example of ambitious architecture.[121] It is not surprising therefore that Apollodorus wrote a book about his achievement. Unfortunately this work has not been preserved, but its existence is mentioned in a classical source.[122] It is possible that this bridge was built with the help of cofferdams.[123] Apart from Apollodorus, there are no other classical authors concerned with civilian bridge building.

3.2.3 Bridges in a military context

Vegetius states that bridges were built by driving piles into the river bed and laying a road on top of them.[124] Caesar is somewhat more informative. In *De Bello Gallico* IV 17,1–18,1 he gives a rather cryptic description of a wooden bridge built over the Rhine by his army in order to carry out a punitive expedition on the other side.[125] The text probably describes a variant of a model of a bridge assumed to be familiar to the reader, and is not discussed further. The lack of clarity in the text has led to a considerable amount of comments and controversy.

These military sources deal with temporary bridges and are of marginal importance to civilian bridge building. More frequent, but even less helpfull, are references to military pontoon bridges.

3.2.4 References to known bridges

Not discussing bridge building but worth mentioning is a passage from Cicero, who mentions in a letter to his friend Atticus that he arrived on the morning of 9 November 44 BC: *ad pontem Tirenum, qui est Menturnis, in quo flexus est ad iter Arpinas...*[126] This bridge was discovered and investigated several years ago.[127]

A similar coincidence occurred with the eulogy on emperor Constantine attributed to Eumenius, in which the construction of a bridge in Cologne is mentioned.[128] This bridge was investigated in the last century and later dendrochronologically dated in AD 310.[129]

118 CIL XXIII, 6934 and Schumacher 1906, 24, also mentioned in: Klumbach 1961, 99 and note 9; Cüppers 1969, 185; Esser 1972, 216.
119 Borrmann 1992, 23.
120 Tudor 1974, 75; Lepper & Frere 1988, 151 date the construction before AD 101 so before Dacia was conquered.
121 Dio Cassius LXVIII, 13, 1–2 and 6. Tzetzes, *Historiarum Variarum Chiliades* II, 34, 66–72 and 86–94.
122 Procopius, *De Aedificiis* IV, 6, 12–14 (edition Dewing 1961).
123 Kroes 1990, 103–4.
124 Vegetius, *Epitoma Rei Militaris* III, 7.
125 In the winter of 55 BC.
126 'near the Tirenian bridge, in Menturnae, where there is a bend in the road to Arpinum'. Cicero, *Letters to Atticus* 16, 14 (13), 1.
127 Ruegg 1983.
128 Paneg. Lat. 7, 13.
129 Weyden 1845; Schmidt 1861; Hettner 1886; Hübner 1886; Keller 1886; Schultze & Steuernagel 1895; Kraus 1925; Cüppers 1969, 188; Hollstein 1967, 79 and notes 21–22; Hollstein 1980, 74.

Ausonius mentiones a bridge with six piers in his poem *Mosella*, written between AD 371 and 393. According to his text it spanned the river Saar right where it flows into the Moselle (Germany). In 1934 a railway bridge was built at this spot. Building stones with bar clamp sockets, wooden foundation piles and pile shoes were found.[130] No further investigation was carried out so it is only known that the bridge must have been large.[131]

3.2.5 References to techniques used

A number of techniques which were used in the foundations of bridges have an interesting parallel in Vitruvius. This Roman engineer wrote his *De Architectura libri decem* in the time of Augustus.[132] The ten books are a kind of concise survey of techniques used at the time by Roman engineers. In them Vitruvius displays a conservative preference for techniques which had been known for some time, he does not discuss a number of more recent Roman discoveries such as vaulting in concrete.

In book V of his treatise, two foundation techniques for building dams and moles in the sea are described.[133] The technique applied depended on the type of concrete available: concrete which could set under water due to the addition of volcanic sand (*pozzolana*) or concrete that had to set in the air. If concrete that set under water was available only a simple formwork of sheet piling was required in which the water remained during building.[134]

The rules of probability make Jüngst and Thielscher doubt about sheet piling which is first made on land and then driven in as a whole. They consider sheet piling made pile by pile on the spot to be more likely.[135] The archaeological finds prove them right. The sheet piling technique described by Vitruvius was found in the first-century bridge at Trier (Germany, AD 71). The sheet piling served to keep out soil as described by Vitruvius.[136] The wall of beams observed in the bridge foundations at Mainz may be seen as a variant of this technique. The height is known only of this formwork and of that at Trier: the latter is 80 cm and the former over 1 m.[137]

Vitruvius' second formwork technique was intended for construction with concrete that needed air to set. One had to make sure that the construction was kept dry for some time.[138] By filling a double wooden wall with clay, a more or less waterproof cofferdam was made. This technique is still used today in small-scale applications. The second-century bridge at Trier which still exists was founded with the help of this technique, although

130 Krüger 1934, 147. Krüger, E. Jahresbericht des Provincialmuseums zu Trier. *Trierer Zeitschrift* 9, 1934, 135–81.

131 Keune 1933, 18.

132 The oldest manuscript of *De Architectura* (London, British Museum, Harl. 2767) dates from the eighth century and is from Northumbria (GB).

133 Vitruvius *De Architectura* V, 12, 3 and V, 12, 5–6.

134 Vitruvius *De Architectura* V, 12, 3: *deinde tunc in eo loco, qui definitus erit, arcae stipitibus robusteis et catenis inclusae in aquam demittendae destinandaeque firmiter; deinde inter ea [ex trastilis] inferior pars sub aqua exaequanda et purganda, et caementis ex mortario materia mixta, quemadmodum supra scriptum est, ibi congerendum, donique conpleatur structurae spatium, quod fuerit inter arcas.*

Translation: then, in the place marked out, cofferdams, formed of oak piles and tied together with chains (or: (wooden) brackets) are to be let down into the water and firmly fixed. Next, the lower part between them under the water is to be levelled and cleared [...by certain means...] and stones mixed with the material from the mortar as above described, is to be carried there; then the space inside the cofferdams is filled with masonry.

135 Jüngst & Thielscher 1939, 175; see on the other hand Schramm 1936, 1407. He later revises his opinion: Schramm 1938, 46.

136 Kroes 1991.

137 Cüppers 1969, 214 and 185 *Abb.* 156.

138 Vitruvius *De Architectura*, V, 12, 5–6: *In quibus autem locis pulvis non nascitur, his rationibus erit faciendum, uti arcae duplices relatis tabulis et catenis conligatae in eo loco, qui finitus erit, constituantur, et inter destinas creta in eronibus ex ulva palustri factis calcetur. Cum ita bene calcatum et quam densissime fuerit, tunc cocleis rotis tympanis conlocatis locus qui ea septione finitus fuerit, exinaniatur sicceturque, et ibi inter septiones fundamenta fodiantur. Si terrena erunt, usque ad solidum, crassiora quam qui murus supra futurus erit, exinaniatur sicceturque et tunc structura ex caementis calce et harena compleatur.*

Sin autem mollis locus erit, palis ustilatis alneis aut oleagineis configantur et carbonibus compleantur, quemadmodum in theatrorum et muri fundationibus est scriptum. Deinde tunc quadrato saxo murus ducatur iuncturis quam longissimis, uti maxime medii lapides coagmentis contineantur.

Translation: In those places however, where the powder (pozzolana) is not found, we must proceed as follows. Double cofferdams bound together with planks and connected with brackets are to be put in the place marked out; and between the supports fine chalk in baskets made of rushes from the marsh is to be trodden in. When this is stamped down well and is as compact as possible, then, archimedean screws, (water)wheels and (water)drums having been placed, the area marked out by this cofferdam is emptied and dried, and here within the cofferdams the foundations are dug.

(Continued note 138, page 494)

the construction of the wooden cofferdams differs slightly from the procedure described by Vitruvius. The remains at Trier are the only cofferdams of this type known from the Roman Period.[139] From the Middle Ages more cases are known of the use of this technique in bridge building.[140]
As mentioned above, Vitruvius does not discuss bridge building in the passages referred to, but the construction of moles. Moreover, his technique is intended for construction in concrete. All the known wooden bridge foundations, however, have a packing of rubble and clay; the use of concrete in wooden bridge foundations has not been observed anywhere. It would be going too far to draw conclusions about Roman bridge building on the basis of a parallel with techniques described by Vitruvius, without any further archaeological evidence. Given the differences already observed, more diversity in the techniques of bridge building must have existed.

3.3 *Unanswered questions*

3.3.1 Technique

From the research done so far, a number of matters have been more or less established. The construction of a foundation on piles has been studied often enough to enable a rough description of the various variants used in Roman times.[141] The technique by which the stone piers were built has been observed in a sufficient number of bridges, and thanks to the second-century bridge at Trier a picture can be drawn of the wooden span and therefore of the bridge as a whole. Two configurations can be distinguished of foundations on piles: those in which the piles are clearly set in rows and those in which the piles are set at about the same intervals both lengthwise and crosswise, and where no rows can be distinguished. It is certain that this is not due to a difference in date of building; there is no question of techniques from different periods or of technical progress.[142] This also applies *mutatis mutandis* to the difference between foundations with cofferdams made of sheet piling and cofferdams in the form of a framework of beams. The two variants occur in combination with both varieties of configurations in the foundation piles.
Kroes suggests an adaptation to riverbed conditions or geology as the only possible explanation, but does not suggest what kind of link could exist between both items.[143] It is also conceivable that the characteristics of a river played an important part in the selection of a building method. No research into this has yet been done.
Nor is much known about the choice of a bridge site. The reason for a bridge being at a certain place is all too often disposed of with the, not incorrect, commonplace that bridges are often built at fords. For the site, length, height and possibly even building method there are more possible reasons which have never been fully investigated, the landscape and its many variables being one of them. The Rhine bridge at Koblenz, for example, is placed precisely opposite a valley on the right bank, an obvious advantage in the construction of a connecting road.
The relation between a bridge and the surrounding road system has so far only been used in a reverse sense: some bridges are dated as Roman because they lie exactly in the line of a known Roman road.
Research into the system of measures used in Roman feet may produce interesting results, as has been seen from research into other Roman building remains. This has never been done in bridge foundations.

3.3.2 Organization

Thanks to the absolute dating possibilities of tree-ring dating, we know that repairs to foundations were

138 *(Continued)* If they (*i.e.* the places) consist of earth down to the solid ground, they are emptied and dried broader than the wall above, and then filled with concrete of stone, chalk and sand. If the place is soft, they are pierced with charred piles of alder or olive and filled with charcoal, as is written about the foundations of theatres and walls (Vitr. *De Archit.* III, 4, 2 is meant). Then the wall is built with dressed stone with joints as long as possible so that the central stones may be well held together at the joints. The *colceis, rotis, tympanis* referred to by Vitruvius are machines for various purposes. Archimedean screw and water drum were made to transport large quantities of water over a low height. Water wheels were more suitable for moving smaller quantities of water over a great height (see for this Oleson 1984, especially part 2, 291–301 and 325–70). Particularly the first two large-scale pumps were suitable for draining building trenches. Roman cofferdams should not be thought of as several metres deep.

139 Cüppers 1969, 52–101.

140 Mesqui 1986, 241–6.

141 Kroes 1990.

142 Kroes 1989, 140.

143 Kroes 1990, 101.

regularly carried out. The repairs must have gone hand in hand with frequent inspections and assessments of the bridge construction, especially the underwater foundations. Somewhere in the military or civilian hierarchy someone must have had this task and initiated repairs. The scanty information about commissioners of bridges does not give us much to go on. What is clear is that the person who paid for the bridge or the repairs was more important than the person in charge of the building project.

Estimates of the time required for building have only been made of the (wooden) Rhine bridge at Koblenz and the bridges at Trier because the data collected there permitted it. The origin of the building material has virtually never been investigated. This and the calculation of the building time could tell us something about the number of people involved in the construction of a bridge, directly or indirectly, via building, supply, supervision and planning.

4 THE LANDSCAPE CONTEXT

4.1 *Method of research*

The objectives of the landscape research have been specified in chapter 1. In order to carry out this research, several choices had to be made. The existing research material is insufficient for an idea of the landscape in the Late Roman Period to be formed. For example, the geological map of this area has not been published and there was no stratigraphic information available for the area east of Cuijk. However, elsewhere in the southeast river area of the Netherlands regional studies have been done which provide information on the genesis of this river landscape. The reconstruction of the landscape in the Late Roman Period, which is the ultimate goal of this chapter, is therefore based on a combination of existing sources[144] and our own field survey.

For the field survey, a rectangular fieldwork area was demarcated, 4.5 km (south-north) by 5.5 km (west-east). This area is referred to as the mesoregion. The geological-geomorphological map of the mesoregion of Cuijk/Mook, scale 1:40 000 (plate 1), and the corresponding lithological profiles (plates 2 and 3) are the result of a field survey of the geological and geomorphological development in this part of the southeast river area.[145] The field survey consisted of a hand auger investigation and a geomorphological survey. Where Pleistocene deposits are found on the surface, geomorphological mapping usually sufficed. Where Holocene deposits are found on the surface, boring was also carried out. There were 223 borings done with the help of an Edelman auger, a gouge and a suction corer. The average boring depth is five metres. The State Geological Service carried out six borings near the Roman Meuse bridge down to *c.* 9 m below the surface. The results of these borings have also been included in the map and the profiles.[146] The legend of the map has been organized in such a way that both geological as well as geomorphological information can be given. The colours reflect the difference in the age and genesis of the deposits. The genesis of the deposit is described under 'deposits', and an indication is given of the lithostratigraphical unit (formation) to which the deposit belongs. River bank deposits of less than four metres thickness and river dune deposits are shown by hatching on the map. In this way the underlying deposits which are not on, but near the surface, are made visible. As will be seen later, these 'hidden' deposits are important to the reconstruction of the former landscape in the mesoregion. The larger landscape forms (geomorphological units) are included under 'geomorphology'. In the case of fossil channels and natural levees, a further classification according to depth and thickness has been made. The detailed morphological information such as height, type of slope and steepness has been omitted from the map because the lithological profile provides sufficient information (plate 2). Each geomorphological legend unit has a code. This code is used to refer to map units from the text, but also to link up the geological-geomorphological map and the lithological profile. The position of the profile is shown on the map (plate 1; A-A'). The code letters (and combinations of code letters) above the profile give information on the genesis. The profile serves to clarify the genesis and not to indicate

144 Schelling 1951; Pons 1957; Hoek & Schorn 1990; Van der Beek & Isarin 1991.

145 The field survey on the left bank of the Meuse was carried out in 1989 and 1990 by R. Isarin and H. van der Beek. On the right bank of the Meuse a pilot study was done by the same people in 1992. The final investigation on this bank was carried out in 1993 by J. van Eijk and H. van der Beek.

146 Thanks are due to J. Broertjes, RGD district Zuid.

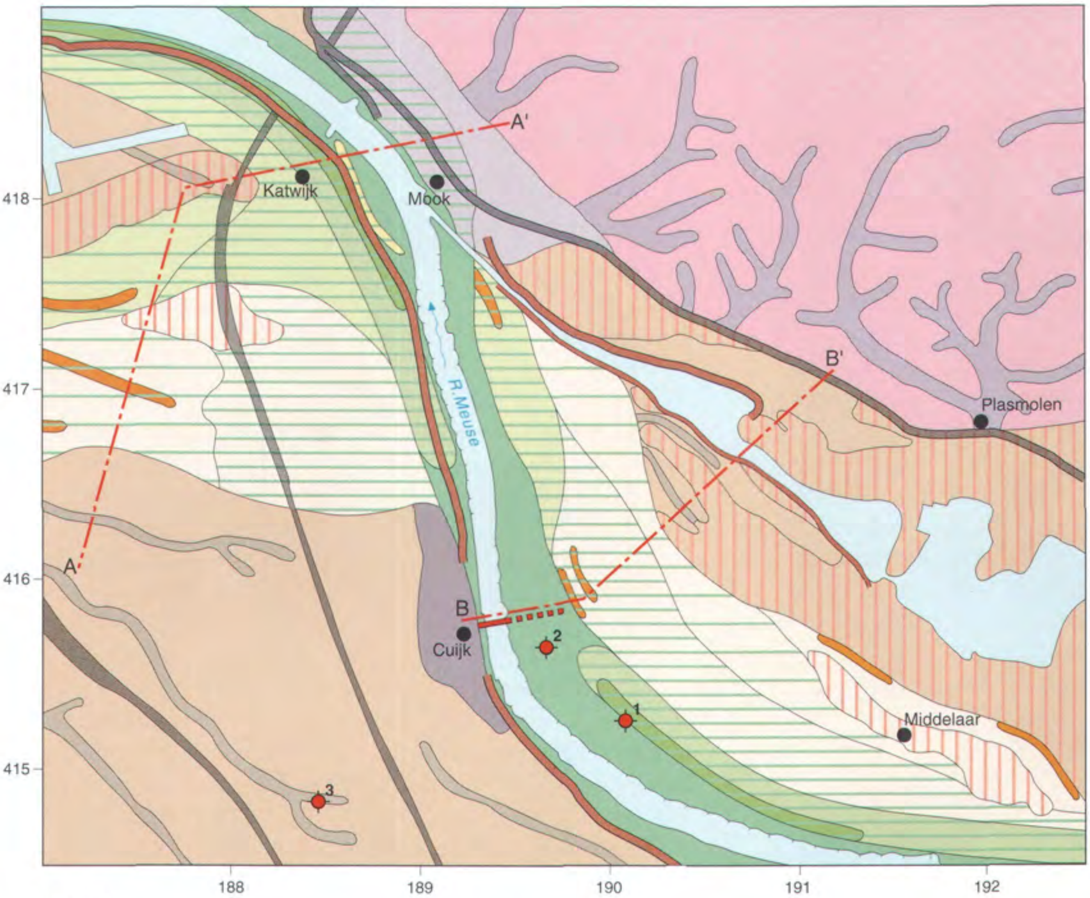


Plate 1
Geo(morpho)logical map of the region Cuijk/Mook, scale 1:40 000.

Legend

Water · Embankment · Dike · Cross section

Roman bridge · Settlement · Site mentioned in the text

Geology

	Subdivision	Formation	Deposits	Geomorphology
Os	Holocene	Betuwe	Residual channel deposits (recent)	Fossil channel
OO O o	Holocene	Betuwe	Levee deposits (and levee deposits on shown foundation)	Levees >4m thick Levees <4 m and >1.5 m thick Levees <1.5m thick
GG G	Holocene	Betuwe	Residual channel deposits	Fossil channel >4m deep Fossil channel <4m deep
kX	Early Holocene *(Preboreal)*	Betuwe	Flood basin deposits	Basin clays on eroded parts of the late dryas terrace
D	Late Weichselien *(Late Dryas)*	Kreftenheye VI	Riverdune deposits, on shown foundation	Riverdunes >1.5 m thick
X Y	Late Weichselien *(Late Dryas)*	Kreftenheye VI	Braided river deposits	River terrace of the Meuse with fossil channels
V R	Middle and late Weichselien *(Bølling / Allerød)*	Kreftenheye V	Deposits of braided and meandering rivers	River terrace of the Rhine and Meuse with fossil channels
Sp	Late Saalien	Drente	Fluvioglacial deposits	Outwash plain or sandr
St Sd	Middle Saalien	Urk	Glacially contorted fluvial deposits	Ice pushed ridges with valleys
H	Early Saalien	Urk	Braided river deposits	River terrace of the Rhine

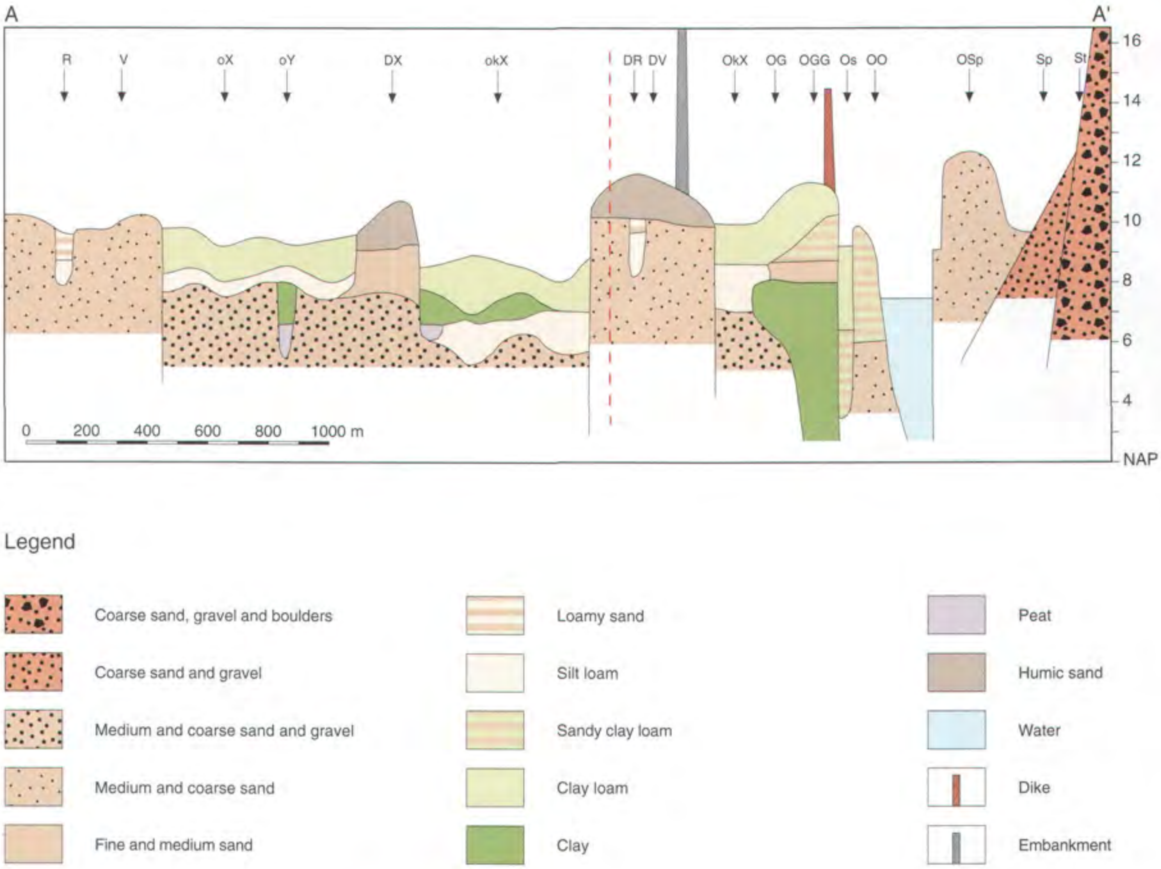


Plate 2 Cross section A-A′ explaining the code on the geo(morpho)logical map of the region Cuijk/Mook.

all lithological combinations. This profile also shows the height of the various deposits in relation to NAP. A second profile line (plate1; B-B′) runs from Cuijk to the ice-pushed ridge and crosses the Meuse at the place where the Roman bridge remains were found. Along this line seven palaeogeographic profiles were drawn (plate 3) showing the situation in the Allerød, the Late Dryas, the Preboreal, the Subboreal, the Roman Period *c.* AD 350, recent *c.* AD 1850, and recent *c.* AD 1970. Figure 40 gives a schematic survey of the developments in the Meuse basin during the last 13 000 years.

4.2 *Landscape genesis until the Roman Period*

4.2.1 Saalian (200 000–128 000 BP[147])

From the geological-geomorphological map (plate 1) it can be seen that Cuijk is situated on the oldest deposits within the mesoregion. It is probably a remnant of the eroded high terrace (code H) which was formed by the Rhine and Meuse before the Middle Saalian. Such residual terraces have been recognized in several locations in the South Netherlands on the basis of the top of the gravel level (plate 2).[148] Under Cuijk, the gravel level was found at 9–9.5 m NAP. The sandy top of the high terrace is at *c.* 11.5 m NAP here. As a result of anthropogenic raising, the highest part of Cuijk is now at *c.* 14 m NAP. The ice-pushed ridge (St) at Mook and Plasmolen was formed in the Saalian. The ice sheet of

147 *Sensu* Koster, 1980.
148 Pons 1957, 5.

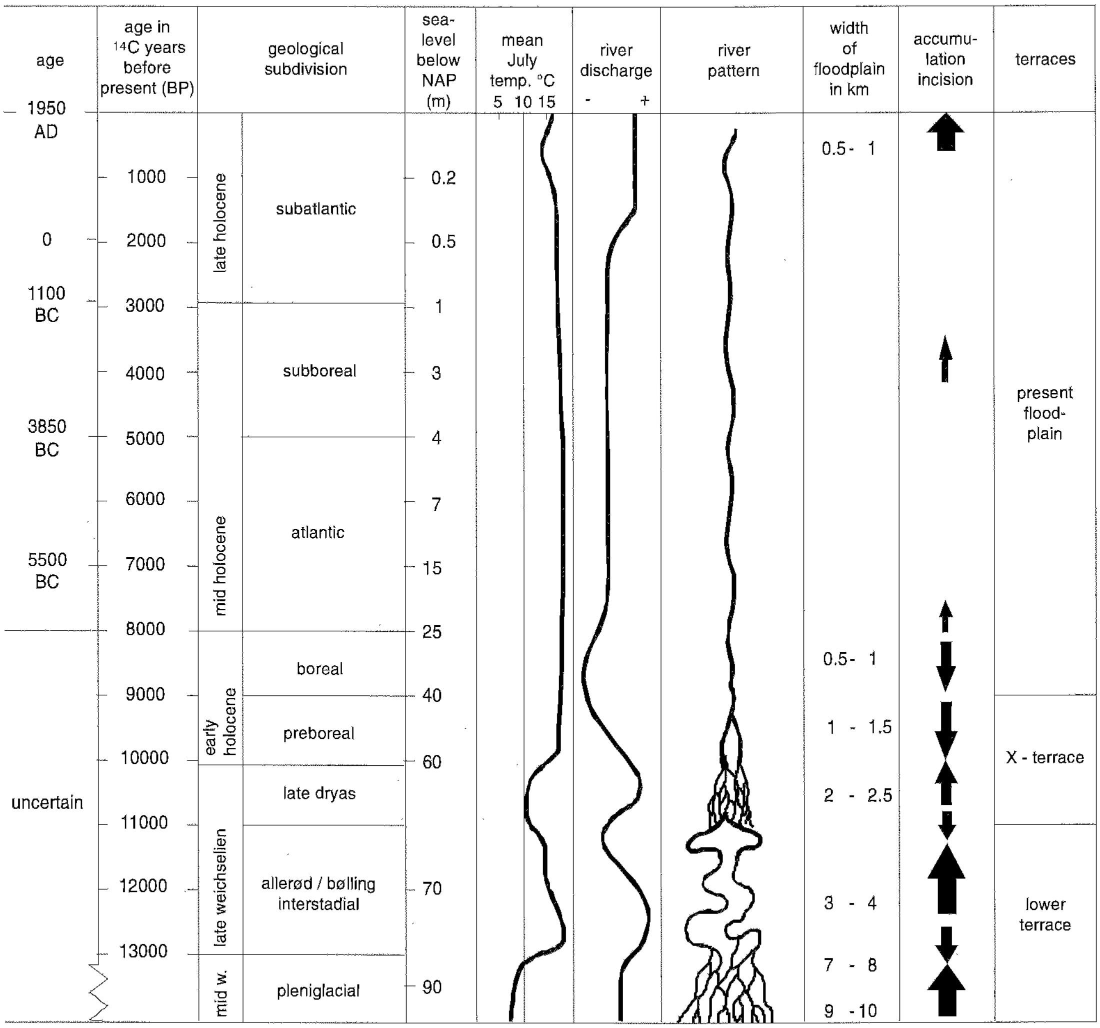


Figure 40 Schematic representation of the fluvial and climatic changes during the Late Weichselian and Holocene. Data from: Coope (1981), Zagwijn (1986), Hoek & Schorn (1990), Van der Beek & Isarin (1991) and Kasse *et al.* (1995).

the Scandinavian ice-cap reached the central Netherlands via the river valleys of that time and pushed the underlying deposits (including the high terrace) up into ridges. Snow meltwater (dry) valleys (Sd) were formed in the ice-pushed ridge. This process took place in the Late Saalian and possibly in the later Weichselian. The meltwater from the ice-cap formed a slightly sloping glacial outwash or sandr at the foot of the ice-pushed ridge. The barrier of ice-cap and ice-pushed ridges forced the Rhine and Meuse to shift their courses to the west and to form a valley together on the south side of the ice-pushed ridge. In the periglacial climate the rivers flowed in a braided pattern and formed a so-called pradoliny *c.* 10 km wide. The greatest part of the mesoregion belongs to this valley. No deposits were found in the mesoregion from the interglacial period following the Saalian, the Eemian (*c.* 128 000–115 000 BP[149]).

149 *Sensu* Woillard & Mook 1982.

4.2.2 Early and Middle Weichselian (115 000–13 000 BP)

In the last glacial period, the Weichselian, the Rhine and Meuse flowed through the valley which was formed in the Saalian. In the Early Weichselian (*c.* 115 000–73 000 BP) the braided rivers formed a plain of gravel and coarse sand in this valley.[150] This plain was built up further with sandy and gravelly sedimentation from braided rivers in the Middle Weichselian (Pleniglacial, *c.* 73 000–13 000 BP). The maximum cold occurred between *c.* 27 000 and 17 000 BP.[151] Sedimentation from the Rhine and Meuse from this period is included in the Low terrace (code V). The still visible channels in the low terrace (R) belong to the final phase of terrace formation. The active river basin of the Rhine and Meuse came to lie near Cuijk. A large section of the originally 10 km wide valley fell into disuse.

4.2.3 Late Weichselian (13 000–10 000 BP [152])
The cold period comes to an end when the Bølling-Allerød interstadial complex begins (*c.* 13 000–11 000 BP). This term refers to a relatively warm period in which there is, at any rate, one short, colder period. The vegetation at first developed slowly. The river discharge was concentrated in a number of channels which functioned simultaneously. However, the channels were deeper and had a low-sinuous character. This river system (code R) is described by Kasse *et al.* as a 'transitional system'.[153] During flooding, a layer of clay was deposited which is found on large sections of the Pleniglacial terrace. The clay layer is not shown separately on the map nor on the lithological profile. During the Allerød (*c.* 11 800–11 000 BP) there is a forest vegetation present: this is at first a forest type in which birch dominates, followed by a forest type in which pine is the predominant species of tree.[154] Water and sediment discharge decreased and the flow became more regular. The branch of the Rhine which, until then, had flowed through the Niers valley left the area.[155] The river pattern of the Meuse now became meandering. The sediments deposited are sandy and are also included in the low terrace. The thickness of the deposits is about seven and a half metres. In the mesoregion the top of the low terrace is between 9 and 10 m NAP. From palynological research in a residual channel of the low terrace (plate 1, location 3) it appears that the channel fill begins in the Late Dryas.[156] This marks the end of the formation of the low terrace. In the Late Dryas stadial (*c.* 11 000–10 000 BP) the temperature dropped. Climatic conditions similar to those in the Pleniglacial returned for a brief time. The water and especially the sediment discharge of the Meuse increased, causing the Meuse to change from a meandering river to a braided river (plate 3b). The braided Meuse broadened the valley by lateral erosion to a width of 2 to 2.5 km. The valley formed in the Allerød was partially filled with the erosion material. In this way a terrace of gravelly sand developed which is known in the southeast river area as X-terrace (code X).[157] Soil samples were also taken in various residual channels in the X-terrace (code Y). In the mesoregion the top of this X-terrace has a height of *c.* 7.5 m NAP. At Cuijk the X-terrace differs from the picture given by this terrace to the south of the mesoregion: a straight, undivided river valley with an almost constant width of *c.* 2.5 km. North of Cuijk, however, the X-terrace forks into two branches between which the erosion remains of the low terrace have been left. One branch follows a course between Mook and Katwijk (the north branch). The second branch bends west immediately north of Cuijk (the south branch).
On the east bank of the former river valley river dunes were found. In the Late Dryas the river bed was regularly dry during the winter periods. As a result, sand became available for transportation by the wind. Particularly at places where the subsoil was damp enough, such as the clay layer of the low terrace, the aeolian sand was caught. Under influence of westerly winds, river dunes were fomed in this way (code D). The village of Middelaar is largely built on one of these river dunes.

4.2.4 Early Holocene (10 000–8000 BP)
With the Preboreal the present warm age began: the Holocene (see fig. 40 and plate 3). Part of the X-terrace was lowered to *c.* 6 m NAP by erosion. From the incutting channels flood material rich in clay was deposited on the lower X-terrace (code kX) (plate 3c).

150 Verbraeck 1984.
151 Vandenberghe & Pissart 1993.
152 *Sensu* Mangerud *et al.* 1974.
153 Kasse, Vandenberghe & Bohncke 1995.
154 Van Geel *et al.* 1989.
155 Hoek & Schorn 1990, 16.
156 Teunissen 1990, 80–1. The xyz-coordinates are 188.420/414.850/8.5.
157 Pons (1957) introduced the name X-terrace; other names for this terrace are the terrace of Geistingen (Paulissen 1973), terrace III (Van den Broek & Maarleveld 1963) and the terrace of Wanssum (Huisink 1998, 29 and 21 fig. 2.2).

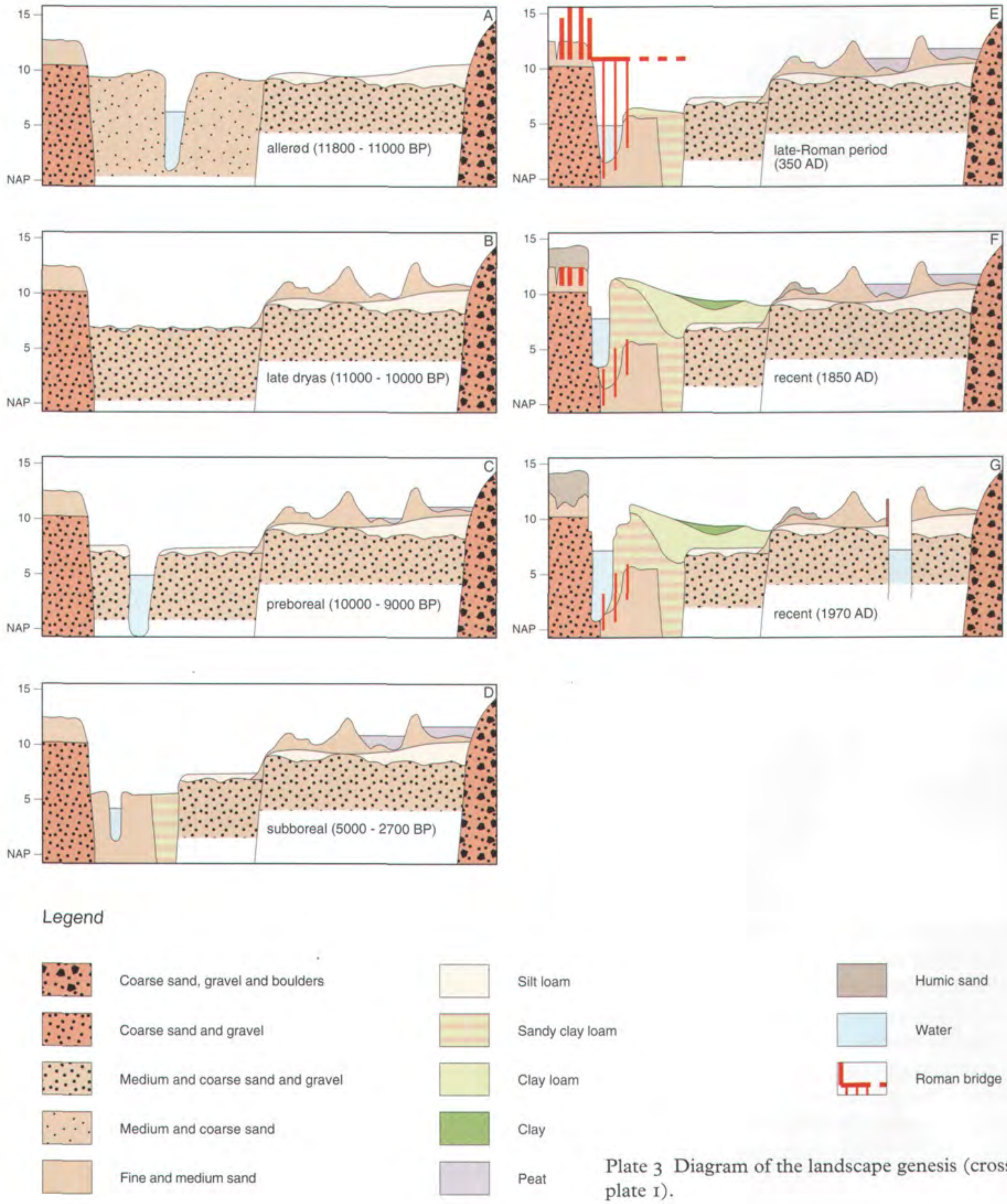


Plate 3 Diagram of the landscape genesis (cross section B-B′ on plate 1).

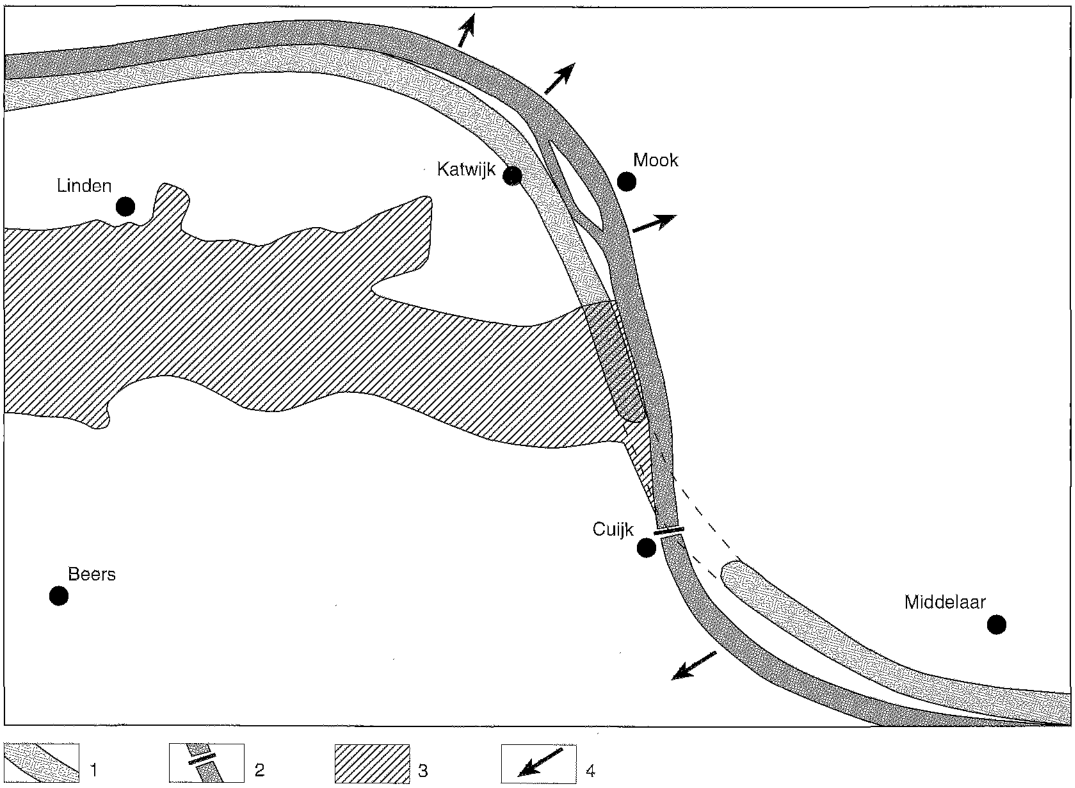


Figure 41 The Holocene Meuse courses at Cuijk (scale 1:50 000). Legend: 1 the Katwijkse Maas (functioned during the Boreal); 2 the Meuse with Roman bridge (active river course from the end of the Boreal until the present); 3 the Beerse Maas (winter bed of the Meuse from *c.* AD 1500 to 1941); 4 direction of migration.

The clay layer of the X-terrace is less well developed than that of the low terrace and is even lacking in places. At *c.* 4 km west of the mesoregion, at the deepest point of a residual channel from this phase, the beginning of silting up is dated.[158] From this it appears that the Meuse made use of the south branch of the X-terrace until 8830 ± 55 BP (GrN 17778) and subsequently only discharged water via the north branch. The Meuse therefore lay in its present (Holocene) valley from the beginning of the Boreal. This Early Holocene course of the Meuse is called the Katwijkse Maas, after the village there (code G and GG).[159] Already in the second half of the Boreal the Meuse again shifted her bed[160] and came to lie in her present position. The date of this avulsion can be seen from a palaeobotanical analysis of the RGD (plate 1, location 1). After the avulsion, the abandoned channel of the Katwijkse Maas served as a flood basin. This residual channel was filled during the Early and Middle Holocene with heavy clays, some humous (as at Middelaar) and some silty (as at Katwijk). Directly after the shift in position, the Meuse at Cuijk is slightly (one to two river widths at the most) more easterly than her present course. This can be deduced among other things from the 9 m borings of the RGD in the present east levee. The heavy clays characteristic of the residual channel were not encountered. However, river bed deposits containing sand and gravel were struck deeper than *c.* 6 m NAP. In chapter 6 observations on the underwater bed at the site of the bridge can be found. The divers reported that part of the Meuse bed consisted of a heavy clay which occasionally appeared

158 Van der Beek & Isarin 1991, 50. The xyz-coordinates are 184.530/417.470/3.3.
159 Van der Beek & Isarin 1991, 56.
160 In the middle reaches of the Meuse there are countless examples of Holocene avulsions where the river completely abandons a bed for some kilometres and follows a new course. It is assumed that this is caused by flooding and obstructions by ice floes (Paulissen 1973, 70).

to be almost petrified. This clayey zone begins at the level of the bridge and can be traced some way downstream. The clay can easily be recognized under water because of the vertical erosional walls cut in it. The sonar scan also gives reflections of these steep walls. This clay body of the Katwijkse Maas is extremely resistant to erosion. Nevertheless, the Meuse has eroded some of this clay layer and shifted laterally in the direction of Cuijk (fig. 41). This lateral movement took place mainly before the Late Roman Period. The presence of this resistant clay layer in the bed of the Meuse will not have eluded Roman engineers, and may perhaps have been an argument for the choice of this location.

In the course of the Holocene a peat area developed between the ice-pushed ridge and the river dunes, east of the Meuse. Seepage water emerged at the foot of the ice-pushed ridge which could not easily infiltrate the soil due to the clay layer present on the low terrace. Under these conditions depressions in the surface were filled up with basin peat and on top of this a raised peat bog developed.[161] The layer of peat at the foot of the ice-pushed ridge was *c.* 1.5 m thick.[162]

4.2.5 Middle and Late Holocene to the Roman Period (8000–2000 BP)

In this period a so-called climax vegetation developed in the Meuse basin.[163] The palaeobotanical research by the RGD reflects high values for mixed oak forest and considerable peaks for elm and lime.[164] This vegetation evaporates 60–80% of the annual rainfall.[165] Only in the winter half-year was there some surplus rainwater which drained into the rain river. There is too little water to fill the Early Holocene bed: the river is 'underfit'. The dimensions of the river would gradually correspond to the decrease in flow (plate 3d). In one of the borings near the remains of the Roman bridge (plate 1, location 2) a thin humous layer in the bank deposits was struck at 6 m NAP and dated. The layer has a date of 3280 ± 100 BP (UtC 2581).[166] At the end of the Subboreal, the bank deposits there are five metres lower than the top of the present bank deposits (11 m NAP). The dating at location 2 also contains an important indication for the position of the Meuse at that time. The Meuse lies between the terrace on which Cuijk is situated and location 2. The distance in between is only 250 m. The course of Meuse at Cuijk is therefore virtually the same as it is nowadays. During boring (down to 5 m depth) in the mesoregion no point bars were found. The absence of point bars is a morphological proof that no meander migration took place. The six deeper borings (down to 9 m depth) by the RGD did strike deposits below 6 m NAP which might be interpreted as point bars. As can be seen from the dating at location 2, these deposits were fomed before the beginning of the Late Holocene.
In the course of the Middle Holocene, the influence of man on the vegetation becomes visible. In the fill of the channel of the Katwijkse Maas (plate 1, location 1), pollen from plantain is found at 4.5 m NAP and at 5.0 m NAP pollen from corn is found. The pollen in the uppermost clay layer give low values for elm and beech. This sediment dates from the Subboreal. The section from 7.15 m NAP to the surface (10.0 m NAP) is partly poor in pollen and therefore difficult to interpret. This section probably dates from after the Roman Period. The surface in the Roman Period was at about 7.15 m NAP at location 1.[167]

4.3 *Landscape genesis during and after the Roman Period*

4.3.1 Bridge and river

The remains of the Roman bridge over the Meuse are the most important source of information about the Meuse in the first half of the Subatlantic period. The building stones for the bridge were probably brought in from the south by river (see 2.2.2). This indicates that the Meuse upstream from Cuijk was navigable for at least part of the year. The Late Roman bridge piers were founded on oak piles. The piles found show a regular pier pattern over the entire width of the present river Meuse. This could imply that in the Late Roman Period the Meuse was in the same place and was almos

161 Verbal communication D. Teunissen who actually saw this landscape.
162 In the 1950s, written objections to the digging of the peat were made on the authority of the municipality of Ottersum at the time. The objections include a description of the peat area.
163 Janssen 1974, 55.
164 Broertjes 1995, 1. The xyz-coordinates are 190.055/415.280/10.0.
165 Based on evaporation data in Zagwijn 1986, 10.
166 The xyz-coordinates are 189.620/415.780/11.0 m NAP.
167 Broertjes 1995, 1. For the pollen analysis the channel fill was sampled every 25 cm. The biostratigraphical limits may therefore be up to 25 cm too high.

as wide as the present Meuse (*c.* 110 m). From the dendrochronological analysis of the piles (see 2.3) another possibility emerges. The bridge has three construction phases: the most westerly pier has piles dating almost exclusively from the second phase (AD 368–369), whereas in all the other piers piles from the first phase (AD 334–343) are plentifully represented. This makes it likely that the pier (or bridgehead) closest to Cuijk was added to the bridge later. Apparently the westward meander migration of the Meuse was well under way in the Late Roman Period. In the report of the excavation of the Castellum Ceuclum it is also stated that the east side of the castellum is missing and had probably disappeared in the Meuse.[168] However, since the clay body of the Katwijkse Maas curbs the erosive power of the Meuse only a comparatively small part of the Roman findspot of Cuijk was lost. The Meuse at Cuijk is no freely meandering river for the massive clay body of the residual channel is a great restriction to its freedom of movement. This is probably why the remains of the Roman bridge have been discovered in the present bed of the Meuse.

To establish a good image of the Late Roman bridge at Cuijk we also need palaeohydrological information. The Meuse is a typical rain river: the maximum flow after a period of rain (3000 m^3s^{-1}) is about a hundred times higher than after a dry period.[169] The high water levels are generally attained when evaporation and interception are at their lowest in winter. The low water levels are reached in summer. In view of the enormous effort required to build a bridge, the Roman engineers will have made thorough investigations in advance about the extreme water levels. The oak foundations of the bridge piers (piles, cofferdam and cover) had to be permanently under water, that is, lower than the lowest low water level. During the reconstruction of the piers, it was observed that the wood of the foundation reached as far as 4.3 m NAP. This level is regarded as the lowest low water level in the Late Roman Period.[170] The highest high water level is also important for two reasons: first, all the wood of the superstructure of the bridge must be permanently above water, and second, in the case of extremely high water the safety of the bridge is affected. The average high water level is the top of the natural levees. With a higher water level, the hinterland becomes flooded and without supplementary constructions the bridge is inaccessible. The average high water level can therefore be derived from the sedimentation height of the levee deposits. During the geological survey, no observations were made from which the level of levee deposits in the Roman Period could be directly inferred. No datable material was found anywhere in the levee deposits (apart from location 2).

4.3.2 Sedimentation after the Roman Period

By reconstructing the post-Roman sedimentation it was possible to estimate the height of the natural levees in the Roman Period. The top of the natural levee is at any rate higher than 6.0 m NAP, because that level was already reached in the Bronze Age (date location 2). At location 1 (plate 1) the level of bank sedimentation in the Roman Period was approximated at 7.15 m NAP. In view of the possible inaccuracy in this estimate and the information on later sedimentation, a Roman natural levee height of *c.* 7 m NAP would seem reasonable. At location 3 a pollen survey was carried out in a low terrace channel during which a flood level was recognized at *c.* 7.8 m NAP in the channel fill and dated.[171] The period of flooding was between *c.* AD 1000 and 1200.[172] So, not until the Late Middle Ages does the water of the Meuse at peak discharge reach the level of 7.8 m NAP. Evidence about the highest high-water level can also be found in the historical sources. In the course of the thirteenth century, more and more quays were built along the Meuse from the west. As a result, the Meuse did not reach its former backlands and deposited its load of sediment in the river bed. The bed of the Meuse became increasingly higher and downstream from Cuijk serious problems developed. From the end of the Middle Ages the Meuse takes an alternative route in times of maximum discharge. The surplus water at Cuijk is drained via the south branch of the X-terrace. Via this route the Meuse water flows through its former backlands before returning to its own bed 50 km further west. This branch of the Meuse

168 Bogaers 1966, 68.

169 Berendsen *et al.* 1986, 93.

170 The piles whose tops are highest were found outside the navigation route in the Meuse. The highest pile top was measured at 3.63 m NAP. On top of this there was a presumed oak cover of 0.6 m (see 5.1.7). The wooden construction therefore reaches 4.23 m NAP. The level of the lowest low water was rounded off at 4.3 m NAP.

171 Teunissen 1990, 81 (pollen diagram Hoenderberg).

172 The dates are: 945 ± 35 BP (GrN-8480) and 730 ± 90 (GrN-8283): derived from Teunissen, 1990.

Figure 42 Land surface in AD 350 and AD 1990 along a section of the profile line B-B′ (plate 2). Legend: A high terrace; B pre-Roman bed and bank deposits; C X-terrace; D low terrace; E river dunes; F post-Roman overbank and bank deposits; G post-Roman anthropogenic layer.

during maximum discharge is called the Beerse Maas, after a village west of Cuijk (see fig. 41).[173] In the sixteenth century the Beerse Maas only flows in a few disaster years, but gradually it becomes a regular winter phenomenon. During the last century, the Beerse Maas often functioned several times per winter. It caused much inconvenience, and is for this reason frequently mentioned in historical sources.[174] Conclusions can also be drawn from this about the sedimentation history in the mesoregion. The X-terrace at Cuijk is approximately 7.5 m NAP in height. Since AD 1500 there have been written sources about the flooding of the Beerse Maas over the X-terrace. As a result, the approximate date can be established at which the highest high-water level was 7.5 m NAP.

Summarized, this produces the following palaeohydrological survey:

1 *c.* 1700 years before the Late Roman bridge, the top of the bank sedimentation was at 6 m NAP (date location 2: 3280 ± 100 BP);

2 *c.* 800 years after the Late Roman bridge there is a phase of flooding at 7.8 m NAP (dates location 3);

3 *c.* 1100 years after the Late Roman bridge the 7.5 m NAP level is regularly flooded (historical sources);

4 the pollen analysis (location 1) suggests that the top of the natural levee there in the Roman Period was at 7.15 m NAP, but this may be slightly too high.[175]

The high-water levels in the Roman Period must be inferred from this information. In the palaeogeographical profile (plate 3e and fig. 42) the top of the Late Roman levee is arbitrarily drawn at 7 m NAP. The level for the highest high water was set at 7.5 m NAP. These values correspond best with the available data. The present height of the natural levee on the east bank of the Meuse opposite Cuijk is 11 m NAP on average. After 1500 AD a *c.* 3.5 m-layer of bank sediments was deposited (plate 3f), which is a substantial increase of over 7 mm per year. The levee deposits are thickest next to the river (code OO), and the layer becomes gradually thinner as the distance from the river increases (code O and o). The deposits also become heavier (more clayey) the further the distance from the river, but the older deposits (terraces and river dunes) do not allow sufficient space for basin formation. Because of the small lithological differences, all post-Roman Meuse deposits in this investigation are included among the levee deposits, therefore also the deposits in the bed of the Beerse Maas. Near Katwijk a

173 The Beerse Maas is referred to in the quotation from Paringet (1752) (see 1.1) ‘ ... below the church, there where the Meuse now flows ...’

174 Buijks 1984 gives a survey; for the hydraulic developments in the Land of Cuijk, see Van der Beek & Isarin 1991, 25–36.

175 Sampling took place every 25 cm.

relatively small residual channel (code Os) was found (plates 1 and 2). According to topographical maps from the last century, the river island of Middelweerd once lay between the Meuse and this residual channel. Paulissen calls the Meuse a typical island river in which the islands retain a constant configuration and position.[176] In the Roman Period a river crossing was often built across a river island, because it is easier to cross two arms of a river. An (Early or Middle Roman) river crossing is also presupposed at the island between Katwijk and Mook (see fig. 41).[177] The location of the Roman Meuse bridge at Cuijk was also investigated to discover whether the bank connection perhaps ran via a river island. At the site of a former river island one would expect to find a relatively thick layer of river-bed deposits, reaching at least as far as the surface of the land at that time. Stratigraphic information did not produce any indications for a former river island.

4.3.3 Recent developments in the landscape around Cuijk

In the course of this century, several important changes took place in the landscape of the mesoregion (plates 1 and 3g). In the 1930s, part of the east bank of the Meuse was excavated in order to increase the holding capacity of the Meuse. To improve navigability, the Meuse was divided into river sections; the mesoregion lies in a river section where a constant water level of 7.5 m NAP is aimed at. In the 1950s, the last peat area at the foot of the ice-pushed ridge was dug and mixed through the underlying sand. The Mokerplas, a lake between Plasmolen and Middelaar, is a result of sand and gravel extraction. The canal to the Mokerplas follows the course of a stream which used to drain the surplus peat water. A dike was built on the left bank of the Meuse obstructing the lateral drainage via the Beerse Maas. This river dike was built as far as possible on the massive clay body of the Katwijkse Maas. Meanwhile (1995) there are plans to build a dike (quay) on the east bank of the Meuse in connection with the floods of 1994 and 1995.

176 Paulissen 1973, 41.

177 During the building of the railway bridge over the Meuse a 'row of heavy oak piles' was seen near Mook in 1881 (Pleyte 1881). This observation was combined with the find of a 'Roman road' at Katwijk in 1861 (Hermans 1865, 19). The asumed bridge between Katwijk and Mook is based on these two observations.

4.4 *Reconstruction of the landscape in the Roman Period*

4.4.1 The abiotic landscape

Figure 42 is a cross-section from Cuijk to the river dunes east of Cuijk. The cross-section shows the present surface of the land and the surface in the Roman Period. The 'height' of Cuijk was slightly lower in the Roman Period. The ground level in the castellum was *c.* 11.6 m NAP and the subsoil consisted of slightly gravelly sand. The highest point of Cuijk was considerably raised after the Roman Period by later inhabitants. The Roman Meuse (Mosa) at Cuijk probably lay several metres further eastward than the present Meuse. The extreme water levels in the river at that time were 4.3 m NAP minimum and 7.5 m NAP maximum. In the Roman Period the Holocene Meuse valley at Cuijk was 450 m wide and the top of the natural levee was at *c.* 7 m NAP. In winter and early spring, the levees flooded and mainly sandy clays were deposited in the valley. In the Roman Period the X-terrace lay at the surface. The X-terrace consists of moderately coarse sand, coarse sand and fine gravel. The weight percentage of gravel fluctuates between 4 and 35%. In this subsoil water is easily drained, so that the X-terrace would have been bone dry and accessible throughout the year. In the X-terrace there were various residual channels. A number of these were localized by auger investigation and are shown in plate 1. The X-terrace channels are almost always filled up with peat. This peat lay at the surface in the Roman Period. The residual channels were wet locations in those days and not easy to cross. The other geomorphogenetical units found in the study area at Cuijk (river dunes, low terrace, ice-pushed ridge and sandr) already formed the surface of the land in Roman times. The only exception is the seepage zone at the foot of the ice-pushed ridge. Stagnating seepage water led to the growth of peat which covered part of the low terrace and the river dunes. Small peat streams emerged from this peat area to converge in a brook which discharged into the Meuse at Mook. The present canal between the Meuse and the Mokerplas follows the course of this brook. During the digging of this canal a wooden structure was found, possibly connected with a (possibly Roman) crossing of the brook. On the flanks of the ice-pushed ridges (code St) no agrarian activity is possible: the groundwater level is far too low and the slopes are too steep (15 to 35%). The valleys (code Sd) are less steep and are suitable for walking but not for heavier transport. The sandr

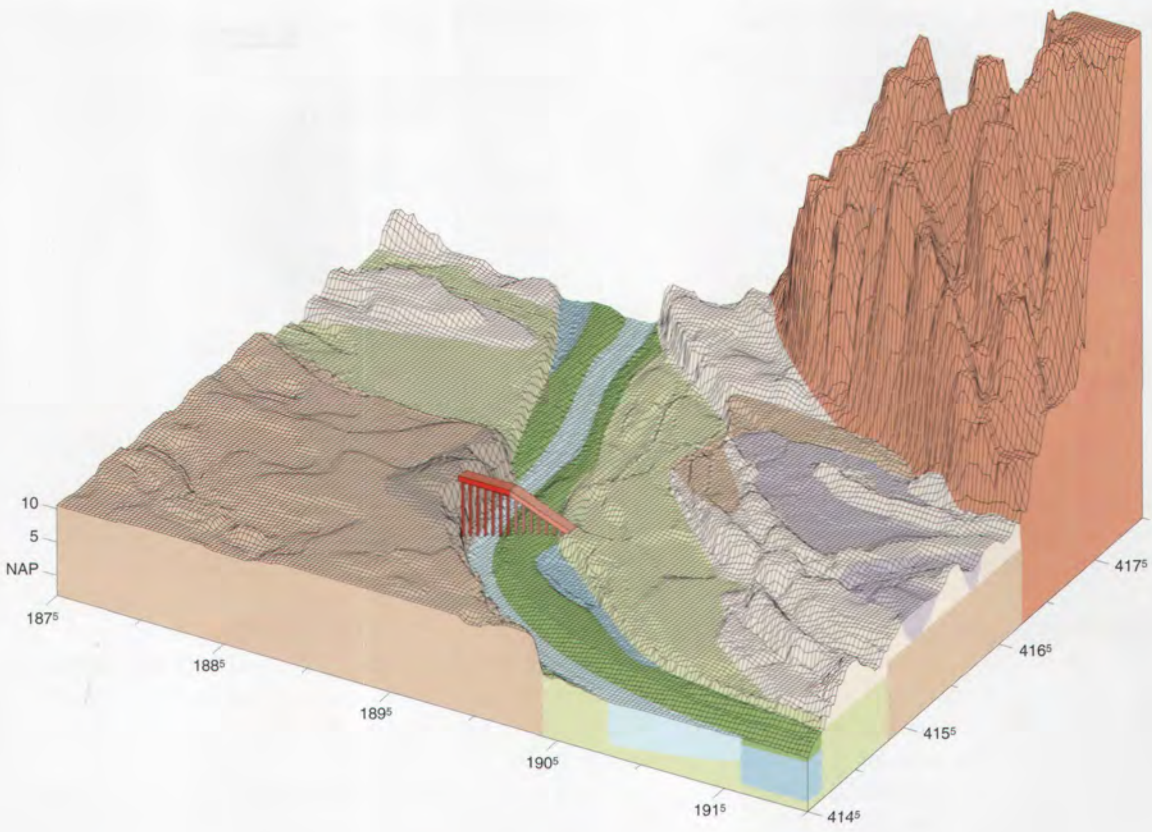


Plate 4a Three-dimensional surface plot (bird's-eye view) of the reconstructed abiotic landscape in Roman times (vertical magnification 37.5x).

(code Sp) at Mook continues as far as Nijmegen. The sandr has a gentle slope (1 to 2%) and a particularly firm subsoil of compact gravelly sand. This type of subsoil is ideal for supporting heavy transport. The top of the low terrace (code V) consists mainly of moderately coarse sand and sandy clay, which was deposited fairly horizontally. Nevertheless the low terrace has a somewhat irregular topography due to the presence of residual channels (code R) and some barren areas of wind-blown sand. The highest river dunes in the mesoregion are up to 15 m NAP. The river dunes consist of moderately coarse sand which is rather loosely packed. The soil is permeable and relatively easily tilled. The river-dune landscape is undulating, with slopes of between 3 and 10%. Plate 4a is a three-dimensional reconstruction of the abiotic landscape in the Roman Period (vertical enlargement 33x). As a comparison, the present landscape is also shown from the same perspective (plate 4b). The two great differences between both figures are the thick layer of

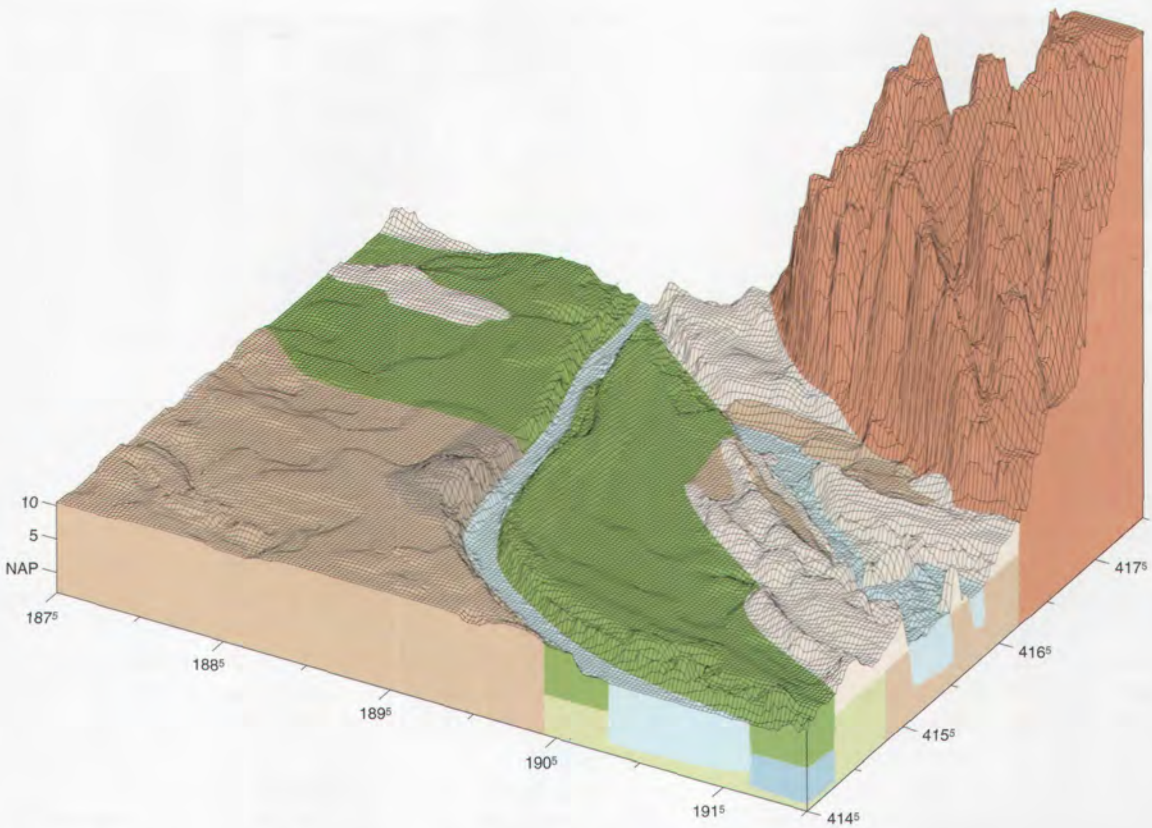


Plate 4b Three-dimensional surface plot of the present abiotic landscape (vertical magnification 37.5x). Legend: see plate 4a.

post-Roman levee sediments and the peat area at the foot of the ice-pushed ridge. The Roman valley of the Meuse at Cuijk has a characteristic terrace morphology. The relative 'height' of Cuijk is prominent in the Roman landscape. The difference in height with the X-terrace is 4 m.

4.4.2 The biotic landscape

Information about the former biotic landscape is mainly obtained from palynological research. In the Pleistocene part of the Netherlands, organic material has usually only been preserved in silted up residual riverchannels. Frequently the silting up process has been interrupted a number of times (erosion or dehydration), causing gaps in the pollen diagram. Palynological research was carried out in two residual channels in the mesoregion. In a residual channel of the low terrace (plate 1, location 3) the profile section between the Late Subboreal (Late Bronze Age) and the Late Subatlantic (Early Middle Ages) is missing in the pollen diagram.[178] The residual channel of the Katwijkse Maas (Plate 1, location 1) shows the same picture. The sediment on the Subboreal deposits shows traces of rust (therefore oxygen was present) and is partially poor in pollen. At the top the pollen content (because buckwheat is present) points to a sediment deposited after 1300 BP. Theoretically, the section in between therefore contains the sediments from the Iron Age, Roman Period and

178 Teunissen 1990, 81 (pollen diagram Hoenderberg). The hiatus lies between the dates 3150 ± 50 BP (GrN-8481) and 1260 ± 25 BP (GrN-8284).

the first half of the Early Middle Ages. The pollen content shows the presence of buckler fern and grasses in considerable quantities. This indicates an open vegetation. Ash willow and peat moss also occur and this points to wet conditions.[179] No ^{14}C date is available so this vegetation pattern cannot simply be linked with the Roman Period. Unfortunately, the palynological research locations in the immediate surroundings of the Roman bridge do not give a vegetation pattern for the Late Roman Period.

As described in chapter 2 in area 6000, behind the piles of the bank structures, some peat was observed which could provide that information. In January 1997 the whole structure came to lie above water, due to a very low water level. Samples were taken of this peat and investigated for macroscopic plant remains. The layer was *c.* 70 cm thick and turned out not to be peat. It was composed of fine plant material, wood choppings (partly oak), bark, charcoal, gravel, sand and some glass, leather, stone, ceramics and remains of insects. It is clearly a layer of settlement waste.

The plant material is very rich in seeds. Apart from a lot of synanthropic plants such as crop weeds and road side weeds the following crops were found: several wheat species, barley, broomcorn millet, flax, beet, olive, walnut, hazelnut, sloe, plum, poppy seed, coriander, dill, fennel and savory. The composition indicates that the layer was formed in Roman times. The information that it contains on cooking habits unfortunately obscures a clear view of the local vegetation, and *vice versa*.[180]

The vegetation in the Roman Period has been reconstructed, on a somewhat grander scale, for the eastern river area of the Netherlands.[181] In the development of vegetation, the most discriminating factor is the relation between pollen from trees and pollen which is not from trees. The changes in this relation reflect the influence of man on the biotic landscape. A decrease in the area of woodland is always accompanied by the presence of cereals and synanthropic herbs. The peak of deforestation is towards the end of the Iron Age, and not in the Early or Middle Roman Period. It is assumed that the influence of the Romans on indigenous agrarian methods of production meant a decrease in the area of arable land, despite the increasing density of population.[182] In a pollen diagram in the valley of the Meuse approximately 6 km south of the Roman bridge, a complete vegetation pattern of the Roman Period can be observed. It is striking that the recovery of the forest vegetation is already visible long before the Late Roman Period. This change cannot be attributed to climatological fluctuations, but is linked with the development of the population.[183] The increase in tree pollen is in step with a decrease in representation of cereals.

To sum up, the biotic landscape in the Roman Period can be divided into three phases.[184]

The first phase at the end of the Iron Age, shows a first increase in the values of tree pollen. The dates range from 2095 BP to 1890 BP. Possibly, this increase is connected with the introduction by the Romans of better agricultural techniques and less intensive stockbreeding. During the second phase, before the Late Roman Period, a further increase in the tree pollen values takes place. The dates are from 1830 BP to 1715 BP. The most likely explanation for it is the decrease in population density, while import of food may also play a part. The third phase at the end of the Late Roman Period and at the beginning of the Early Middle Ages shows a peak in the tree pollen percentages (and therefore a low in the non-tree pollen percentages). This has been established at various locations in the eastern river area between 1600 BP and 1315 BP. The population density is then at a minumum.

The reconstruction of the biotic landscape at the Roman bridge is by no means certain. If there was a (small) agrarian centre of production near the Late Roman bridge, to supply the population of the Castellum Ceuclum with food, for example, this agrarian activity would hardly have been perceptible in the overall vegetation pattern of the eastern river area. The palynological research locations at the bridge do not give any information about the Late Roman Period. For the reconstruction of the vegetation near the bridge there is no other option for the time being than to concur with the general pattern in the eastern river area. The pattern is basically as follows: of the tree pollen, ash is dominant with *c.* 40% of the pollen total. Then come oak with *c.* 11%, hazel with *c.* 3.5% and beech with *c.* 2.5%. The

179 Broertjes 1995, 2.
180 Mr W.J. Kuijper of the Archaeological Centre of the University of Leiden was kind enough to investigate the samples and to give us the preliminary results.
181 Teunissen 1990, 147–50.
182 Teunissen 1990, 150.
183 Teunissen 1990, 92–3.
184 Teunissen 1990, 154.

other species of tree are below 1%. The total of all tree pollen is around 60% in the Late Roman Period and rises to 80% in the Early Middle Ages. Of the non tree pollen, the main representatives are cereals with an average of 2%, sorrel with 2% and plantain with 1%. In the course of the Early Middle Ages rye appears.[185]

5 TECHNICAL RECONSTRUCTION

5.1 *Reconstruction of the bridge*

5.1.1 Guidelines

Thanks to earlier research into Roman bridges, the method of building is largely known. The reconstruction that was made will be discussed in the order of building. The following steps will be dealt with:
- the cofferdam;
- the foundation piles;
- the framework of beams;
- the fill of the foundations;
- the cover of the foundations;
- the construction of the stone pier;
- the superstructure;
- the road surface.

This list makes it clear that a reconstruction of the find complex at Cuijk is hardly possible: *in situ* parts were only found of the foundation piles and (perhaps) the fill. A scientifically sound reconstruction will, by necessity, focus on the foundation and the rest will have to depend on a literature search.
One can also regard reconstruction as an added method of research and as a model on the basis of which new questions can be formulated. In practice it appeared that this procedure indeed led to new questions and to solutions which would otherwise never have arisen. This is frequently the case when three-dimensional objects are under investigation.
The following basic assumptions have been formulated in order to direct the way in which the data on the find material were supplemented;
- all data that cannot directly be derived from the finds in the Meuse must be substantiated by means of archaeological parallels;
- the final reconstruction must be structurally sound, independent of the archaeological data from Cuijk or from parallels;[186]
- data which cannot possibly be reconstructed exactly or approximately must be indicated by a minimum and/or maximum value;
- since the piles found have been carefully measured, all kinds of queries may arise as to the measurements in Roman feet in the foundations. For the reconstruction, a Roman system of measures was assumed, even where a random choice is concerned, as for example the height of the parapet;
- landscape information, as far as can be reconstructed for the Roman Period, should be indicative of the reconstruction of the bridge as a whole. After all, the bridge was made to fit the landscape;
- the water level in the Roman Period must have been of great influence on the design of the bridge. Oak is most resistant to rot both above and below water, but not in a changing environment. This must have been taken into consideration during the building of the wooden parts of the bridge. The lowest low-water and the highest high-water level in the Roman Period must therefore be included in the reconstruction.

5.1.2 The cofferdam

A comparison of sufficiently preserved wooden bridge foundations from the Roman Period shows that these always had some sort of cofferdam around the foundation. Two techniques are known: a wall of beams laid on top of each other and sheet piling.[187] The latter technique is the most frequent. There are three reasons for the construction of a cofferdam. The first is to keep out soil during building so that mud and sediment do not wash into the future foundation. Second, the cofferdam encloses the stone and clay filling in the foundation after building and protects both foundation and pier from being undermined. Third, the cofferdam holds the entire foundation structure together so that it is not pushed apart by the weight of the stone pier.
The piles in pile group 2000 are driven in at very regular intervals. They are also so well preserved that it appears unlikely that only those piles which fit into the regular pattern have been preserved by chance.[188] Sheet piling would therefore be most unlikely.

185 Teunissen 1990, 152–3.
186 However fundamental it may be, the basic assumption that the reconstruction must be structurally correct has so far only been applied to the reconstruction of the Rhine bridge at Koblenz; see Schieferdecker 1981.
187 Kroes 1990.
188 In fact, the presence of piles could be predicted during the investigation once this regularity was discovered.

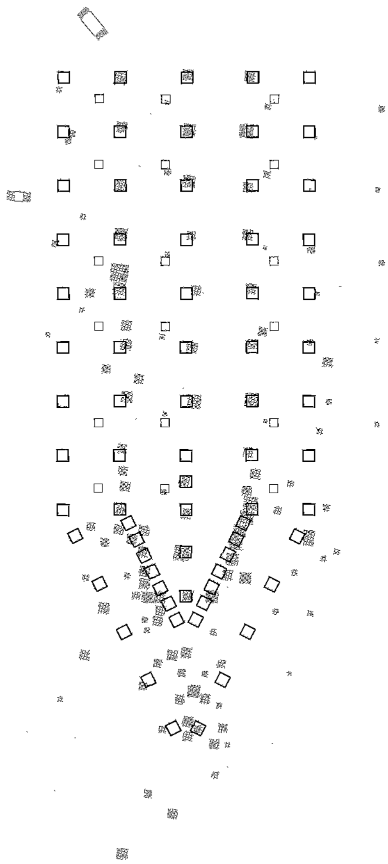


Figure 43 Plan of pile group 2000 with projection of pile-driving plan (see fig. 44)

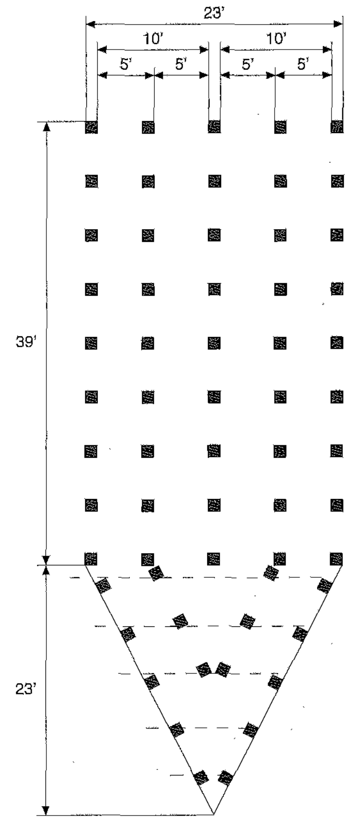


Figure 44 Reconstructed pile-driving plan of pile group 2000 with measurements in Roman feet.

The discovery of several beams in area 2000 supports the conclusion that the foundations at Cuijk had a cofferdam made of beams as was established earlier in Mainz.
In the reconstruction the beams were laid along the inner side of the outer row of piles. In this way the outwardly directed pressure which develops in the foundation due to the weight of the pier is diverted via the beams to these piles.

5.1.3 The foundation piles
The most completely preserved groups of piles in Cuijk are 2000 and 3000. For a reconstruction of the foundation plan these groups are taken as a starting point (see fig. 12). The pile groups 2000 and 3000 appear to have been arranged in five rows of heavy piles in the longitudinal direction of the pier (see 2.1). The most conspicuous in group 2000 are the three central rows of piles D, E and G. In particular, the fact that rows D and G on the upstream side appear to end in a point consisting of piles driven in close together makes one suspect that this was the foundation of the cutwater of the stone pier. The great regularity in the spaces in between the piles in rows D, E and G, the equal diameter of the piles and the central position within the entire group of piles suggest that this was in fact the foundation of the body of the pier. In pile group 3000 the three central rows (B, C, and D) also appear to be present, again in the middle of the concentration of piles. In this last group it was established that these three central rows had pile-shoes, whereas the two outer rows did not (see 2.1 and fig. 45).

On the basis of the excavation plan, a hypothetical pile-driving plan was drawn up in which rows of piles were set in a straight line as far as possible. This does not so much reconstruct the actual foundation but rather the Roman architect's draft pile-driving plan (figs. 43 and 44). Between the schematical pile-driving plan of the engineer and the excavation plan deviations may arise while pile-driving, during the 1600 years or so of the foundation's existence and while measuring during the excavation. With the help of the reconstructed pile-driving plan it was possible to find out how a possible framework of beams may have lain, but this will be discussed later. The foundation can be divided into a rectangular section and a section under the cutwater. The width of the rectangular part is *c.* 6.8 m. This is 23 Roman feet. More interesting, however, is the division of the pile-driving plan: starting from the central row of piles a division can be made into 5 and 10 feet which determined the positions of the rows of piles. One must not measure from the middle of the piles, though, but from one side. If the plan was measured out with string in advance, this procedure will have been more practical.[189] This pattern can be observed in both 3000 as well as in the somewhat asymmetrical group 2000. In pile group 2000, however, the middle row seems to have been driven in on the other side of an imaginary line. The length of the rectangular part is 11.6 m, about 39 feet. The distance between the cross rows does not work out in round feet. Two reasons for this can be put forward. Because there are nine cross rows, it is possible to drive in the two outermost rows of piles first, then a row in the middle, then two rows between the middle and the two outermost rows and finally four more in the spaces between the five rows already driven in.
Another possibility is that measurements were not made in feet but in palms (1 palm is 1/4 foot); the space between the cross rows measures *c.* 15 palms.[190]
In the cutwater of the foundation one can see the rows D and G clearly converging to form a point. This heavy pile foundation appears to be an added protection of that part of the pier which might be imagined as being most prone to erosion.[191] The angle formed by the longitudinal rows in the cutwater of the foundation with the rectangular section of the foundation corresponds to the angle encountered in the stone material, namely 65° (see 2.2.2.4).
In the piles around this point several cross rows have been reconstructed, always consisting of four piles, set at about 1 m from each other. This does not appear to be based on a measurement in Roman feet or any other units of measurement (fig. 44).

5.1.4 Pile-driving depth

Data on the depth to which the piles were driven in provide more information about the method used by the builders. The profile at right angles to the direction of the current of the piles in pile group 3000 shows a parabolic line of depths (see fig. 13). The piles were driven in to depths differing close to 2 m. The points of the piles follow the course of the top of a layer of coarse sand and gravel. The outermost rows of piles and the foremost piles are driven in deeper, while the piles more to the centre are standing in the highest part of the sand and gravel layer. The less deeply driven-in piles in the middle of the foundation also have pile-shoes, in contrast to the outer piles (fig. 45).
A number of conclusions can be drawn from this information. The fact that the points of the piles follow the sand layer makes it unlikely that the bank was formed by the counteraction of erosion by the foundation; one would then expect to find equal pile depths. Several shorter piles were not driven into the sand layer but still stood upright in the river bed. This shows that the layer of sand and gravel was allready buried in Roman times and is not the result of scour and fill in later times.
The sand and gravel layer is technically capable of bearing a load. The fact that the piles were driven in down to this layer indicates that the builders were aware of this and moreover, that they regarded the pile as an element which could transfer a load to firm layers of soil. There is a discussion in the literature about whether this kind of pile was known in antiquity. Several authors are of the opinion that in fact only the compression pile and the friction pile were known (see 3.1.1). A pile in the modern sense has never been recognized and is not found in classical texts either. Cüppers surmised on the basis of the varying length of

189 The use of string was demonstrated in Trier by the find, inside a cofferdam, of a wooden reel for builder's string. Cüppers 1969, 131, no. 8 and *Abb.* 148.

190 The center to center distance is therefore 19 palms.

191 In fact most erosion occurs at the downstream side of the pier. The best hydrodynamic shape for a pier therefore is with a rounded end at the upstream side and a triangular 'cutwater' at the back. The best shape the Romans had (*e.g.* the second-century bridge at Trier) was the exact opposite.

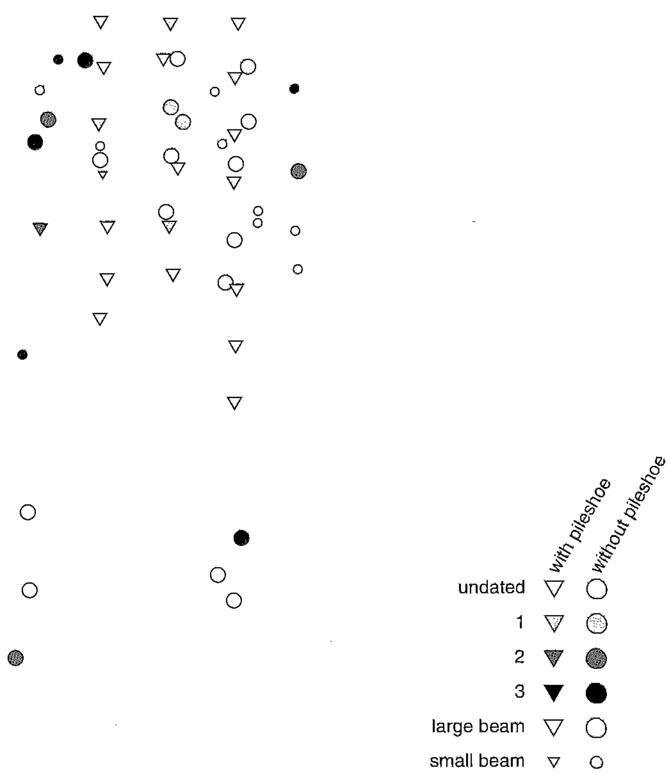


Figure 45 Plan of pile group 3000 with phasing and an indication of the presence or absence of pile shoes (scale 1:150).

piles and the soil profile that the piles in Trier followed the underground course of the supporting sandstone and loam layers, but was not able to demonstrate this.[192] This now appears possible with the finds in Cuijk and the assertion *daß die Römer Tragpfähle oder Langlastpfähle im modernen Sinne, also Hölzer, die soweit in den Boden gerammt werden, bis ihre Spitzen auch in größeren Tiefen liegenden festen Baugrund erreichen, nicht kannten*[193] would seem to be unfounded.
Whether the builders already knew the course of the underground layer of sand before they started pile-driving is unfortunately uncertain. Possible Roman methods of geophysical prospection are completely unknown, although one of Pliny's letters to Trajan and the latter's answer suggests that it was done and thought of as a separate, and necessary, activity that could be done against certain costs in preparation for building.[194] Familiarity with the subsoil is not the only possible explanation for the differences in depth. If the builders kept to the following three rules during pile-driving, the same pattern would have emerged:
1 piles of a standard length are made on the quayside;
2 piles along the edge of the foundation and not under the body of the stone pier, are not regarded as directly supporting and are therefore driven in without pile-shoes, irrespective of whether they reach a supporting layer or not (this could even have been an economy measure);
3 piles are driven in until they are 'finished' or until they strike a supporting layer. In the latter case, the surplus part of the pile is sawn off (the discovery of a 7.5 m long, apparently unused foundation pile in area 1500 could confirm this (see 2.1.2).

According to this hypothesis, the presence of a pile-shoe depends on the pile's position in the foundation, not on the soil, and the builders only become acquainted with the exact structure of the soil during building. Two observations might falsify this hypothesis:
– piles *with* a pile-shoe on the *out*side of a foundation which reach *into* a supporting layer;
– piles *without* pile-shoes *immediately under* the stone pier which do *not* reach a supporting layer and are not part of a repair phase.

Only this 'constraining evidence' could demonstrate a direct link between the availability of a supporting layer and the use of a pile-shoe. It would also establish the fact that prior to the building of the bridge the structure of the subsoil was already known, for a pile-shoe is of course attached before the pile is driven in.
Another point needs to be made concerning the depth to which the piles were driven in. In pile group 3000 no piles that supported the cutwater of the pier have survived. In Mainz it was precisely those piles that were driven in to a rather shallow depth. Furthermore they were used with the original tree top upwards, contrary to the rest of the piles in the foundation.[195] It is thought that this way of driving piles in was inspired by the idea

192 Cüppers 1969, 3.
193 Borrmann n.d., 25.
194 *Epist.* X, 90–91.
195 Cüppers 1969, 186.

that it would make the piles stand firmer. It fails to explain, however, why not all piles were driven in this way.

In Cuijk all piles that were salvaged had been used top-down, as is usual with rammed piles. If the piles under the cutwaters were driven in the same way as in Mainz, this would explain their absence in pile group 3000. The same piles did survive in the less disturbed pile group 2000. This hypothesis can (and should) therefore only be tested when the piles of pile group 2000 are salvaged in the course of some future excavation.

5.1.5 The framework of beams

In Mainz in the last century cross walls were found inside the cofferdam of the bridge foundations which probably served to reinforce the foundation (see fig. 37).[196] By attaching the piles to a framework of beams, individual piles were prevented from slanting after building, due to weight or other causes. Cofferdam and framework were built as a whole. The beams set on top of each other were also fixed together. As joints, slice joints, dowels and nails were used.[197]

Indications for a framework of this type in the foundation were also found at Cuijk. The method of pile-driving provides a first lead. The second is the beam from area 2000 which has an oblique cross lap joint at one end the angle of which fits well into the cutwater of the foundation (see fig. 17).

Between the piles of group 2000, twelve smaller piles are visible (rows C and F, see fig. 12). Together with a number of piles from rows D and E they form regular octagons in the plan. They are driven in to about 1.50 m (fig. 46). These small piles can be interpreted in different ways. The first possibility is that the piles belong to an earlier or to a later bridge; it frequently happens that bridges are built on the same spot in the course of time.[198] In view of the distance between the small piles and their size this must then have been a wooden bridge. The piles may also belong to the excavated foundation. They might then have been part of the foundation of a work floor. The thicker piles could have been driven in from this floor. However, it would seem unnecessary in this case for the piles to have a square cross section.

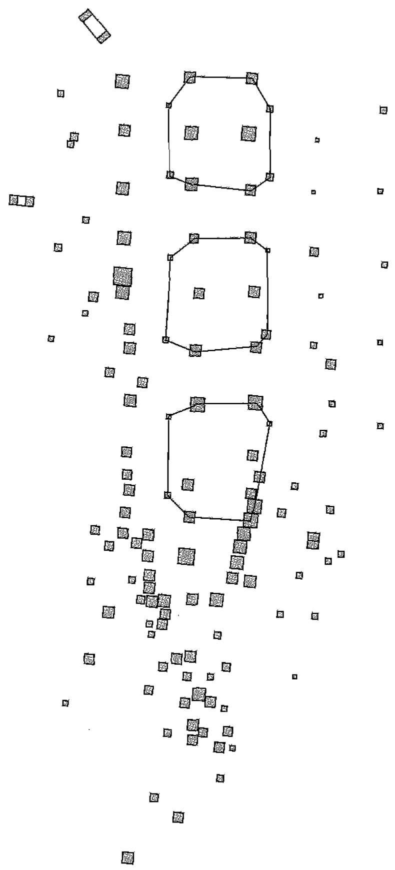


Figure 46 Plan of pile group 2000 with octagons drawn in (scale 1:150).

There is a third explanation. The small piles are always positioned diagonally opposite the closest large pile. In this way it is possible to fix the position of two cross beams with only two piles. The squaring procedure would then be more sensible because it makes it easier to join the beams and piles. In the reconstruction, a beam framework was made in combination with the cofferdam based on this 'fixing' principle (fig. 47).

For the missing construction wood in the foundation,

196 Börrmann n.d., 24.

197 Cüppers 1990, 467.

198 Something similar was observed at Trier (Hollstein 1980, 135), Palzem (Cüppers 1969, 177) and Geneva (Blondel 1933, 1938, 1954) where predecessors of bridges have been found, and in Trier (Hollstein 1980, 146 *Abb.* 57 and 149–50), where a successor was discovered.

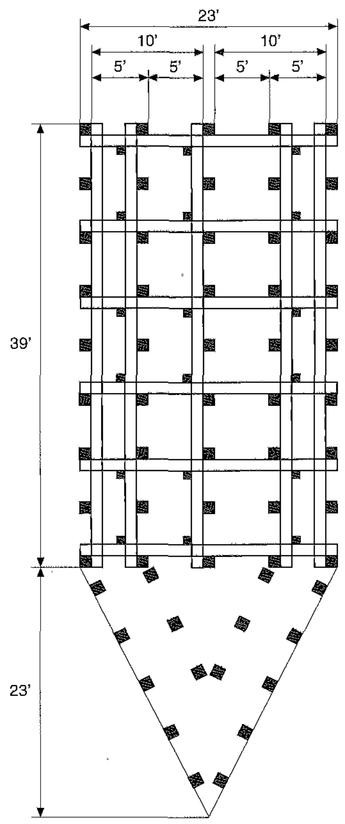


Figure 47 Reconstructed pile-driving plan of pile group 2000 with framework and cofferdam.

beams with a diameter of 1 x 1 Roman foot (*c.* 30 x 30 cm) were assumed, because this size corresponds best to the space encountered between the large and and the small fixing.
At the back of the foundation, the distance between large and small piles is somewhat larger. A rather thicker beam (*c.* 2 feet) may have lain here.
In Mainz a number of layers of beams were found on top of each other. In Cuijk it was no longer possible to establish whether several layers of beams were present, and if so, how many. In the reconstruction a minimum of two beams was opted for to indicate that, as in Mainz, there may have been more than one layer.

The nature of the joins used in Mainz make it impossible to build the framework 'outside wall first', after which the inside structure could be built. Instead every single layer of the framework had to be completed before the next could be built. Cofferdam and framework formed one single structure.

5.1.6 The fill

In the bridge foundations at Trier, Cologne, Koblenz and Mainz, fillings of rubble were found, sometimes combined with clay.[199] This would appear to have been common practice. During the excavation of the Meuse bed, a large quantity of irregularly shaped tuff was discovered between the piles, and only there. These were mostly lumps of 5 to 30 cm, but there were also rectangular blocks.
In the basin of the Meuse, there is no volcanic rock. The apparent conclusion is that tuff was part of the foundation packing. The nearest place where tuff occurs is the Eifel. In wet conditions tuff tends to cementate.[200] This probably explains the find of a quantity of cement-like concretions among the tuff. The mention of hard raised layers of tuff on the riverbed in 1752 may indicate that more of the filling of the foundations was still intact at that time (see 1.1.2, note 14)

5.1.7 The covering of the foundation

During the investigation of the first-century bridge in Trier, nails were found in the heads of the piles which can only be explained by the presence of beams on these piles. Cüppers reconstructed a covering layer of beams on the foundation, using a Roman bridge foundation in Hungary as a parallel.[201]
In his publication, Borrmann assumes that this layer of beams is unique for Trier, and that other bridges were built directly on the pile heads and the filling in between.[202] In doing so, he ignores two things. Other bridge foundations have not all been as well preserved as the Trier foundations and, moreover, they have not all been investigated as thoroughly. The absence of indications for a layer of beams in other bridges could easily be due to the find conditions and methods of research rather than to the absence of such a layer. Secondly, three considerations can be given why the foundations should be adequately covered:

199 Cüppers 1969, 42–4; Schultze & Steuernagel 1895, 140; Kraus 1925, 234; Schmidt *et al.* 1867, 4–5; Schneider 1880, 110.
200 Verbal communication Ing. Kurstjens, Technical University, Delft, 04-11-1993.
201 Cüppers 1969, 44 and note 97; 193–4 and *Abb.* 163.
202 Borrmann n.d., 24.

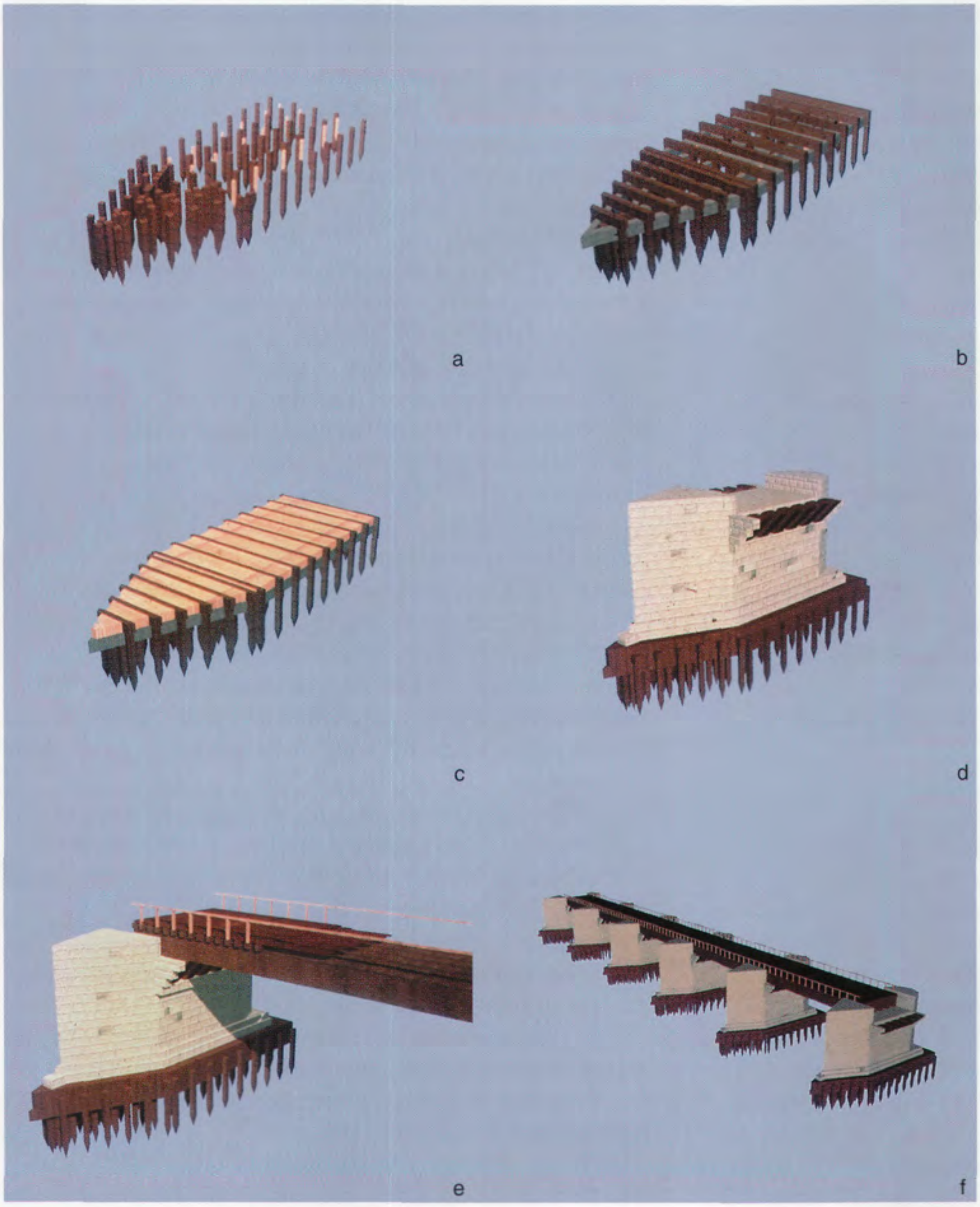


Plate 5 Three-dimensional reconstruction of a bridge pier in six steps. The purple stones correspond in size, shape and processing to the stones excavated. On the basis of these characteristics it is likely that they had a similar position in the original pier: a foundation piles; b beam framework and cofferdam; c wooden foundation mattress; d structure of the stone body of the pier; e the complete pier with road surface and parapet; f bridge of six piers.

– to prevent the stone filling between the piles from washing away;[203]

– to prevent separate stones from the body of the pier from subsiding if the filling in the foundation started settling;

– to distribute the weight of the pier as a whole more evenly over the piles.

This so called 'foundation mattress' would appear necessary in Cuijk. As a hypothesis, a covering made of two layers of beams was made in the reconstruction (see plate 5 and fig. 48). The first layer consists of beams placed on the piles in the transverse direction of the foundation. Filling wood was reconstructed between these supporting beams which is not supporting

203 The presence of the piers in the river causes a turbulent current which has an erosive effect that should not be underestimated. Engineers at the Technical University of Delft considered prevention of the erosion thus caused to be the first priority of any bridge builder.

because it does not lie on the piles but on the cofferdam and the beam framework. Because the supporting beams in this layer are further apart than the size of most stones, a second layer of longitudinal beams appears necessary, so that an optimal distribution of forces is attained. A second layer of beams which is capable of bearing a load is therefore laid over the first layer. It should be noted, however, that there are no archaeological parallels for this.
For the beams in this double floor a thickness of 1 foot was chosen, just as with all the other beams. The double covering is therefore 60 cm thick. How the layers of beams were attached to the foundation is of course unknown since they are hypothetical.
The Roman bridge engineers would have ensured that all the wooden parts of the foundation were permanently under water, and lower than the lowest low-water level. For the height of the foundation (expressed in NAP) it was assumed that the highest pile head (3.63 m NAP) was indicative of the original level of all the pile heads. The original pile head level has been established at 3.7 m NAP. Taking into consideration the hypothetical double covering layer, the foundation would then reach 4.3 m NAP.

5.1.8 The pier structure
On the basis of the reconstructed plan it is assumed that the stone pier rested on the three central rows (D, E and G in area 2000). A pier width of at least 3.30 m fits on these three central rows. This is very narrow compared to the narrowest known Roman bridge founded on wood. The piers at Palzem were probably 4 m wide with a span of only 10 m.[204] Judging from the span at Cuijk (around 19 m), a wider pier would seem more probable.
Hypothetical rounding up of the minimum dimensions was opted for. The piers at Cuijk have been made 15 feet wide in the reconstruction. The form of the pier has been reproduced in such a way that the rectangular part of the pier, *i.e.* without the cutwater and rounded end, is exactly 25 feet long. The angle derived from the piles in the cutwater of the foundation and the building stones found is naturally the same angle as that between the rectangular section and the cutwater of the stone pier.
The bridge piers were, in all probability, used as a stone quarry after the bridge fell into disuse. As a result most of the stones have disappeared and those left were no longer *in situ*. Nevertheless, in the light of the model of the pier, and based on the form, the surface treatment and the construction features it is possible to establish where and how a stone was placed. The original top surface of most stones can still be recognized and in a number of stones also the original outer side. In addition, several stones were found with an oblique side fitting the transition from the rectangular section to the cutwater of the pier. With these data a stacking plan was drawn up, using a number of guidelines:
- existing stones are not laid on or next to each other because it cannot be proved that they did actually lie on or next to each other, they are separated by hypothetical stones with sizes roughly corresponding to the sizes of the stones found;
- the stacking plan was arranged in such a way that in as few layers as possible, as many different kinds of stones are fitted, especially those with traces of unusual processing;
- these layers of stones are constructed in such a way that butt joints do not run into each other;
- a precision of 2.5 cm was maintained.

When drawing up the plan, the first guideline could not be fully sustained. Laying stones, which had actually been found *ex situ*, on top of and next to each other was therefore not avoided but kept to a minimum.
Because only few building blocks have survived that show signs of joints it was suspected that only the outer shell of building blocks was jointed, so as to function as a kind of revetment. The reconstruction therefore shows regular blocks on the outside of the pier and more irregular blocks and spolia stacked on the inside without being jointed.
This method of construction is conjectural, but a parallel for the same line of thought can be found in the east abutment of bridge 2 at Chesters where the stones along the outside were joined by long tie bars.[205]
Another parallel is the Roman all-stone bridge over the Köprüçay (Eurymedon) in present day Turkey. The piers of this bridge were clearly constructed in two distinct parts: the outer shell of building blocks and the inside filling of concrete.[206] Divers recovered some iron tie bars from the river bed which had a standard length

204 Cüppers 1969, 177 *Abb.* 152 and 178.
205 Bidwell & Holbrook 1989, fig. 15 and plate 2.
206 Grewe *et al.* 1999, Abb. 5.

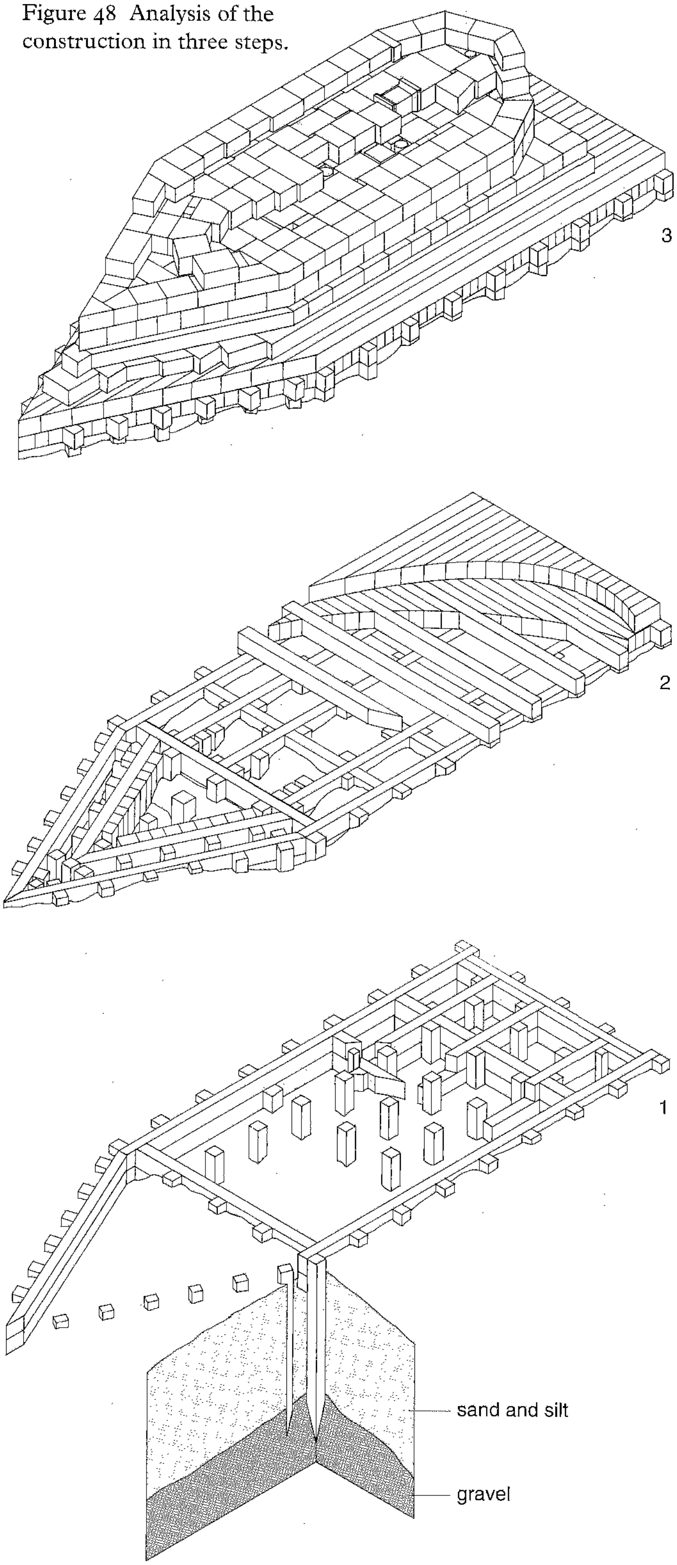


Figure 48 Analysis of the construction in three steps.

and were provided with hooks and rings with which they could be fixed to one another, thus forming a chain.[207] The slots in the building stones needed for these tie bars were not found, but – unfortunately – assumed on the basis of the same Chesters bridge 2 mentioned above.[208]

The stacking plan consists of two complete and two incomplete layers of stone and was drawn to a scale of 1:50 (fig. 48). Naturally it is not a true reconstruction but an illustration of the functions of the very different types of stone and traces of processing. The findspot of the stones was not taken into account: the stacking plan consists of stones from various piers. The first few stone layers of the piers in Trier consisted of irregularly finished stones which do not form a true pointed cutwater and a rectangular back. These layers probably lay under the river bed or under rubble. The stacking plan for the piers at Cuijk has two of these irregular layers (fig. 48).

The further structure of the pier is regular, with a cutwater and a kind of rounding at the back. A pier with a rectangular back placed in a river is a bad design. The turbulence which develops behind a rectangular pier would cause considerable erosion which would weaken the pier. However, indications for a rounded back, as in Trier, have not been found. As a compromise, a segmented back was opted for in the reconstruction. With the angled stones found, a reasonable rounding could be achieved in four 'facets'. It is quite possible though, that the piers had a cutwater on both ends, as in Zurzach (see 3.1.6).

At the top of the pier a stone corbel and protection for the supporting shores of the wooden span was made, as observed by Cüppers in Trier but, unfortunately, not in Cuijk (see plate 5).

5.1.9 Height of the piers

The Roman engineers will have made sure that the wooden parts of the superstructure of the bridge were permanently above water (higher than the highest high-water level). An estimate has been made, based on sedimentation data (chapter 4) of the level of the highest high water in the Roman Period. Starting from this level, the left pier has been drawn in figure 49 with the minimum pier height necessary to keep the wooden superstructure above water.

The probable height of the bridge can also be

207 Grewe *et al.* 1999, 3 and *Abb.* 8–10.
208 Grewe *et al.* 1999, 12, note 5.

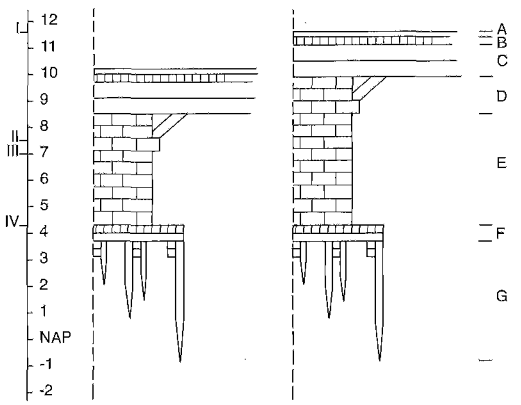


Figure 49 Reconstruction of the height of the bridge (scale 1:200). Legend: A road surface; B rafters; C bridge girders; D shores; E pier; F foundation mattress; G foundation piles, cofferdam and framework.; A–D superstructure; F–G foundation; I average land surface in Roman Cuijk; II highest high water level around AD 350; III average high water level around AD 350; IV lowest low water level around AD 350.

calculated from the ground level of the former castellum Ceuclum. From the documentation of the excavations at the site of the castellum in the 1960s, an average ground surface level can be derived of *c.*11.6 m NAP. The right pier in fig. 49 corresponds to this ground level. Because it is not likely that the bridge was higher than the ground level in the castellum, this must have been the maximum pier height.
Two heights of piers were reconstructed: a minimum pier with the bridge deck at 10.2 m NAP and a maximum pier with the bridge deck at 11.6 m NAP. In the minimum pier, the space between the underside of the girders and the maximum level of the average high water is only one metre. This space appears to be too little, because at high water tree-trunks and ice-floes are carried along by the river. Such objects can cause a serious obstruction with catastrophic consequences for the bridge.
Another consideration is the difference in height (4.6 m) between the two banks of the Meuse in the Roman Period. The top of the east bank is 7.0 m NAP which is 3.2 m lower than the bridge deck with a minimum pier height and 4.6 m lower than the bridge deck with a maximum pier height. In both cases an access bridge or incline is necessary. If the bridge continued as far as the X-terrace situated 300 metres east (7.5 m NAP), the difference in height is 2.7 and 4.1 m respectively compared to the minumum and maximum bridge deck levels. The access from the X-terrace to the minimum bridge deck level would then have a gradient of 0.9%, and the access to the maximum bridge deck level 1.4%. In figure 50, two variants are shown. It is, of course, quite possible that a dam continued the incline further inland so that it could be built at any angle of slope.
To sum up, the following can be concluded about the height of the piers (and therefore the height of the bridge): the bridge deck of the Roman bridge over the Meuse was no lower than 10.2 m NAP and no higher than 11.6 m NAP. The lower option is less probable because it does not fully exclude the risks. The higher option has the advantage of connecting with the level of the castellum. With the high as well as the low option, a difference in height arises on the east bank. This finally results in low gradients in both cases (from the X-terrace)

5.1.10 Construction of the superstructure
The centre to centre distance between the foundations measures 19.2 m. With a (hypothetical) pier-width of 15 feet this would produce a span of 50 feet. Finds of Roman bridge remains in Northwest Europe indicate that most bridges from this period had a wooden span. Voussoirs are hardly found anywhere, also not in Cuijk. A wooden span is not only quicker and cheaper to build, but in times of emergency it is quicker to demolish. This was regularly done in ancient times.[209]
Two possibilities for a wooden span can be opted for in the reconstruction: a wooden vault as depicted on Trajan's column,[210] or a construction consisting of straight bridge girders which are supported by shores fixed in the piers. This construction was demonstrated in the second-century bridge in Trier. The first possibility is by far the most elegant. However, from the stylized representation on Trajan's column several constructions can be derived.[211] They all have in common that they are complicated structures (see fig. 38). A construction

209 Dio Cassius LXVIII, 13, 1–2 and 6; Polybius VI, 55; Livius II, 10.
210 Scene no. XCIX (Lehmann-Hartleben 1926).
211 Kraus (1925, 241) makes an attempt as does O'Connor (1993, 144).

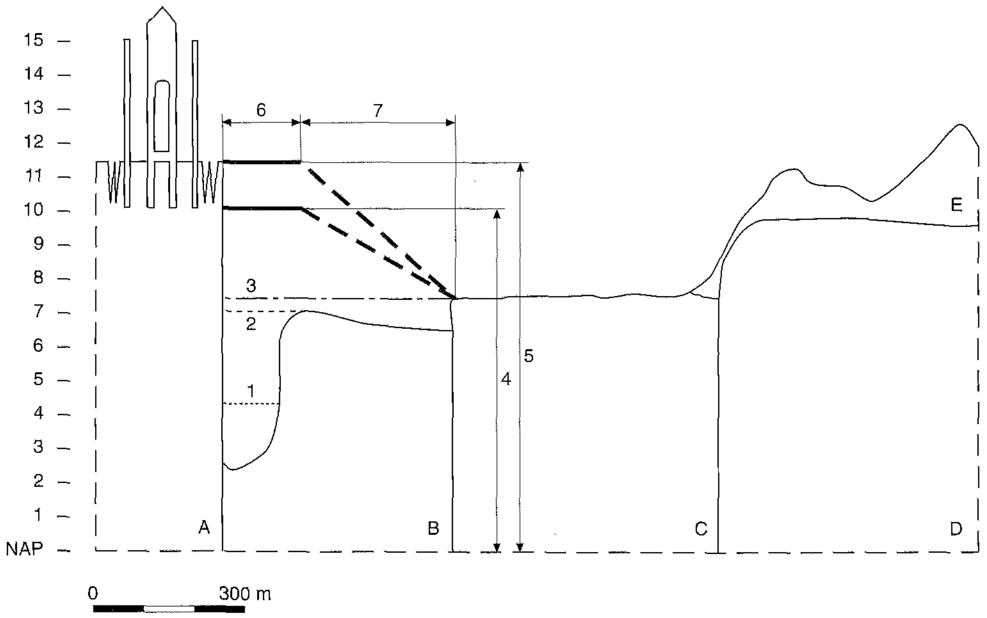


Figure 50 Minimal and maximal dimensions of the Late Roman bridge based on the combination of archaeological and geological data (vertical exaggeration 67x). Legend: A high terrace; B pre-Roman bed and bank deposits; C X-terrace; D low terrace; E river dunes; 1 average lowest low water level around AD 350; 2 average high water level around AD 350; 3 highest high water level around AD 350; 4 minimum height of bridge (see fig. 48); 5 maximum height of bridge (see fig. 49); 6 demonstrated length of the Roman bridge; 7 probable continuation of the bridge or approach. The slopes drawn actually have a gradient percentage of 1.4 and 0.9 degrees.

like the one in Trier would appear most feasible. It does require enormously thick beams, but the construction is extremely simple. It seems more suitable for the turbulent late fourth century.
To be strong enough, the beams would have to be about one-twelfth to one-tenth of the length of the span. The reconstructed span is roughly 15 m. It is shortened by the shores at both ends of support. These supporting shores have been given a hypothetical height in the same ratio to the span as in Trier: 1.5 m or 5 feet.[212] The effective span is thus 3 m less. From the remaining 12 m the thickness of the beams can be deduced: *c.* 1.20 m or 4 feet. An oak tree with the required girth for this thickness is difficult to find, but the same effect can be achieved by laying two thinner beams on top of each other and joining them with dowels, so that the beam behaves as if it were one whole.[213] The required length (12 m) can be obtained quite easily with oak trunks.[214]
In the reconstruction, six bridge girders and shores were assumed, the same number as was observed in Trier (see plate 5).

5.1.11 The road surface
The basic assumption is that the road surface lay level on top of the bridge. This means that all the piers extended to the same height.
On the bridge girders, rafters were placed crossways. Their cross-section measures 1 x 1 foot. This somewhat random size was prompted by the idea that this gave the best chance of getting the rafters and any possible parapet symmetrically aligned with the piers, since the measuring in the reconstruction is done entirely in feet. From the point of view of strength, this size would appear to be more than sufficient. On the rafters a double layer of planks was laid crossways, to ensure an optimal distribution of load. To complete the picture a parapet was placed on the bridge, 4 feet high (*c.* 1.20 m), consisting of sections also 4 feet wide. This kind of construction can be seen in almost every contemporaneous depiction of Roman bridges.

5.1.12 The length of the bridge
The maximum length of the bridge is 450 m. This is the width of the Meuse valley at Cuijk in the Roman

212 The supporting struts in Trier are 2.13 to 2.40 m high with a span of *c.* 22 m. This is a ratio of roughly 1:10. With a 15 m span the struts would be 1.5 m high.
213 Two horizontal beams of equal diameter lying on top of each other without any joints can only take twice as much weight as one beam. One beam made up of two beams on top of each other joined with dowels can, however, support four times as much because it behaves as a whole. Cüppers also reconstructs the horizontal beams of the bridge in Trier, which are 1.20 m thick too, as two superimposed beams joined with dowels.
214 Schieferdecker 1981, 321.

Period. If a regular distance between piers of 19.2 m is assumed, a bridge can be reconstructed with a bridgehead on the Cuijk side and 24 piers. However, it is not known whether a different construction was used beyond a certain point in the gently rising valley on the Mook bank. A dam would not be inconceivable in that part of the valley which was rarely under water. Between areas 4000 and 500 there is a distance of 120 m. It is reasonable to assume that the bridge continued from area 4000 as far as the castellum. This is a distance of 30 m. The archaeologically demonstrated length of the bridge is therefore 150 m. A minimum of eight piers and one bridgehead with the pier spacing indicated is therefore certain.

5.1.13 A golden section?

In the measurements of the bridge a number of regularities can be discovered which, though they may be coincidental, are too interesting to go unmentioned. The distance from pier to pier is 65 Roman feet. The rectangular part of the pier foundation measures 39 x 23 feet and the cutwater is 23 feet in length. When marking out these measurements it might be more useful to round them off to 40 and 25 feet. One then has a one-foot wide strip around the entire foundation which can be regarded as a working or measuring space, or where perhaps extra beams were placed. This is, of course, hypothetical. The rounded-off measurements of the foundation are then 25 x 65 feet, with a cutwater 25 feet long and a rectangular part 40 feet long.
The ratio of these three main figures (25–40–65) is 5:8:13.[215] Both 5:8 and 8:13 are considered workable approximations of the so-called golden section, a ratio which divides lines in such a way that the ratio of the short and long sections is equal to the ratio of the long section to the whole line. This ratio is frequently used in classical architecture.[216]
An expansion of this hypothesis is shown in figure 51. Within a basic square of 65 x 65 feet two strips of 25 feet can be added to the left side and to the base. In the strip on the left a rectangle of 25 x 40 feet is thus produced, the rectangular part of the foundation, with below it a square of 25 x 25 feet into which the cutwater fits. By placing several of these rectangles side by side a plan develops for the foundations of the entire bridge. However well these proportions may fit, there are so many steps between what was found and this design on paper that it would be inadvisable to draw any far-reaching conclusions from them.

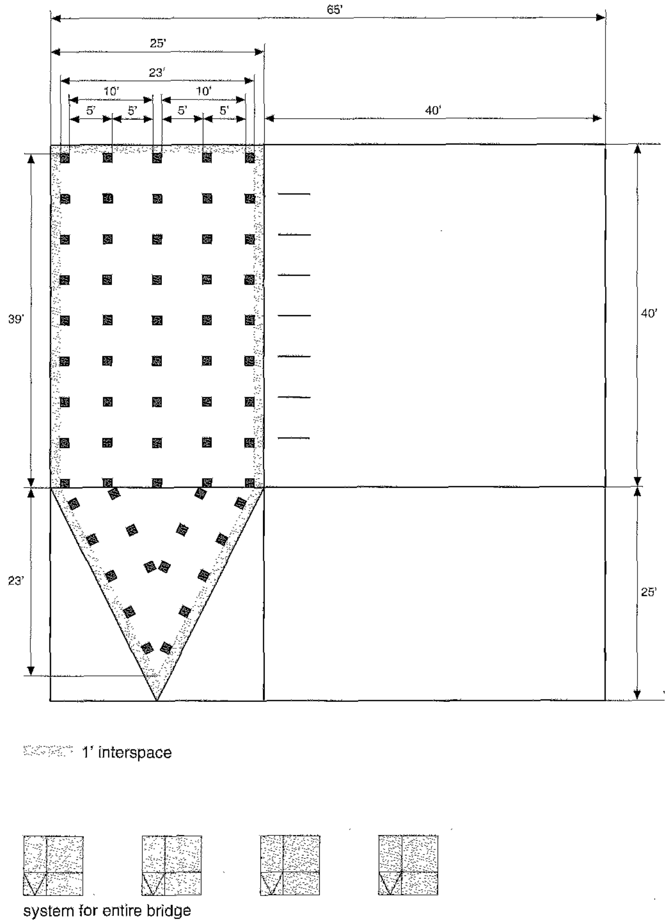


Figure 51 Measuring scheme of the foundation according to the golden section. Measures are in Roman feet.

215 Expressed in a 5-foot measure (*passus*) it even literally comes to these figures.
216 The ratio can be approximated by Fibonacci's series of numbers; this starts with 0 and 1 and each successive number is the sum of the two previous ones:
0 1 1 2 3 *5 8 13* 21 34 55 89 144 233 377 610 987 1597 *etc.* Any two consecutive numbers are an approximation of the golden section, with the approximation becoming more precise as the numbers in the series become higher. The actual ratio is $1:\sqrt{1^1/_4}$.

5.2 *Use of materials*

5.2.1 Introduction

The construction of the bridge at Cuijk entailed a considerable demand on the resources available. For wood, forests had to be cut down, and for stone, buildings were demolished. In addition, considerable numbers of people were engaged for some time on the construction, supply of materials and the logistic organization. To get an idea of the size of the building project calculations can be made of the use of materials. The starting point is the reconstruction as explained in the previous chapter.

5.2.2 Wood

According to the reconstructed pile-driving plan, the foundation of one pier comprised 71 heavy foundation piles and an estimated 18 smaller piles. Apparently, more piles were deemed nescessary, for in pile-group 2000 as much as 139 piles were discovered. The difference cannot only be interpreted as deing caused by repairs.
In order to estimate the total amount of wood used, a total of 100 piles was assumed, of which 80 heavy piles and 20 smaller piles. The foundation piles are 3 m long, on average, and the smaller piles 1.50 m. With a thickness of 30 cm for the foundation piles and 20 cm for the smaller piles, the former require 21.6 m^3 and the latter 1.2 m^3 of wood. The total length for all piles is 270 m, 240 m for the foundation piles and 30 m for the smaller piles.
According to the reconstruction, a framework of beams can be assumed to require 135.65 linear metres of wood per layer.[217] With two layers, the minimum, this would be 271.3 m altogether. With the same thickness for the beams as for the foundation piles, 24.4 m^3 of wood is required.
In the reconstruction of the Cuijk foundation, two layers of beams were opted for as a foundation mattress. The first layer includes a great deal of filling wood which is not load-bearing. For this reason only the load-bearing beams are taken into consideration plus a beam along the edge of the foundation. These are nine beams of 6.8 m and six beams in the cutwater of 6.8 x 0.5 m which is 81.6 m together. The beams along the edge are 2 x 11.53 + 2 x 7.6 (in the cutwater) = 38.26 m long. The total length of 119.86 m implies 10.79 m^3 wood with a thickness of 30 cm.
With a width of 6.2 m, 21 beams with a cross-section of 30 x 30 cm are needed for the second covering layer.[218] The average length of the beams is 11.53 + 0.5 x 6.8 = 14.93 m. The 28.22 m^3 of wood required for this measures 313.53 linear metres.
For the span, six bridge girders 1.20 m thick and 60 cm wide are required.[219] The 1.20 m is attained by laying two beams of 60 cm square on top of each other and joining them with dowels. For this, 12 beams 19.2 m in length are needed. That is 230.4 linear metres altogether, or 83 m^3 of wood.
For the rafters, the standard beam of 30 cm was taken, and these were laid at 30 cm intervals. The minimum length is equal to the width of the road, 7.4 m. For 19.2 m, 32 of these rafters are required which is 21.3 m^3 of wood and 236.8 linear metres of beam.
For reasons of convenience the double layer of planks on top of the rafters is not taken into account.

5.2.3 Stone

For the reconstruction of the foundation, the inside measurements were estimated as follows: for the rectangular part 10.93 x 6.5 m,[220] for the cutwater 6.21 x 6.21 m.[221] The surface area of the space to be filled is 109.5 m^2. With two layers of beams in the beam framework there is 60 cm in height to be filled. By comparison: the filling at Trier was 80 cm thick, and at Mainz at least one metre. This is therefore a conservative estimate, if not a minimum. The space to be filled therefore measures 65.7 m^3. Because part of the space is already taken up by the beams (24.42 m^3) only 41.28 m^3 is required for the fill. Assuming that the filling material originally consisted of tuff (1600 kg/m^3) we arrive at 66 048 kg.
According to our reconstruction, the stone piers measure 14.05 by 4.44 m with a minimum height of 4.2 m. The cutwater is 4.44 m long and the rear is assumed to be rounded. This gives a surface area of a

217 Per layer five beams of 11.53 m length (57.65 m), seven beams of 6.8 m width (47.6 m), and four beams of 7.6 m in the cutwater (30.4 m).
218 The width is exclusive of the outermost piles which take up a strip of 0.3 m: 6.8 - 2 x 0.3 = 6.2 m.
219 The number of six horizontal beams equals the number of (demonstrated) beams of the second-century bridge at Trier.
220 In the width, twice 0.3 m was deducted for the strip of piles. In the length only once 0.3 m, for the piles at the rear.
221 Twice 0.3 m was deducted both in the width and in the length.

Table 4 Quantities of stone required.

	1 pier		8 piers		24 piers	
	tons	m^3	tons	m^3	tons	m^3
building stone	550.36	211.68	4402.88	1693.44	13 206.64	5080.32
tuff	66.05	41.28	528.40	330.24	1585.20	990.72
total	616.41	252.96	4931.28	2023.68	14 793.84	6071.04
number of average size stones	1003		8024		24 072	

	1 pier	8 piers	24 piers
iron			
pile-shoes	240 kg	1 920 kg	5 760 kg
clamps	456 kg	3 648 kg	10 944 kg
total iron	696 kg	5 568 kg	16 704 kg
lead	520 kg	4 160 kg	12 480 kg
total metal	1 216 kg	9 728 kg	29 184 kg

Table 5 Quantities of metal required.

	1 pier	8 piers	24 piers
piles	270.00	2 160.00	6 480.00
beam framework	271.30	2 170.40	6 511.20
layer 1	119.86	958.88	2 876.64
foundation mattress	313.53	2 508.24	7 524.72
arch	230.40	1 843.20	5 529.60
rafters	236.80	1 894.40	5 683.20
total	1 441.89	11 535.12	34 605.36

Table 6 Quantities of wood required in linear metres to be worked.

pier of 50.4 m^2. The amount of stone needed for a 4.2 m high pier is 211.68 m^3.

Sandstone weighs approximately 2600 kg per m^3. A pier therefore weighs 550 368 kg. With an average stone of 80 x 60 x 44 cm (0.2112 m^3) *c.* 1003 stones are needed per pier. The total surface area of stone at 2.188 m^2 per stone comes to 2193 m^2.

5.2.4 Metal

At a rough estimate, about 40 foundation piles in the centre of the foundation had a pile-shoe. These weigh *c.* 6 kg. For one foundation therefore *c.* 240 kg of iron is needed. For the bar clamps a clamphole of 14 cm length, 2 cm depth and 4 cm width was assumed. The hooked part is 4 cm long and 4 cm deep.[222] For the clamps, a bar 2 cm square and 28 cm long was assumed plus twice 4 cm for the hooks.[223] An iron clamp therefore weighs 1.14 kg.[224] In the clamp sockets there is still room for 1.3 kg of lead to be poured in to secure the iron clamp.[225]

Since not so many stones with clamp sockets were found it would appear that only the outer stones were fixed together with clamps. The circumference of the pier (31.75 m[226]) divided by the average length of a building stone (80 cm) produces roughly 40 stones along the outside of a layer of stone, and therefore 40 clamps. At 4.2 m height and a stone layer 44 cm thick on average, *c.* 10 layers of stone may be assumed. The total number of clamps then comes to 400. These joints require 456 kg of iron and 520 kg of lead.

5.2.5 Quantities for the entire bridge

The number of piers of the Roman bridge over the Meuse is unknown. A minumum of eight piers and a maximum of 24 piers is assumed. Because the river probably had a fairly constant depth at the site of the

222 A joint consists of two clamp holes with a clamp. Two clampholes measure 356 cm^3.

223 In total 144 cm^3.

224 Assuming a density of 7.9×10^3 kg/m^3.

225 356 cm^3 - 144 cm^3 = 112 cm^3, assuming a density of 11.3×10^3 kg/m^3.

226 2 x 7.39 (rectangular part) + 2 x 5 (cutwater) + $\frac{2.22^2\pi}{2}$ (rounding).

bridge the minimum height has been taken for all piers instead of estimating the individual height of each pier. The data calculated above provide the following picture of the materials that would have been required. The quantity of stone for one pier would nowadays fill a freight train of 12 wagons with a length of 240 m (table 4).[227] For eight piers, 90 wagons (1.8 km) would be needed and for 24 piers 269 (5.38 km). The trains would need 1, 3 and 5 standard Dutch electric locomotives respectively to get them moving.[228] From the quantity of stone needed for 24 piers, at least nine railway platforms of minimum Dutch standard size could be built.[229] Suppose we take the total mass of iron and lead required (29 184 kg, table 5) as being only iron. Then 540 m of rail can be made of that, which means 270 m of railway track.[230]

With the number of linear metres of wood required for 24 piers (almost 35 km) 8.6 km of railway track could be provided with sleepers (table 6).[231]

5.3 *Building time*

5.3.1 Method

On the basis of the materials used, an estimate could be made of the building time. Such calculations have been done twice previously. The building time of the wooden Rhine bridge at Koblenz (Germany) was calculated on the basis of a number of data on Caesar's Rhine bridge, for which the total building time is known.[232] For bridges with a similar construction to the Roman Meuse bridge one must consult Cüppers' publication on the bridges in Trier. The first century bridge in particular is of importance here. Cüppers makes use of a number of estimates and assumptions to calculate the total number of hours it must have taken to build the bridge. With this number, 515 452 hours in total, he concludes that the first-century bridge (seven piers) could have been built by 200 men in 257 days, at any rate within a year.[233] Most time is taken up by pile-driving and stone-dressing. For the second-century bridge, which was founded directly on firm ground with the help of cofferdams, Cüppers arrives at 180 735 hours. For this, 100 men would have been busy for about 180 days.[234] These results appear very low. Cüppers' calculations do not take into account those activities connected with quarrying the materials, organization, logistics, transport and assembly. He only estimates activities connected with the manufacture of bridge parts and those which are carried out on the construction site itself.[235] It is clear that the activities which have not been included are the most complex ones and the ones which, moreover, show a high degree of interdependence. When more of these activities are included, the number of variables to be estimated and assumed becomes disproportionately greater.

The activities used by Cüppers have the advantage that they can be estimated with only few assumptions and that they are comparatively independent from each other. Although only estimating the basic hours required to manufacture the building material has the disadvantage that it has little to do with the reality of construction and it is not an accurate indication of the building time, it does however provide a measurable and (especially) a comparable estimate of the amount of work entailed because the number of variables is kept to a minimum.

227 Assuming 55 tons maximum load per wagon and a total wagon length of 20 m. Thanks to Mr Doorneboom, NS Cargo.

228 Assuming a total weight per wagon of 80 tons and an electric locomotive of 4.5 megawatt power. Thanks to Mr L. Reijnders, NS Railinfrabeheer.

229 Assuming 80 cm height, 3 m width and 250 m length. Thanks to Mr M. Cuijpers, V. d. Worp, Almelo.

230 Assuming the standard rail IC 54, which weighs 54 kg per metre. Thanks to Mr Dirks, Volker Stevin Rail and Traffic Contracting BV, Baarn.

231 The standard Dutch sleeper is *c.* 2.4 m long. Under one kilometre of track there are 1667 sleepers. Thanks to Mr Dirks.

232 Mensching 1981; Caesar, *De bello Gallico* IV, 17–18, 1.

233 Cüppers 1969, 212–5 and 160.

234 In his calculations there are a few minor errors. After correction, the figures for the first-century bridge are 929 577 hours (work for 200 men during 480 days), and for the second-century bridge, 657 569.2 hours (200 men in 354 days). Cüppers' main conclusion that the bridge founded directly on firm ground takes about a third less working hours than the pile bridge therefore holds good. Kroes 1989, 155–6.

235 If we take one horizontal bridge girder as an example, Cüppers does not include the following:
- *outside the work site* raw material (tree-felling, removal of crown and branches), organization (which activites take place where?), logistics (food supply, tool production and supply), transport (from site of felling to building site);
- *on the work site* assembly (positioning of the beam in the bridge structure), logistics (hoisting possibilities, mode of transportation on the building site, food supply, shelter organization), ramming apparatus, *bottlenecks*, distribution of work, absence through illness, hold-ups due to bad weather.

	amount to be worked per pier in Cuijk	time required	Cuijk	Trier
piles	270 m	1.66 h/m	450.00	104.66
pile-driving	100.0 units	200 h/unit	20 000.00	50 000.00
framework	271.30 m	1.66 h/m	452.16	n.a.
fill	41.28 m^3	8 h/m^3	330.24	768.00
foundation mattress layer 1	119.86 m	1.66 h/m	199.76	n.a.
foundation mattress layer 2	313.53 m	1.66 h/m	522.55	670.00
stone processing	211.68 m^3	2 h/m^3	423.36	2700.00
surface dressing	1096.50 m^2	8 h/m^2	8772.00	54 000.00*
span	467.20 m	1.66 h/m	778.66	1714.26**
total			31 928.73	109 956.92

Table 7 Hours per pier.
* For the sake of convenience, Cüppers calculates with stones of 1 m^3. The stones used in Trier are indeed considerably larger than those at Cuijk.

** This figure is calculated by Cüppers for the entire bridge. To obtain the value for one pier, Cüppers' figure is divided by 7, which is the number of piers in Trier. In addition, Cüppers calculates the amount of wood needed for the horizontal beams twice in order to include the shores. In our calculations, the wood for the horizontal beams is only counted once, both for Trier and for Cuijk.

For this reason and for the sake of comparability, Cüppers' method of calculation is used for the Roman bridge over the Meuse.[236]

5.3.2 Basic assumptions
The following of Cüppers' estimates and assumptions are used. To drive in the piles, a pile rammer is needed which is operated by a number of people. Cüppers estimates that 20 men required about 10 hours per pile. Two hundred manhours per pile seems a great deal. In view of the number of blows which he assumes, Cüppers arrives at only one blow per two minutes. However, workmen cannot keep up the same effort for ten hours, and one must also allow for (measuring) breaks and the moving of the ramming apparatus.
As a measure of the time required for adzing the wooden beams Cüppers takes 10 hours per 6 metres of wood, 1.66 h/m.
From the building trade Cüppers derives the number of 8 hours per cubic metre of filling material for filling the foundation.
In Trier, an average of five sides per stone are assumed to have been dressed. For Cuijk, only three sides are assumed because most of the material was re-used. With a total surface area of all stones of 2193 m^3, the surface area of stone to be processed would be half: 1096.5 m^2. It would take 8 hours per square metre of stone to dress the surfaces, according to Cüppers.
For the cutting of things like clamp sockets Cüppers estimates 2 hours per cubic metre of stone.[237]

5.3.3 Results
With the figures estimated above, table 7 has been drawn up which, for the sake of convenience, is limited to the work required for one pier.[238]
It is clear that it took far less time per pier to carry out the activities calculated above for the bridge in Cuijk than for the first-century bridge in Trier. There are a

236 Bidwell & Holbrook (1989, 47–9) calculate the building time of Chesters bridge 2, a Hadrianic all stone bridge. Contrary to Cüppers they have tried to incorporate quarrying, transport and assembly, using American figures from 1909.
237 Bidwell & Holbrook (1989, 48) mention 2.276 days per m^3 of sandstone for 'preparing the blocks from quarry rough-cuts'. When using Cüppers' figures the average block Bidwell & Holbrook use (1.2 x 0.5 x 0.4 m, *i.e.* 2.56 m^2 and 0.24 m^3) would result in 20.96 hours of work (20.48 surface dressing and 0,48 other processing). The two figures amount to roughly the same amount of time (*c.* 21 hours) if we assume an eight-hour working day.
238 The figures in table 7 are based on the corrected figures of Cüppers from Kroes 1989, 155–6.

number of reasons for this. In Trier the number of piles per square metre is greater and the cofferdam is also made of sheet piling, whereas with the cofferdam at Cuijk which consisted of horizontal beams, a more labour-saving method was used. In addition, considerable time was saved at Cuijk by re-using stone. Both activities are by far the most time-consuming and for this reason in Cuijk only about half and one-sixth of the length of time estimated for Trier was required respectively.

5.3.4 Discussion

With all these calculations it should be noted that the piers at Trier are about twice as high as the minimum pier at Cuijk.

One may also question the assumptions made about the pile-driving activities. The piles at Trier were about 2.5 m long, whereas the average length at Cuijk is 3 m. The extra length of the Cuijk piles may have required a longer pile-driving time. On the other hand, the river bed at Cuijk is considerably softer than in Trier.[239]

A pile 30 cm square and 3.00 m long weighs approximately 270 kg. The pile-rammer should theoretically have the same weight as the pile. However, in order to set a pile-rammer of this weight in motion, twenty men would each have to pull 13.5 kg. In Trier the piles 2.50 m in length only weighed 225 kg.[240] This is only 11 kg tractive power per man. We could easily put 40 men (tractive power 6.75 kg/man) to work in Cuijk on a pile-rammer and thus double the number of manhours. Moreover we should remember that no allowance has been made for a considerable loss of tractive power due to the elasticity of the rope used, the friction in the pulley and so on.

But suppose another 20 000 hours of pile-driving and 9000 extra hours of stone-cutting per pier are counted. The construction of the pier would then take 29 000 hours more, making the total amount of time needed almost twice as long. Even in this latter case the time invested would still be well below that of Trier. This discussion does therefore not affect the conclusion.

It is clear that these kinds of calculations are extremely speculative. In the case of a simple activity such as pile-driving, for example, a whole series of tricky variables is involved: pile length and weight, firmness of the soil, firmness and depth of the supporting layer, the number of men engaged in pile-driving and the number of blows per minute. All this calls for caution before making all too enthusiastic use of the results of this kind of research.

5.4 *The reconstruction of the river bank structures (area 6000)*

The foundation piles in area 6000 possibly belonged to a quay or embankment. In January 1997, a brief investigation could be carried out due to the extremely low water level caused by a continuing period of frost. Samples were taken of the organic debris, borings made, piles measured and photographs taken, but further research is necessary (fig. 52). No investigation has been done into the depth to which the piles were driven in. On the basis of the tree-ring dating of phase A between AD 320 and 342, this quay may have been used during the construction of the bridge or it may have been part of structures connected with the building of the fort under Constantine I. It is not possible on the basis of four dates to define phase A more precisely. Although only two phases can be identified on the basis of the dates of the bank structures, the three rows of piles give the impression that the embankment has been adjusted at least three times. The two piles set at about 15 m from the bank could indicate an extension or dam into the river. It is uncertain what the function of the heavy beams projecting obliquely from the embankment was.

A second interpretation is also possible, namely that the cluster of piles was the foundation of an upstream extension of the castellum wall into the river, especially since the position of the piles is in line with the excavated south buildings in the castellum on the left bank. This might have been a continuing wall and tower as reconstructed in Ladenburg (fig. 53).[241] The deposition of pottery between the piles suggests a hiatus in the function of area 6000. The majority of the pottery dates from the first quarter of the fourth century AD, whereas there is hardly any material from the second

239 Cüppers 1969, 2–3 and *Abb.* 3 shows that the piles were driven through a layer of gravel into a layer of red, crumbly, weathered sandstone containing clay as well as quartz inclusions, or into a layer of red loam. He assumes the weathering is post-Roman.

240 Cüppers 1969, 212. However, he also mentions a diameter of 0.4 m. This would make the weight of the pile come to 400 kg. *Ibid.* 213, note 386.

241 Heidinga & Offenberg 1992.

Figure 52 Find area 6000 lying dry during the extremely low water level in January 1997 (piles have a card attached).

and third quarter. It is possible that in the first quarter of the fourth century some kind of bank structure or quay was constructed in this area and that there was a great deal of human activity on this spot, causing a large amount of pottery to be left. The structure was then renewed or repaired at least three times. In the second half of the fourth century, during the rebuilding of the stone fort under Valentinian I, a wall and a defence tower were built into the water. The area then changed its function, and the deposition of pottery is nil. Possibly in the period of the first construction of the fort under Constantine I, the access to the bridge lay outside the fort across the left bank in the vicinity of the quays and was later moved to a route through the fort under Valentinian I.[242]

An important element is the presence of a layer of organic debris of about 70 cm thick between the piles of the structure which dates to the Roman Period (see chapter 4). This organic debris could only be preserved in stagnant water, in this case behind the sheet piling of the structure. It is therefore probable that the Roman Meuse bank lay near pile rows 1, 2 and 3. The base of the organic debris along pile row 2 is at 4.44 m NAP which also determines the average low-water level of the Meuse in the Roman Period. An estimate had already been made of the average low-water level at 4.30 m NAP on the basis of the height of the bridge foundation (see 5.1.6). These two independent estimates correspond relatively well. The top of the organic debris is at 5.04 m NAP. There are indications that there was also a layer of organic debris behind pile row 3, but that this has eroded. It is possible that during each period of repair the sheet piling shifted slightly in the direction of the fort of Cuijk in response to the erosion by the river in the convex bend.

242 Results and publication of the excavations at Cuijk could shed more light on the matter, especially concerning the route of the road. Not much is known either about the buildings along the Meuse. Some of the remains there have been eroded by the Meuse.

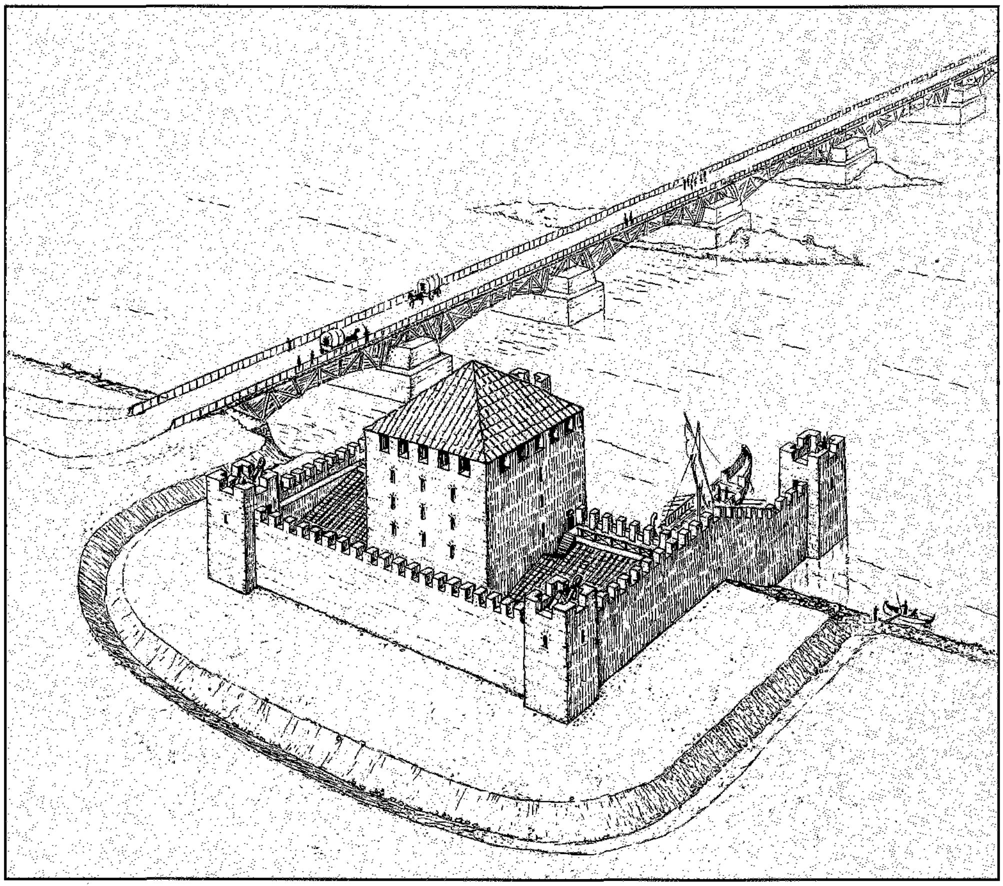


Figure 53 Impression of the castellum at Ladenburg (from: Heidinga & Offenberg 1992).

6 THE BRIDGE IN A HISTORICAL-GEOGRAPHICAL CONTEXT[243]

6.1 *The political and military developments in the delta of the Rhine and Meuse in the fourth century AD*

After the arrival of the Romans in about 15 BC, the history of the Rhine and Meuse delta was determined for five centuries by the troops stationed along the Rhine. The relation with the Germanic tribes on the other side of the Rhine was stabilized by means of treaties in the course of the first century AD. The peace which ensued enabled such a surplus of food to be produced in the fore and hinterland of the *limes* that the soldiers along the Rhine and the increasing urban population could be fed. The demand of the military and civilian population gradually led to the rise of large-scale farms (*villae*) in the *limes* hinterland. To get all necessities and raw produce to their destinations new roads were quickly built and existing roads were included in the new Roman infrastructure.

After the year 170, the peaceful coexistence between the Roman empire and the Germanic tribes across the Rhine came to an end.[244] Invading Chauci inflicted heavy blows on the population between the Rhine and the Seine. Moreover, there also appear to have been internal problems even within the *limes* in the same period. During the third century the continual Germanic invasions from the north and the incursions of Alemanni in southern Germany culminated in the fall of the *limes* shortly after the middle of the third century. Earlier, in about 260–270, the population in the south of the Netherlands appears to have abandoned its territory.

243 For a more detailed description of events, see Willems 1981 and 1984; Horn 1987.

244 Thoen 1991.

Two decades later, in 293, caesar Constantius Chlorus, with great military effort, again incorporated the lost territory in the empire.[245] The Lower Rhine area, the former province of Germania Inferior, was transformed into the new province of Germania Secunda. A start was also made on the rebuilding of a number of military fortifications on the Rhine. The son of Constantius Chlorus, emperor Constantine I (306–337), further reorganized the border defences.[246] After several comparatively peaceful years, there were again, according to the historical sources, invasions by Germanic tribes, called Franks, under emperor Constans (337–350).[247] The Romans were not capable of a powerful military defence and entered into a federation with several Frankish tribes, with the objective of stopping other invading groups, as *foederati*.[248] This policy was followed several times in later years.

The usurpation by Magnentius in 350 resulted in a period of great unrest which appeared to undo all the stability which had been built up since Constantius Chlorus. Parts of the Roman empire were lost as a result. Under Julian, who was then active as a general under Constantius II (337–361), Cologne (Colonia Agrippinensis) was recovered from the Franks in 356 and Strasbourg (Argentorate) from the Alemanni in 357. In 358 Julian repaired at least three forts on the Meuse and equipped them as depots for his further actions.[249] He also assured the Rhine troops of a good supply of corn by safeguarding the route from Britannia, via the Rhine. This was done by putting several forts along the river into use again, including Castra Herculis (Meinerswijk).[250] In 360, when Julian (360–363) is emperor, the Lower Rhine area again appears to be under Roman control and punitive expeditions are carried out east of the border, well into the Transrhenine territory.[251] Willems suggests that it was now, for the first time since the fall of the *limes* in the third century, that the border defence programme set up by Diocletian (284–305) and Constantine I fully functions.

Shortly afterwards, Julian leaves for the eastern part of the empire, and after a period of comparative quiet, the Frankish activities start up again. Valentinian I (364–375) attempted to check this danger by further reinforcing the existing defence systems on the Rhine and Danube. He had many new *castella* built on the border in 368–369, and had others, including the one at Cuijk, rebuilt.[252] Various new *burgi*, including that at Asperen, were built along the route Cuijk-Qualburg/Alt-Kalkar.[253] With more troops and quick counteractions the lines of defence in Germania Secunda functioned satisfactorily for a number of years.[254] Under his rule, the system of a defence in depth was further perfected (see 6.2).

It remained relatively peaceful for a long time – until 388. Then, according to the historical sources, there is again talk of a Frankish threat, but the Frankish general in Roman service Arbogastes quickly put things right in the Lower Rhine area.[255] From then on, an active *foederati* policy was pursued by Arbogastes and his successor Stilicho.[256] The settlement at Gennep was possibly founded by Frankish *foederati* as a result. It lay at a strategic point, close to the road from Cuijk to the Rhine, slightly south of the place where the river Niers flows into the Meuse.[257] As a result of this policy, the Romans were reasonably successful in frightening off potential intruders. The Frankish leaders made sure

245 De Boone 1954, 61; Willems 1984, 273–4.

246 Von Petrikovits 1971, 182–4; Willems 1984, 285. It is probable that Constantine I was the instigator of the building or rebuilding of the fortifications at Rossum, Maurik, Nijmegen, Malden-Heumensoord, Cuijk, Qualburg and Maastricht, among others.

247 De Boone 1954, 8281; Willems 1984, 276. For example, the former territory of the Batavians in the Betuwe (prov. of Gelderland) appears to have been occupied shortly after 340 by Frankish allies, possibly Salians.

248 De Boone 1954, 86–9 and 91; Willems 1984, 277. It is probable that the Frankish Salians had already inhabited the river area since 340. A treaty was possibly concluded with them under Constans.

249 One of them was very probably Cuijk; others may have been Kessel, Rossum, Lottum, Heel and Stokkum. De Boone 1954, 89–90; Willems 1984, 293.

250 Ammianus Marcellinus XVII 9 and XVIII 2, 3–6; Willems 1984, 195.

251 De Boone 1954, 96 and 99.

252 Von Petrikovits 1971, 184–7.

253 Hinz *et al.* 1968; Horn 1987, 430–1.

254 De Boone 1954, 107; Willems 1984, 278. Important is the mention of conflicts in this area by Ammianus Marcellinus (XXVIII 5, 1–8). Apparently there was a Saxon invasion at Deuson, the town of Diessen in the province of Noord-Brabant, where they were stopped by Salians who inhabited the area. Afterwards they were wiped out by troops which had hastened there from the hinterland.

255 De Boone 1954, 110–4.

256 Willems 1984, 279.

257 Heidinga & Offenberg 1992.

they were handsomely remunerated by the Romans.[258] The great breakthrough of the Rhine border at Mainz in 406 had hardly any influence on events in the Low Countries. Only after Britain had chosen her own way did the central river area of the Netherlands lose its strategic position as supply route for British corn for the Rhine troops. After 420 the Franks invaded the *civitates* situated between the Rhine and Meuse and assumed possession of them. In about 430, they were subjected by the Roman general Aetius, but as *foederati* they were allowed to retain the area. In the same period the Salians moved further south. Their king Chlogio succeeded in founding his own kingdom north of the river Somme. Other Frankish peoples also strived after their own land in Roman territory. Around the middle of the fifth century large groups of Franks crossed the Rhine. Cologne was conquered just before the year 459, and subsequently became the seat of a Frankish king. This meant the end of Roman influence on events in the Rhine and Meuse delta.

6.2 *The strategy of defence in depth*

The concept of defence of the Roman border underwent a radical change in the Late Roman Period. The static and linear defence tactics which had been so successful from the emperor Claudius until the third century, no longer guaranteed an optimal security of the border since the incursions by Transrhenine tribes began in the end of the second century. This forced the Romans to review their old, mainly frontal strategy. It was replaced by a defence system which, instead of a rigid line, consisted of a defensive zone behind the actual border, the Rhine, which proved more resistant, even to incursions deep into the hinterland. These changes had their repercussions on the organization of the army and the military infrastructure in the fourth century.[259] It is probable that the *castellum* and the bridge at Cuijk played an important part in the new concept of defence. Defence in depth also meant a revaluation of the regional infrastructure.

As a result of the alterations in the army and the system of command, the mobility of the army in the Low Countries was increased.[260] From the third century onwards more and more specialized units were added to the army, with the emphasis lying on cavalry.[261] The main reform consisted of a division of the army into two parts, each with a different task, the *limitanei* and the *comitatenses*. The *limitanei*, the static border troops, were stationed on the Rhine and on the coast. They did not, however, form the only line of defence, as had previously been the case. The forts on the Rhine occupied by *limitanei* formed strongholds. Their main task was to delay possible invaders for so long that a mobile intervention corps, the *comitatenses*, had enough time to advance to threatened spots. The border forts also served as supply stations for relief forces. The mobile army was stationed in strategically situated forts and fortified towns behind the existing border and were able to reach the threatened spots on the border quickly via the major roads.[262] In Germania Secunda a number of Frankish cavalry troops formed the core of the mobile corps. Defence was further increased by including Frankish population groups within the empire. They were allowed to settle immediately behind the border and were expected to defend their own territory.

This strategy of defence in depth formed part of the so-called 'grand strategy',[263] the first parts of which were possible already realised during the rule of Gallienus (253–268). At that time, the static army units were turned into mobile reserves as a reaction to the many border breakthroughs.[264] Under Diocletian the idea of a frontally directed strategy of defence from the *limes* was totally abandoned, and a deeper defensive zone behind the border was created. Constantine I implemented numerous organizational changes to the army from 312 on to perfect the system. Only after great efforts did this new system of defence achieve its full scale under Valentinian I.[265]

258 Willems 1984, 297–8, concerning the great gold hoards from the late fourth and fifth centuries which were discovered at Rhenen and Velp.
259 Willems 1984, 274–5.
260 Many have already studied this issue. The starting point for the study of the composition of the army in the Late Roman Period remains the *Notitia Dignitatum* containing the composition of the army in the time of Honorius, which may be regarded as a reflection of the changes throughout the fourth century. See also Brulet 1988; Luttwak 1976; Von Petrikovits 1971; Willems 1984.
261 Bechert & Willems 1995, 105–6.
262 Brulet 1988.
263 Mommsen 1889, 195–275.
264 Willems 1984, 274.
265 Willems 1984, 274 and 278.

6.3 *The bridge in relation to the routes at regional and local levels*[266]

6.3.1 Method and study area

The bridge at Cuijk had a function in the Roman infrastructure. The framework of this infrastructure was laid in the Early and Middle Roman Period. The road system comprised a whole range of road types: *diverticulae* (footpaths), *viae privatae* (private roads), *viae vicinales* (local roads), and *viae publicae* (public roads). The latter are the actual main roads which were built and maintained by the state, often for military purposes.[267] The most important routes in the Roman Period are shown in the Tabula Peutingeriana (see fig. 3).

Because Cuijk is embedded in a military network of forts and roads we should first examine a larger area which can be divided into three zones (fig. 54 and plate 6) before going any further. This area is bordered on the west by the line Nijmegen-Cuijk-Blerick, where there were several fortifications on the left bank of the Meuse which served as bases for sorties for the *comitatenses*. The *castella* were linked by a main road,[268] which ran from Blerick towards Maastricht and Tongres. Nijmegen – Noviomagi on the Peutinger map – is the most northerly place in this area and is situated on the transition between the Dutch Rhine and Meuse delta and the Roman hinterland. Here a fort was built on the present Valkhof in about 320, which was rebuilt in stone several decades later. Archaeological evidence suggests that the fort was in use until into the beginning of the fifth century.[269] Between Cuijk and Nijmegen the watchtower of Malden-Heumensoord was situated.[270] Along the Meuse there were a number of forts, the most northerly of which was Cuijk (Ceuclum).[271] Further south, between Cuijk and Lottum, we have no archaeological evidence. It is likely that there were also watchtowers at regular intervals of about 16–17 km along the Meuse, as there were along the Rhine.[272] Calculating the distance from Cuijk, one would expect to find the next fortification between Boxmeer and Vierlingsbeek, but no traces have been found. In Lottum there are indications for a Late Roman fortification.[273] Approximately 7.5 km further, increasing evidence is found on the left bank around Blerick (Blariacum)[274] and on the right bank around Venlo indicating intensive habitation in the Roman Period. There was probably a crossing over the Meuse here.[275]

On the east side the area is bordered by the line Nijmegen-Qualburg-Moers-Asberg. On the bank of the Rhine were the strongholds of the *limitanei*, which were also interconnected by a main road. Along the Rhine there were fortifications at Qualberg (Quadriburgium),[276] Alt-Kalkar (Burginatium),[277] Xanten (Trice(n)sima(e)),[278] between Xanten and Rheinberg (Calo)[279] and at Moers-Asberg (Asciburgium).[280]

There is archaeological evidence from the area in between, such as the remains of *burgi*, roads and bridges, on the basis of which a secondary road network can be assumed. This road system formed links between the main routes along the Rhine and Meuse and was guarded by soldiers in *burgi*. In the study area the following five secondary routes are assumed (see plate 6):[281]

1 Cuijk-Asperden-Alt-Kalkar;

266 Following Willems (1987, 7) the word 'route' is used for a reconstructed road: the line along which the actual road would have run. If the term 'road' is used, archaeological traces have been found. See also Willems 1981, 63–70.
267 Luys 1984, 107.
268 Between Blerick (Blariacum) and Cuijk (Ceuclum) traces of a supposed road have been found and documented in various places so that part of the route can be called a 'road'.
269 Bechert & Willems 1993, 70; Bogaers & Rüger 1974, 76–9; Van Enckevort & Thijssen 1996, 88–90 and 96–8; Willems 1984, 146.
270 Bechert & Willems 1995, 72; Bogaers & Rüger 1974, 81–3; Holwerda 1933. This small fortification (coordinates 188.320/422.740) possibly dates from as early as the third century and functioned until well into the fourth century.
271 Under Constantine I a fortification was built here which was rebuilt in stone by Valentinian. Bechert & Willems 1995, 72–3.
272 Bechert & Willems 1995, 109.
273 Bogaers 1987; Bogaers & Rüger 1974, 88; Willems 1984, 291–3.
274 Byvanck 1947, 66.
275 Haalebos 1993; Schotten 1993; Schotten 1995, 13–22.
276 This is probably one of the places which was fortified by order of Julian in 356. Bechert & Willems 1995, 63–4.
277 Bechert & Willems 1995, 63; Horn 1987, 452–3.
278 Bechert & Willems 1995, 50.
279 Bechert & Willems 1996, 49; Bogaers & Rüger 1974; Willems 1984, 292.
280 This *burgus* was built under Valentinian I (364–375). Bechert & Willems 1995, 49.
281 The routes to the north of Nijmegen have been discussed by Willems (1981, 66–70). They are not included in this study, nor are the connecting routes between the Meuse and Rhine south of Xanten.

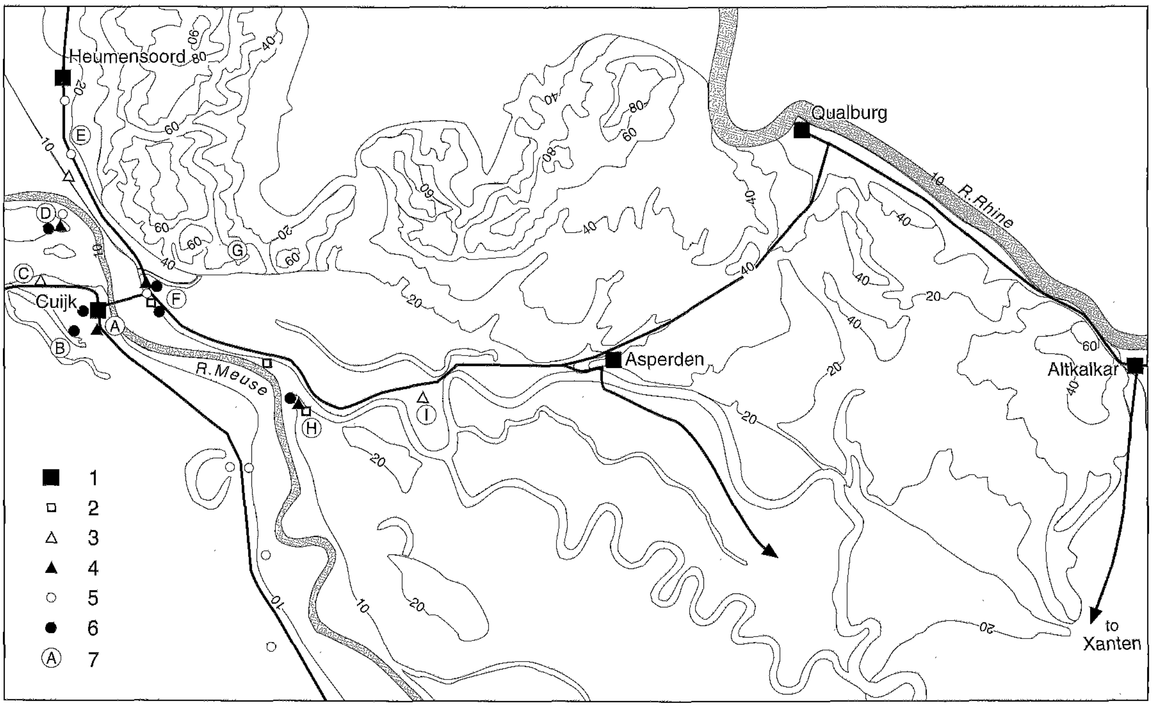


Figure 54 Contour map of the area between the Meuse valley and the Roman course of the Rhine, with local routes and major findspots.

Legend: 1 Roman fortification; 2 Late Roman/Early Medieval settlement or fortification; 3 Roman cemetery; 4 Late Roman/Early Medieval cemetery; 5 report of a (Roman) road; 6 Late Roman/Early Medieval settlement; 7 area from plate 8.

2 Xanten-Venlo-Heerlen-Aachen;[282]
3 the connection on the right bank of the Meuse via Maastricht-Venlo-Gennep-Cuijk;[283]
4 the bank connection Venlo-Blerick;
5 Cuijk-Rossum.

The certainties and uncertainties concerning the routes which linked up with Cuijk will be discussed below. Because many remains from the Late Roman Period have been found in the river-dune area directly east of the Meuse at Cuijk, the possible pattern of roads in this area will be dealt with in a separate section.

6.3.2 The south-north route: Tongres-Blerick-Cuijk-Nijmegen

The main road from Tongres follows the left bank of the Meuse as far as Cuijk. In the County of Cuijk, the road along this route is well documented.[284] The road lies on the sandy low terrace and follows the Meuse valley as much as possible. The only irregularities in this route are caused by large residual channels in the low terrace. The Meuse valley is *c.* 3 m lower than the low terrace and a steep slope marks the transition. Between Oeffelt and Cuijk the road is described at four locations. The width of the road at these places was *c.* 5.6–6.5 m and the thickness of the gravel layer varied from 20 to 35 cm.[285]

282 Van Es 1972, 87; Willems 1987, fig. 3. The section of the route Xanten-Venlo-Swalmen is sufficiently documented for it to be designated a 'road'.

283 The road remains which make this connection probable were found to the south of Venlo. Ever since the publication of Ort (1884, 128), a route has been surmised between Venlo and Gennep. So far, there is no archaeological evidence to support this.

284 The excavation was done by C.R. Hermans between 1860 and 1864, and the report appeared in 1865. The landscape then revealed far more details than it does nowadays. By contemporary standards it is a dream investigation: the mayor himself accompanied the researcher and insisted on the cooperation of all landowners and land users. During the investigation of the road, the procedure was: (1) field survey for concentrations of gravel, (2) exploring the subsoil with a probe and (3) digging a trial trench right across the Roman road and then describing the cross section.

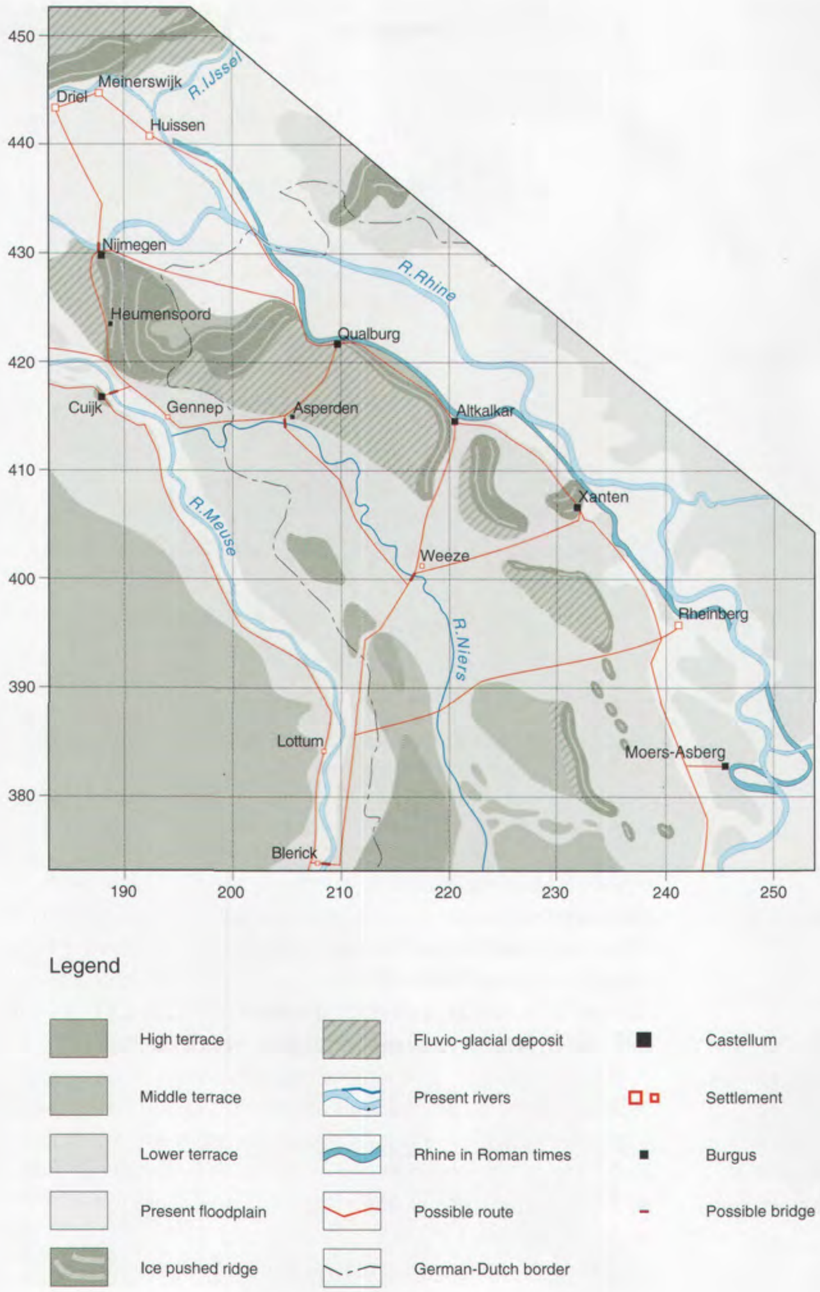


Plate 6 Geomorphological map of the macroregion with fortifications, routes and the course of the Rhine in the Roman Period.

At Cuijk the low terrace lies up against the *c.* 1.5 m higher high terrace, and the road gradually ascends as far as the *castellum* Ceuclum. Just before the *castellum*, beside the road, are the previously described cemeteries (plate 7, area A, nos. 81 and 82). In the *castellum* there is a layer of gravel 8 m wide whose thickness has not been recorded (plate 7, area A, no. 90). In the Early or Middle Roman Period this route ran from the *castellum* possibly to Katwijk further along the left bank of the Meuse. Two observations of a road were made there. The gravel layer there was 5.5 m wide and 30–40 cm thick (plate 8, area D, no. 83). At Katwijk there is said to

285 Hermans 1865, 20–1; Putker 1986, 23.

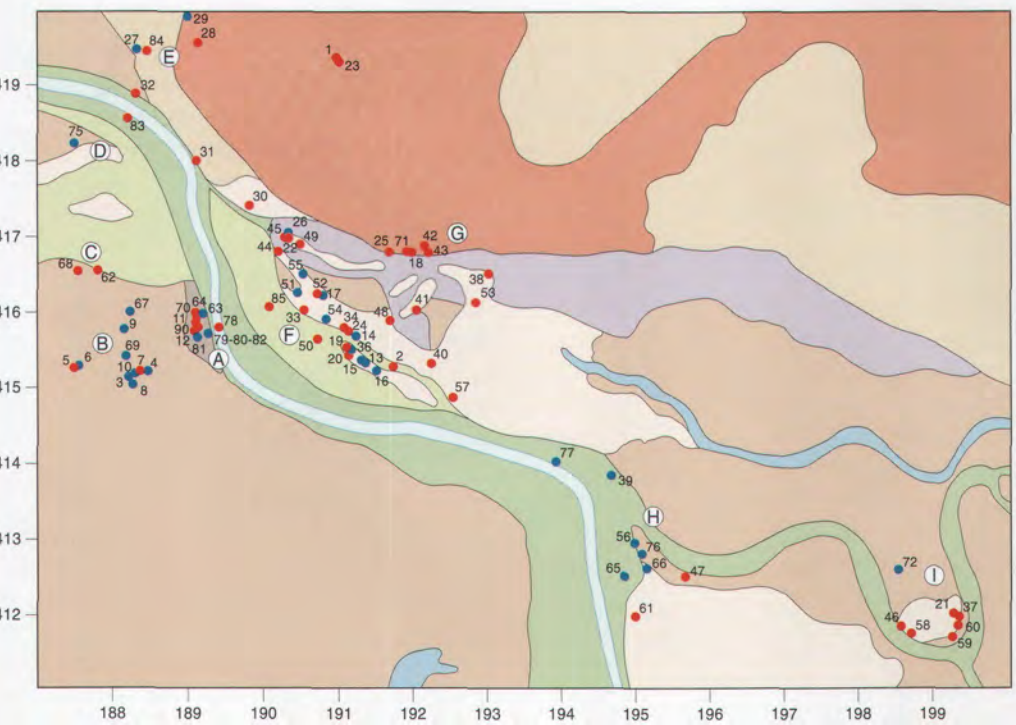
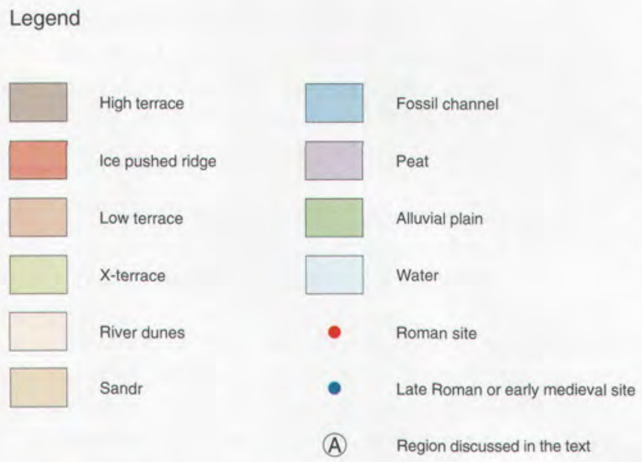


Plate 7 Distribution of Roman and Medieval findspots in the region Cuijk-Mook. Regions and findspots are discussed in the text.



have been an Early or Middle Roman crossing over the Meuse (plate 7, area D, no. 83).[286]

In the Late Roman Period, the approach to the Meuse bridge most likely lay in front of the gate of the *castellum*. From the point of view of security, it is probable that the road coming from the south did not run right through the *castellum* but went around it along the east wall on the bank of the Meuse. However, it is not inconceivable that the approach to the bridge did run through the *castellum*. After crossing the bridge, it is uncertain how the road continued. There are two options: the route turned left immediately and ran over the natural levee to Mook, or the route went more or less straight ahead to the river dunes and then via the high dunelands (approximately via the present Elzenstraat) to Mook. Immediately north of Mook there is a mention of a road flanked by a cemetery (plate 7, area E, nos. 27 –

286 This view is supported by two observations. As a result of a report from 1862, a Roman road surface 30 to 40 cm thick and 5.50 m wide near the former ferry between Katwijk and Mook was described (Hermans 1865, 19). Several years later, in 1881, a 'row of heavy oak posts' was observed on 29 May by Pleyte during the building of the railway bridge (Pleyte 1880, 60–1; 1881; 1888, 60–4). Both observations were combined by Pleyte into 'a road to' and 'a bridge over' the Meuse respectively. Pleyte's report does not reveal which of the two structures he observed. It does not seem logical to assume a bridge at this unprotected spot. Moreover, from Cuijk a depression would have to be crossed to Katwijk which was exposed to the whims of the river. A side-scan sonar recording of the river bed at this location in 1990 did not reveal any remains of piles. Possibly there was a landing quay or a ford here in the Middle Roman Period. In the surroundings of Katwijk and Linden remains were found of Middle Roman and Early Medieval burials (plate 7, Area D, no. 75).

cemetery – and 84 – road. The road from Mook to Nijmegen runs over the sandr (outwash plain) at the foot of the ice-pushed ridge. Across this plain the road roughly follows the 20 m contour line, past the *burgus* of Malden-Heumensoord. An excavation in 1998 made clear that the road in the neighbourhood of the *burgus* had no gravel layer. Between the two road-ditches the cart tracks were clearly visible.

6.3.3 The east route Cuijk-Gennep-Asperden

The route Cuijk-Gennep-Asperden begins with exactly the same uncertainties as the route from Cuijk to Nijmegen. After the bridge crossing at Cuijk, there are again two options. First the route can turn south immediately and continue along the top of the natural levee of the Meuse as far as the mouth of the Niers and neighbouring Gennep. The other possibility is that the route went more or less straight on from the bridge as far as the river dunes before turning southward. We shall return to both options in chapter 6.3.5. The route probably ran across the river dunes, roughly via the present Elzenstraat and Bloemenstraat, in the direction of Gennep on the Niers.

Excavations between 1988 and 1990 have revealed a Late Roman settlement on the Stamelberg near Gennep. The settlement was founded at the end of the fourth century and was in use at any rate until the middle of the fifth century. Younger settlement traces have been found, though these could not be studied more closely (plate 7, area H, nos. 56, 61, 65 and 66). During recent excavations, Early Medieval settlement traces have also been discovered in the centre of Gennep.[287] In a neighbouring cemetery a number of Early Medieval graves were excavated as well as Late Roman burials (plate 7, area H, no. 76). All this gives reason to assume that the route from Cuijk to the Rhine ran via this place, especially since there was possibly a Roman fortification at the mouth of the Niers (plate 7, area H, no. 77).[288] This lies 5 km further south, and is visible from Cuijk.

From Gennep to Asperden the route runs over the low terrace on the north side of the Niers valley, but south of the residual channel in this terrace. The area north of this residual channel receives a great deal of surplus water from the ice-pushed ridge and was partially covered with peat, making it difficult to access. It is possible that the Early Medieval cemetery of Ven-Zelderheide lay on this route (plate 7, area I, no. 72).[289] Towards Asperden the sandr and the Niers valley come closer and closer. The surplus water from the ice-pushed ridge discharges here directly into the Niers, making peat development impossible. At the point where the sandr and the Niers valley converge – at Asperden – the route appears to reach a dead end. It is probably for this reason that a *burgus* was built here (see fig. 54 and plate 7).[290] This watch post was probably built under Valentinian I and remained in use until shortly after 400. The *burgus* is situated on high ground between an easily accessible dry valley in the sandr on the north side and the Niers valley on the south side. Just past the *burgus* a steep valley slope leads the route into the Niers valley. At this spot, around the turn of the century, heavy wooden piles were observed which ... *von einer alten Brücke herführten, welche die südlich gelegenen flachen Ländereien mit dem Gelände nördlich der Niers verbanden.*[291] The unusual position of the *burgus* in the landscape reminds one of a road fork. The route through the dry valley in the ice-pushed ridge leads to Qualburg, and the route through or along the Niers valley leads to Alt-Kalkar and Xanten (plate 7).

6.3.4 The west route Cuijk-Rossum

There is hardly any archaeological evidence to support the existence of a route from Cuijk to Rossum. On the basis of military logic, the *castellum* of Cuijk must have had some connection with the next *castellum* downstream on the Meuse. On the basis of landscape logic, this route will not have run from Cuijk in a northerly direction on the left bank of the Meuse because the terrain there is too hilly. Probably a more westerly option was chosen, via the cemetery on the Heeswijkse Kampen (plate 7, area C, no. 62).[292]

287 Heidinga 1992.

288 At this strategic point at the mouth of the Niers are the remains of the Genneperhuis, a fortification of which there are reports from as early as the 11th century (Heidinga & Offenberg 1992, 124). In January 1997, great lumps of possibly Roman tuff were encountered in the bed of the Niers at very low water, as well as earlier Roman finds (verbal communication J. Schotten). Van Es 1991, 13; Heidinga & Offenberg 1992, 67.

289 The find material dates the burials to the sixth and eighth centuries (Wagner 1993). Follow-up investigation in 1997 roughly confirmed the date of the cemetery.

290 Bechert & Willems 1995, 73; Hinz & Homberg 1968; Willems 1984, 149.

291 Hinz & Homberg 1968, 169.

292 Hessing 1990 and in prep.

However, within the cemetery, no Late Roman graves were found. Possibly the road followed the steep slope between the low terrace and the X-terrace in the direction of Kessel and Rossum, but traces of a Roman road have never been found along this route. During dredging activities near Kessel, heavy masonry and Roman material was brought to light, probably from a Late Roman fortification.[293] At Rossum, where the Meuse and Waal come very close together, there was probably a fortification, Grinnes, in the Late Roman Period, which was in use from the time of Valentinian I until into the fifth century.[294]

6.3.5 The route over the river dunes at Middelaar
Both the Cuijk-Nijmegen and the Cuijk-Gennep routes have an alternative, leading over the river dunes east of the Meuse. Apart from whether this was the correct alternative in the Late Roman Period, it can be established on the basis of the pattern of finds that there was, at any rate, a connecting road between Mook and Gennep which ran across the river dunes. The road can then be projected along a series of find reports, while some burial finds can be assembled into cemeteries (plate 7, area F, nos. 30, 45, 22, 44, 52, 17, 48 and 40). This route appears to coincide well with the present Elzenstraat and Bloemenstraat in Middelaar. The pattern of finds makes one suspect that development took place along these streets. In the Late Roman Period and the Early Middle Ages, there was a sizeable settlement around the present village nucleus of Middelaar (8, area F) which was flanked both in the south-west and north by a cemetery. The presence of Late Roman burials is, however, uncertain.[295]
On the river dune, the remains of a *villa* complex were investigated. The traces of a Late Roman settlement were found on the site (area F, nos. 13 and 14).[296] At the place where the Elzenstraat now comes to a dead end at the canal leading to the Mokerplas, heavy beams forming a trackway were reported during the digging of this canal in the 1950s.[297] The canal was dug on the site of a former peat stream. The find material has been lost, making further investigation impossible.[298]
The Roman road along the Elzenstraat-Bloemenstraat route was probably never paved; at least, no road surface has ever been found. In the vicinity of the Elzenstraat, at the foot of the river dunes, the presence of a stone floor has been mentioned (plate 7, area F, no. 85).[299] Since the location is exactly on the line of the axis of the bridge, and since it is logical to reinforce a road at a point where it starts sloping, additional investigation was carried out on this spot.[300]

6.3.6 The connection between the bridge and the east bank
We must first briefly discuss the way in which Roman roads were built. A Roman main road consists of straight road segments and is preferably laid out horizontally, avoiding landscape obstacles as much as possible.[301] Also of importance is the military safety of the road.[302] Apparently the landscape in the great river valleys fulfilled these conditions best. Many of the Roman roads which we are familiar with were built on the dry terraces or natural levees along rivers. The Roman main roads in the Rhine and Meuse valleys are good examples. For secondary roads, the same criteria were used, but less strictly. There were official guidelines for the width of the various types of Roman

293 Verwers 1977.
294 There could also be an important Late Roman river crossing here, but fluviatile erosion at this spot limits possibilities for research. Bechert & Willems 1993, 71–2; Willems 1984, 293.
295 Apart from the investigation into the *villa* at Plasmolen (Braat 1934) and trial investigations by local amateurs (AWN Nijmegen, H. Verscharen) no excavations have ever been done in this area. This assumption is based on data obtained from local amateurs and supplemented by literature research. Peters 1973; Proos 1988; Willems 1984.
296 Verscharen 1982, 16; Willems 1984, cat. no. 508.
297 Verbal confirmation was obtained in 1989 via the Cuijk branch of Smals bv Grint en Zandexploitatie Maatschappij, Katwijk, the company which at that time had the concession for sand and gravel extraction in the Mokerplas. See also 1981, 122–3 and 130–1, cat. nos. 379–384.
298 Although some of it is still present in the Mook town hall.
299 Thanks are due to H. Verscharen and J. Morren for the report. The coordinates are 190.510/416.040. At a level of 9.8 m NAP, a probable stone floor (or road) was discovered in 1981, *c.* 1 m below the surface, during the erection of a fence. Some of the flat stones – dark-grey limestone with clear traces of wear on the upper surface – were excavated. In March 1983 the stones came into the possession of H. Verscharen, who explored the findspot in April 1983 with a probe. Gravel and stones could be felt 110–115 cm below the surface. As a result of the bridge investigation, this findspot was reported in September 1993 by J. Morren. The stones were handed over for research.
300 See note 299.
301 Luys 1984, 10. These principles are mentioned by almost all authors on this subject.
302 Chevallier 1972, 79.

road,[303] but these are not always traceable in the remains of Roman roads found in the Netherlands.[304] The Roman roads were generally constructed like a dam and flanked by trenches, so that they remained passable in all weather conditions. The building material for a road is almost always of local origin. In the catchment area of the Meuse, a combination of sand, clay and gravel was frequently used in road-building. For crossing low and wet areas wooden trackways were also incidentally used in the Meuse valley.[305] In the west of the Netherlands, mounds of wood and earth were built on which the road surface came to lie.[306] In places which were permanently dry, paving could even be omitted,[307] like the road mentioned earlier near the watchtower Malden-Heumensoord.

In order to find a connection between the bridge and the supposed road on the east bank, a search was made for the most easterly remains of the bridge. These proved to be covered with a thick layer of holocene deposits, so that no results could be obtained by aerial photography, electric conductivity survey or magnetometer investigation. Nor was it possible by means of boring through the layer containing post-Roman sediment which is about 6 m at the present levee, to demonstrate a Roman road surface at the end of the bridge. For this reason, another strategy was chosen.

The observed length of the bridge is 150 m. From this point there are two options for a continuing route and a connection with the route system on the east bank. The first is that the road links up with the bridge immediately and runs over the levees from the Roman Period in a southward direction to Gennep and in a northward direction to Nijmegen. This option has a risk of flooding. The second possibility is that (the road coming) from the bridge was continued as far as the X-terrace and connects with a road across the river dunes near Middelaar. This would make a dry crossing of the Meuse possible throughout the year. Moreover, the connection with the road over the highest part of the river dunes (Elzenstraat) could be reached via the shortest route.

Further research focused on the two options, the 'levee road' and the 'extended bridge' (figs. 55 and 56). It was decided that hand auger investigation be done on the levee where the post-Roman sedimentation layer is only about 4.5 m thick and at the place where the bridge possibly linked up with the X-terrace, where the sedimentary layer was *c.* 1.8 m thick. As a starting-point, boring transects were placed over the assumed route of the road at right angles to the expected road direction, with boreholes at intervals of 5 m. As a result of this strategy, it should prove possible to trace any remains of paving, changes in the soil composition or humous discolourations which might indicate the presence of a road surface. It was important that the background value of the soil (particularly the gravel fraction) had already been extensively mapped as part of the bridge investigation. It did not seem likely that later flooding would have (completely) washed away the body of the road.

First of all, the 'extended bridge' option was investigated. If it existed, it would have lain at about 7.5 m NAP on the level of the X-terrace. Figure 55 shows the position of transect OO′ on the X-terrace. This transect is perpendicular to the axis of the bridge. The transect is so placed that more or less any road which led from the bridge to the river dunes would be intercepted by the 82 hand borings which were made to a depth of 5 m. At two places a higher percentage of gravel was encountered, but further investigation did not yield any more indications for the presence of a road.[308] A similar set-up was used to find the road surface of the hypothetical 'levee road', which might have lain on top of the Roman levee at a height of *c.* 7 m NAP. No trace of gravel or any other road surfacing was found here either. Altogether 257 borings were done for the entire investigation, none of which produced any evidence for a road.

Perhaps the basic assumptions were not correct. The choice of a bore interval of 5 m may have been too generous.[309] On the other hand it is possible that no road surface or road body was built. Since it is mostly

303 Chevallier 1972, 66.
304 A full survey of the findspots until 1986 of Roman roads in the Netherlands is given by Putker 1986.
305 Luys 1984, 108 and 132.
306 Bult & Hallewas 1990, 12–13.
307 See Van Enckevort & Zee, 1996, photograph on page 61; only part of the Roman surface shown is covered with gravel.
308 The findspot, which is situated precisely in the line of the axis of the bridge was also investigated (plate 7, Area F, no. 85) but nothing was found. This casts doubts on the reliability of the find report.
309 Borrowed from Luys 1984, 108. Research by Schmidt and Scheider in the Rhine valley indicates that the average width for the top layer of the gravel dam is 18 feet (*c.* 5.32 m) and 14 feet (*c.* 4.14 m) respectively.

Figure 55 Search operations for Roman roads on the right bank of the Meuse: a layout of the search sector between the end of the bridge and the nearest (dry) riverdunes; possible roads between bridge and riverdunes must be located within this sector; b boring transects crossing the entire search sector (O-O′) and the levees (S-S′ and T-T′), extra search transects (P-P′ to R-R′) and special search area's (X and Y). Legend: 1 Roman bridge; 2 bridge axis; 3 report of paving, possibly from a Roman road; 4 search sector; 5 Roman villa; 6 Late Roman/Early Medieval cemetery; 7 contour lines of river dunes; 8 special search area; 9 boring transects.

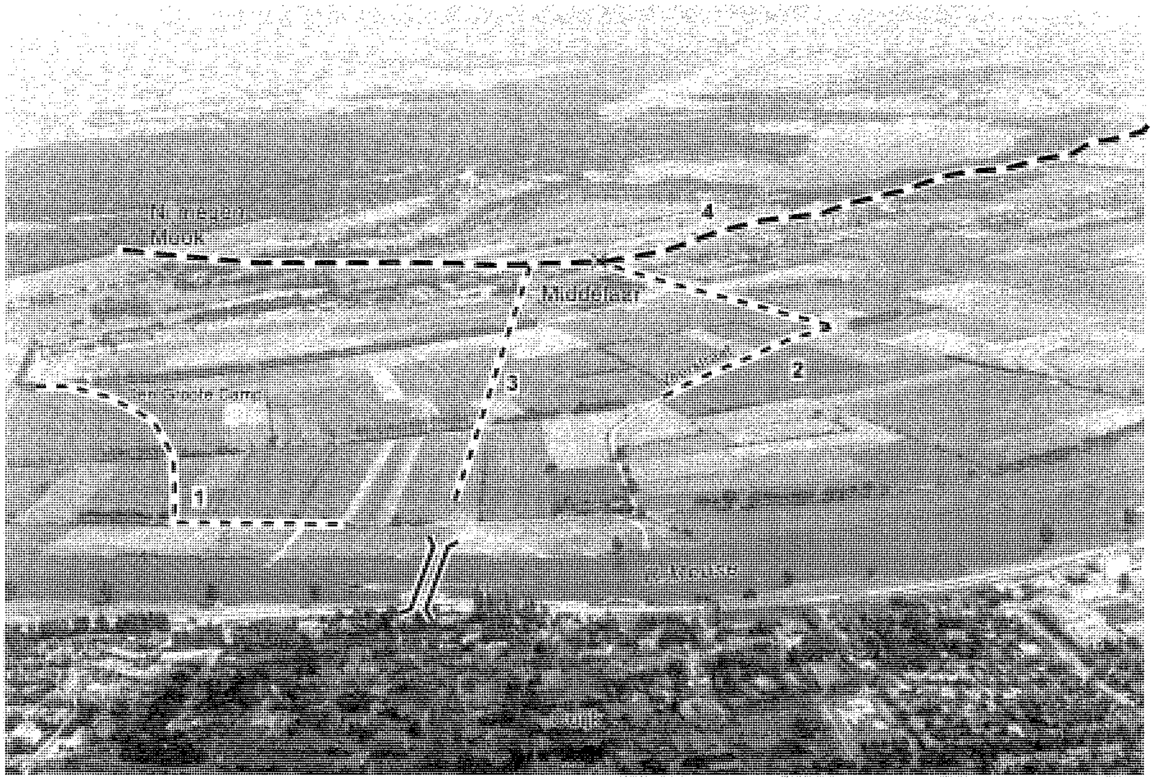


Figure 56 Possible Roman routes east of the Meuse, drawn on to an aerial photograph.

1 possible connection with the bridge along the Meuse over the former levee; 2 possible connection with the bridge via the ferry road to Middelaar; 3 possible connection with the bridge via a straight line to Middelaar; 4 the major north-south route over the river dunes of Middelaar. (photo kindly made available by the town of Cuijk)

the hard road sections which are found, these finds possibly determine the picture we have of Roman roads, even though they perhaps occurred less frequently than we might expect. It is also possible that this road in particular was intended for the cavalry corps from Cuijk. Cavalry roads are never paved because horses do not like to walk on a surface of gravel or rubble.[310] What is certain, is that the hypothetical road did not disappear as a result of erosion. Boring did not show any traces of erosion, but all the post-Roman sediments observed are sandy clays or light clays which were deposited in a relatively peaceful environment. High energies capable of eroding a gravel road did not occur.

310 Verbal communication (28-10-1993) from veterinary surgeon J.M. Hermans, Langbroek, who specializes in horses.
311 The felling date is ad 393 ± 5 (see 2.3.1).

6.4 *The bridge in a historical-archaeological context*

The Cuijk bridge is situated at a junction of roads in a border zone organized for defence in depth. This system of defence relied heavily on quick communications. For this, it was essential that the Meuse could be crossed at all times. It is logical to assume that the bridge was built in a military context. So an attempt can be made to link the separate building phases of the bridge to the Late Roman written sources, and to historical events.
As we have already seen, three building phases can be distinguished in the foundation piles on the basis of the dendrochronological data (see 2.3.1). The first building phase can be dated to 347–349. The first repairs were done in the winter or early spring of the year 368/69, and the last repairs in about 393.[311]
The construction phase of the bridge was in the time of

Constans. The date of the first construction cannot be linked with any historical fact. The Frankish incursions before 341 described above were history by then, and the actions of the usurper Magnentius between 350–360 and Julian's reaction to them (360–363) still had to take place. It is surprising that the bridge was only started some 25 years after the building of the *castellum* under Constantinus I. It would appear that the building of the bridge took place in a comparatively peaceful period which gives rise to the idea that Constans further expanded the system of defence reorganized by his father, which was only able to function with good road communications.[312] The river bank structures in area 6000 were probably built during or shortly after the building of the *castellum* under Constantinus I, judging from the many pottery sherds from this period.

In the early spring of 369, during the rule of Valentinian I, the bridge was extensively renovated. The tree-ring dating of these repairs can be clearly linked to historical sources. It is probable that Valentinian I was on a working visit to Nijmegen on 20 September 368.[313]

After the departure of Julian in 361, the problems with the invading Franks increased and Valentinian I appears to have intervened in the case personally from Trier.[314]

Under general Theodosius, the father of the later emperor Theodosius, the river area was again brought under Roman control.[315] This led Valentinian I to instigate a large-scale building programme which was to result in the complete restoration of the border defences and in more stability on the Rhine border between Raetia and the North Sea.[316] In doing so, he placed the emphasis on the further implementation of the already existing system of defence in depth. Not only the Rhine border, but also the *castella* situated more inland were reorganized. In this context, the *castellum* at Cuijk was even rebuilt in stone and given round towers.[317] The dendrochronological dating of the second building phase of the bridge therefore corresponds well with the historical mention by Ammianus. Valentinian's army command probably found the twenty-year-old bridge at Cuijk to be in a poor state of repair. Together with the rebuilding of the *castellum*, the bridgehead on the left bank (area 4000) was almost completely renewed or perhaps built for the first time in that year. Restoration of several piers was also carried out. Between 388 and 398 the bridge was repaired for the last time.

Apparently it was necessary for drastic repairs to be done to piers 3000 and 4000. These repairs can possibly be linked with a number of historically dated events between 387–398. In about 387/388 the usurper Maximus (383–388) is defeated and Valentinian II (375–392) regains control of the Gallic part of the empire.[318] During this period of unrest Frankish groups again start to move in the direction of Roman territory, though they are partially defeated in about 387.[319]

A punitive expedition to the transrhenine Frankish territories undertaken from Neuss in around 388 has disastrous consequences for the Romans. Eventually the Roman army commander Arbogastes under Valentinian II succeeds in settling matters across the Rhine. In doing so, he destroys numerous settlements of the Chamavi and Bructi. This event is said to have taken place in 389, one year after the Frankish invasion.[320]

After the murder of Valentinian II by Arbogastes in 392, the new emperor Eugenius leaves for the Rhine border to complete Arbogastes' task by concluding a new treaty with the Franks. A mention of a victory over the Germani and of Saxon prisoners of war makes it likely that several skirmishes also took place in 393.[321] During the first stage of Honorius' reign, between 395 and 406, things were relatively quiet according to the historical sources. After a tour of inspection, his general, Stilicho, again brings the Rhine border into a state of defence. Only once does there appear to be talk of subduing the rebellious Franks; this is dated in 398.[322] It is not certain whether these events under Arbogastes or

312 Bloemers & Thijssen 1990; Bogaers 1967, 108–11; Bogaers & Rüger 1974, 84–7.

313 De Boone 1954, 103; Von Petrikovits 1978, 206.

314 De Boone 1954, 72, 82 and 91.

315 Willems 1984, 278 and note 58.

316 Ammianus Marcellinus xxviii 2, 1–4; De Boone 1954, 106.

317 Bogaers 1967.

318 De Boone 1954, 110.

319 De Boone 1954, 112, note 758.

320 Curiously enough, Byvanck (1943, 678) dates this event in the winter of 392/393, when Arbogastes joins the usurper Eugenius. This is possibly the same action as described by De Boone (1954, 115). Van Es (1981, note 172), however, dates this action in 389 because Sculpius Alexander (cited by Gregory of Tours: ii, 9) states that it must have taken place in the year after Quintinus suffered a defeat in 388. Willems (1984, 438) does not commit himself, and only mentions several years after 388. De Boone (1954, 115) describes yet another action under Eugenius in 393, which he interprets as an action against the Germans but not against the Franks.

321 De Boone 1954, 115.

322 De Boone 1954, 116 and 118.

Stilicho have any connection with the latest repairs to the bridge. In view of the comparative peace during the first stage of Honorius' rule, the restoration under Stilicho would appear to fit the dendrochronological dating best.
The bridge most probably continued to function until into the beginning of the fifth century. Stilicho has to call his troops to Italy in 402. Franks and Alemanni cross the border en masse in 406, the system for keeping the bridge in repair will have disappeared. At the same time the military necessity for maintaining the bridge will have ceased. On the basis of the intervals between the phases of repair of the bridge, it may still have functioned until the end of the first quarter of the fifth century.

7 CONCLUSIONS

7.1 *Deposition*

A total of 337 piles and beams were found on the bed of the Meuse, 294 of which were *in situ*, while 116 building stones and spolia were found *ex situ*. The bridge location comprises 258 foundation piles *in situ* and the river bank structures comprise 36. As a result of the excavation of three find areas, a total of 123 piles and 77 stones were removed from the middle of the Meuse: areas 3000, 4000 and linked with them, areas 3200, 2400 and 2600 were completely removed; from the other areas only parts were removed. The distribution of the find material over the river bed and the condition of the finds are clear evidence that the original remains have been seriously eroded. Three factors were probably involved.
First, the bridge remains were re-used. This can be stated with certainty in the case of the stones, for far too few stones were found to build a bridge, and stones of this size cannot have been moved by the river. It is also remarkable that most of the stones were found in the deeper part of the river.
The second factor is that bridge remains have been lost as a result of the normalization of the Meuse and the increase in shipping in the 20th century. The navigation channel has been dredged several times. There are no *in situ* finds in find area 3700 in the middle of the channel. The find areas next to the navigation channel (3000 and 4000) are most eroded on the channel side. In these find areas the piles sometimes project some metres above the river bed. The timber is of good quality, making it likely that the bed was recently eroded. This may partly be due to the construction of groynes on the east bank causing the current in the west part of the river to increase. Next to the present landing quay a complete find area (5000) has possibly been lost due to the building of the quay and the movement of shipping connected with it.
Third, bridge remains will have been worn away by natural processes of erosion or carried off by the current. It is certain that almost all the piles *in situ* were originally longer. This wear has also been observed in area 1500 which is partly buried in the bank at a sheltered spot behind a groyne. This shows that the wear is not only due to modern shipping, but is also caused by the Meuse, laden with sediment, which has flowed over the tops of the piles for over 1500 years.
At least one pier foundation (area 500) is covered with a thick layer of levee deposits. The majority of these were deposited after dikes were built along the Meuse in the Late Middle Ages. The levee deposits have an average accretion of 7 mm per year. Area 500 was therefore far less subject to erosion than the other find areas. The pile top struck while boring in area 500 (at 3.8 m NAP) reaches a greater height than those in the other piers (maximum 3.63 m NAP).
Small find material was only found at protected places. In the centre of pier foundation 2000 a complete pot was found, possibly a building offering. Furthermore in area 6000 small find material has been preserved in a layer of organic debris. This layer accumulated behind a riverbank protection or jetty in the Late Roman Period and has remained there ever since.

7.2 *Representativeness*

The find material from the bridge consists almost entirely of foundation piles and building stones belonging to pier structures. Nothing has been found of the other bridge parts such as the superstructure and the road surface. The representativeness of the find material can only be judged from the piers. On the basis of the pier reconstruction it is assumed that a complete pier consisted of *c.* 100 piles and *c.* 1000 stones. These figures can be related in three ways to the find material.
1 The find material of the individual pier is compared with the quantity of material of the theoretical pier. Of

the 100 theoretical piles 1% was demonstrated in area 500, 35% in area 1500 which was only partly excavated, 126% in area 2000, 51% in area 3000 and 54% in area 4000. In area 2000, therefore, a greater number of piles were present than the pile-driving plan indicates. Extra piles were driven in in connection with a number of repairs in this area. Of the 1000 theoretical building stones *c.* 0.5% was found in area 2000, about 3.5% in area 3000, and in area 4000 slightly less than 2%.

2 The total find material is compared to the demonstrated bridge length of 150 metres which spanned the river and had eight piers. Eight piers theoretically contain 800 piles and 8000 stones. A total of 337 piles and 108 stones were found. In other words, 42% of the piles and only 1.35% of the stones.

3 The total find material is compared to the materials needed to build a bridge of 24 identical piers and a length of 450 m across the whole Holocene valley of the Meuse. For 24 piers 2400 piles and 24 000 stones are needed. The find material therefore represents 14% of the piles and only 0.45% of the stones.

The representativeness of the stones therefore lags far behind that of the piles. From the point of view of secondary usage this is not surprising.

7.3 *Dating and phasing of the bridge and the bank structures*

Of a total of *c.* 300 foundation piles 58 samples were taken for dendrochronological dating. Only 37 (10%) of the total number of piles found were used for dating.

The bridge had three building phases. The first construction can be dated between AD 347 and 349. The second phase represents extensive repairs or restoration dating from the spring of AD 369. The final repairs were carried out around the end of the fourth century in AD 393 ± 5. Assuming this regularity in the repairs, the bridge was certainly in use between *c.* 350 and the end of the first quarter of the fifth century. Piles from the first phase are to be found, without exception, in the centre of the foundation. The piles from the second phase are somewhat further outward, while the piles from the last phase of repair were driven in on the outside of the foundation. This observation supports the phasing. Repairs are, after all, done from the outside.

The pottery from the bridge is dated at the end of the fourth century and does not cover the entire period of the bridge's existence. The number of fragments is small.

The date of the first construction of the bank structures is uncertain, but would be between AD 320 and 340, which could make this building activity partly overlap the first construction of the bridge. The second phase is dendrochronologically dated in AD 373. The bank structures were repaired at least twice, but probably more often. In time they were probably shifted towards the left bank because of the erosion of the convex bend of the river. The pottery finds here are plentiful, with a wide dating between the first and fourth centuries. Three-quarters of the material dates from the first half of the fourth century. Pottery from the second half is virtually lacking, which may point to a change in use of the site. The ^{14}C date of the organic debris between the piles supports the dating to the Roman Period.

7.4 *Construction*

The bridge at Cuijk was a stone bridge founded on wooden piles. It is almost certain that the superstructure was also made of wood. The stone piers were built in so-called dry masonry, *i.e.* without mortar. This type of bridge was common throughout the Roman empire.

The bridge was certainly 150 m long and possibly 450 m. This means a bridge with a minimum of 8 and a maximum of 24 piers respectively given the span of *c.* 19 m.

From landscape data it appears that a height greater than 11.6 m NAP for the road surface of the bridge was useless and that a minimum height of 10.2 m NAP must be maintained, based on the estimated water levels in the Roman Period. The pier size used is rather small and similar to the early fourth-century bridge in Cologne. However, if a bridge length of 450 m is assumed it is a sizeable structure, comparable to Roman bridges over the Rhine.

The foundation is of a type observed earlier in Maastricht and Mainz. This is a foundation with, on the one hand a cofferdam of horizontal beams, and, on the other hand, widely spaced foundation piles. Both the cofferdam of horizontal beams and the widely spaced piles have been observed before, also in combination. The assumption that there must have been a reinforcing framework of beams inside the cofferdam would appear to be justified on the basis of the foundation plan. This phenomenon too has been observed before.

The excavation at Cuijk has produced much

information about Roman foundation techniques, especially at a detailed level. On the other hand, no insight has yet been gained into the connection between the foundation method and the type of subsoil. For this, more information is needed especially about other bridge locations. For Cuijk, both the foundation and the geological conditions have been described as well as the character of the river which may also have played a part in the choice of building method.
An unexpected discovery was that most of the stone used to build the bridge came from the demolition of other structures.
Another discovery completely beyond the scope of the original research plan was that the Romans were familiar with the concept of the end-bearing pile as we now know it: a building element which directly transfers the weight it supports to a solid layer in the subsoil, analogous to the function of a pillar above ground. Up to now, the friction pile and the compression pile had been demonstrated, but Roman knowledge of the end-bearing pile has only been surmised.
The answer to a question connected with this, namely whether the builders had prior knowledge of the composition of the subsoil before starting to build, is still uncertain.
Area 6000 is a separate problem. It is fairly certain that it was built at least 10 years before the bridge. Investigation so far has only permitted a number of hypotheses to be put forward: river bank protection, landing quay, jetty, foundation of a *castellum* wall or tower ending in the river or bridgehead of a pontoon bridge.
It was unexpected and reassuring for the researchers to discover that the layer of organic debris found in area 6000 confirmed the water levels in the Roman Period which had already been reconstructed on the basis of the highest pile-tops.

7.4.1 Possibilities and impossibilities of reconstruction
An attempt was made to discover a Roman system of measures from the excavation plan, or to impose a Roman system of measures on it. This did, in fact, prove possible, but is difficult to substantiate. The use of an interval of 5 Roman feet (1 *passus*, ca. 1.5 m) between the lines along which the longitudinal rows of piles were set out, is probable.
The possibility of a general building plan or scheme was examined on the basis of a possible fixed proportion (the golden section) which appeared to be inherent in the general system of measures. This proved to be even more hypothetical and can hardly be considered verifiable.
The state of preservation of the findspot was not such that a reconstruction could be made based exclusively on the excavation data. Particularly in the case of parts other than the foundation, the reconstruction made is highly dependent on earlier research, namely the excellently preserved and researched bridges in Trier.
Nevertheless, a broadly based investigation both in respect to the disciplines involved and to matters of detail provides far more information. As a result, valuable information may be brought to light which might never have been demonstrated on the basis of the features and finds alone. The archaeological story becomes more complete as a consequence.

7.4.2 Costs, materials used and duration of building
It is only possible to give an indication of the use of materials on the basis of the reconstruction, so it is actually a model on the basis of a model. It is, at any rate, clear that the bridge at Cuijk has been a project which required a great deal of investment, even by present standards.
Even for a minimal bridge of only eight piers some 1600 m^3 of wood were required: more than ten linear kilometres of wood. In addition, more than nine tons of metal (five tons of iron and four tons of lead) and almost five thousand tons of stone were needed.
Assuming a specific gravity of fresh oak of 1000 kg/m^3, this means over six and a half tons of material. That would nowadays fill a train of *c.* 120 wagons, 2.4 km long. For a bridge of 24 piers it is 19.5 tons of material and a train of 360 wagons 7.2 km long.
The time needed to build the bridge cannot be estimated. To do so would require insight in variables which are not only hardly possible to estimate but which also often influence each other. However, one can make a comparison with other bridges. Starting from the amounts of material, several basic activities which are easy to estimate can be calculated. In this way it is possible for statements to be made, at least in the relative sense. The first-century bridge on piles in Trier appears to have taken far more 'building time' than the bridge at Cuijk. The main reasons for this are: the use of a foundation construction at Cuijk which was quicker to build and the secondary use of building material. The costs of the bridge cannot be indicated. The materials used and the building time based on them are already models. To calculate the costs would be going too far.

However, it is indubitable that the bridge must have demanded great sacrifices, the financial ones maybe even the least of them.

7.5 *Landscape*

7.5.1 Reconstruction of the landscape

The Meuse at Cuijk has not changed its position, at least not since the Roman Period. The most convincing argument for this is that the Late Roman bank structure or jetty is at virtually the same spot as the present landing quay of Cuijk. Because it is unusual for a meandering river to have a fixed position for so long, an explanation was sought in a geological survey. This showed that a Boreal residual channel of the Meuse filled with heavy clay was preventing the present Meuse at Cuijk from meandering. Due to the absence of lateral erosion there were good possibilities for a palaeogeographical reconstruction of the abiotic landscape. From this reconstruction it appears that the two banks linking the bridge differed at least five metres in height. The *castellum* lay high above the river on the edge of an old terrace. The low-lying right bank was flooded during high water levels of the river. Since it cannot have been the intention of the bridge builders to let the bridge end in an area which was periodically subject to flooding, it is assumed that the bridge structure spanned the entire Holocene Meuse valley. Because the Meuse at Cuijk does not shift its position for the greater part of the Holocene period, the Meuse valley here is at its narrowest and in the Roman Period was only 450 metres wide.

It also proved possible to make a partial reconstruction of the water levels in the Roman Meuse. The flow of the rain river Meuse in winter is two and a half times that of the summer, on average. The average low water in the Roman Period has been reconstructed at *c.* 4.3 m NAP. This reconstruction is based on the level that the foundation piles of the piers were driven in and the layer of organic debris behind the Late Roman pile structure. The average high water in the Roman Period did not exceed 7.5 m NAP, because a Meuse terrace at that level was not flooded in the Roman Period. A small layer of peat at 6.0 m NAP in the levee deposits near the bridge is dated in the Bronze Age. From this it follows that the Meuse banks at the Roman bridge were between 6.0 and 7.5 m NAP. In the many borings that were done in the levee deposits, the former Roman land surface was not observed.

During the reconstruction of the biotic landscape no new insights were acquired within the study area. Palynological research in this area has not so far led to pollen diagrams with useful profile sections for the Roman Period. A compilation of various palynological investigations in the eastern river area of the Netherlands points to a vegetation pattern with a relatively large wooded area in the Late Roman Period.

7.5.2 Choice of location

The commissioner of the bridge and the Roman bridge engineers chose the location at Cuijk. Landscape factors will certainly have played a part in the construction of the bridge.

In the Roman Period the Meuse terrace on which the *castellum* Ceuclum was situated was a relatively high point along the Meuse, which projected at least 5 m above the deposits in the Meuse valley. Over this low valley the Romans had a good view of the south (the mouth of the Niers) and the north (Mook/Heumensoord). The Romans had been familiar with the Cuijk location for several centuries before the bridge was built. During this time, it would not have escaped their attention that the Meuse at this location has no tendency to shift its course and that the valley is narrow here.

The route Tongres-Nijmegen must cross the Meuse somewhere. Cuijk is the most suitable location. First, the route profits most from the natural barrier of the Meuse if it runs west of the Meuse as far as possible to the most northerly opportunity for crossing. Second, the route runs from the south to Cuijk over a supporting sandy soil without any abrupt differences in height, but directly north of Cuijk there is a tricky, low-lying area with peaty residual channels which is avoided if the Meuse is crossed at Cuijk. Third, the most northerly segment of the Meuse near Cuijk is straight and therefore has the relatively flat bed necessary for a river crossing or a bridge structure.

7.6 *The function and historical context of the bridge in the Late Roman Period*

The bridge and the fort of Cuijk lay far behind the Rhine *limes* and formed part of the system of defence in depth characteristic of the late Roman Period. This system could only function with a good infrastructure. The bridge formed a link in one of the main connecting axes in the Rhine-Meuse delta which runs from Tongres via Maastricht and Nijmegen to Arnhem; at Cuijk this route crosses the Meuse. In addition, the bridge linked the *castellum* of Cuijk with a route running via Gennep and Asperden to Xanten, Qualburg or Alt-Kalkar on the Rhine *limes*.

Despite an extensive hand boring investigation, no physical link was found between the bridge remains and a road.

The construction of the bridge takes place under Constans. Building starts between AD 347 and 349. At that time there is a period of relative peace in the border zone, achieved by concluding treaties with the invading Franks. As part of the system of defence in depth, Constantine I already had a fort built on the site of a first-century fortification. Possibly a pontoon bridge first linked the fort with the other bank of the Meuse. The building of the bridge gives the impression that Constans was carrying on the work and ideas of his father and continuing the adaptation and expansion of the military infrastructure. Indirectly, therefore, he will have been the commissioner. In the building of the bridge use was made almost exclusively of re-used stones. This must have been much cheaper than quarrying new stone.

In AD 368, under Valentinian I, the bridge was thoroughly renovated, as was the fort at Cuijk. One even gets the impression that a completely new pier was built on the fort side. This again emphasizes the idea that Valentinian I may be regarded as the perfecter of the system of defence in depth. The date of AD 368 fits almost too well in the contemporary statement by the historiographer Ammianus Marcellinus that in 368/69 Valentinian reinforced the whole Rhine border from Raetia to the North Sea with forts. The row of forts along the Meuse also appears to have been included in the reconstruction programme of the defence system.

The last phase of restoration takes place between AD 388 and 398. A number of historical references are known from this period which indicate that these were particularly turbulent years in the border zone. It is questionable whether the restoration was still carried out in the spirit of the defence system. The actions under Arbogastes between AD 388 and 393 could be linked with the repair activities. On the other hand, the border renovation under Stilicho after AD 395 or a campaign against the Franks in AD 398 may also have been the reason for the repairs.

The date of the river bank structures makes one suspect that these were part of the overall building plan of both the bridge and the fort. It might have had the function of river bank protection or landing quay necessary for transport activities connected with building. It could also have been the bridgehead of a pontoon bridge over the Meuse as a predecessor of the fixed bridge. The area around the bank structures was possibly included in the fortification of Cuijk in the second half of the fourth century in the form of *castellum* walls continuing into the Meuse.

ACKNOWLEDGEMENTS

In contrast to what is current in an academic publication, a number of orgnizational aspects of the project will be briefly discussed. The work was done between January 1992 and December 1993. The fieldwork was carried out in the summer months and the analysis and recording took place in the winter months. Altogether about 1500 hours of work was done under water, most of which was devoted to measuring. The site is situated in a busy navigation route. The necessary supervision of shipping was done by the Department of Works (*Rijkswaterstaat*). We would like to thank D.A. Klaver, H.G.W. Eman, T. de Vries and the crew of the R.W.S. Grave, especially J. Janssen, G. Spreeuwers and B. Leenders, for ensuring that the diving work was unhindered by shipping.
The realization of the project was done by an organization set up specially for this research, which operated under the responsibility of the Department of Under water Archaeology (AAO) of the ROB. The permanent staff of the project carried out the investigation and supervised a group of about fifteen volunteers who were responsible for their own study area. The cooperation between specialists and amateurs proved to be of great importance to underwater archaeology: local knowledge of the region is of great value to the archaeological heritage. After a request made by the director of the AAO, the Foundation for Advancement of Underwater and Marine Archaeology (BOS) took on the funding of the project. After an initial sum from the AAO, the municipalities Mook and Cuijk and the provinces of Noord-Brabant and Limburg contributed financially to the research. With the help of municipal institutions, the Museum Ceuclum and local service clubs, the support of sixty local firms and organizations was enlisted (see below). This meant that approximately 70% of the total and material budget was covered.
This method of financing calls for a considerable investment of time and creates an obligation to keep volunteers and financiers/sponsors sufficiently informed. On other hand it creates a broad basis.
PR was one of the central activities of the project organization, essential in keeping the project going. Lectures were given, an information bulletin appeared, open days were organized and the media were informed. A documentary was also made about the investigation and its results and finds appeared in a non-specialist publication. Finally, we thank T. Douwsma and H. Hoogewoud of the Audiovisual Service of the Catholic University of Nijmegen for the work that is being done on an exhibition and a full-size replica of a bridge pier.

Permanent staff of the project organization
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Appendix I & II

APPENDIX I The piles

excavation area	pilenumber	length	width	UHM	above riverbed	cm NAP height top	cm NAP height bottom	pileshoe	lifted	first ring	last ring	sample number	certain date AD	fase	number of tree-rings	sapwood
100	lv92-04							yes	yes	300	351	cuy066		2	52	no
100	lv 103							yes	yes	275	371	cuy006		3	97	no
200	lv 207	260	30					yes	yes	268	349	cuy001		2	82	yes
700	lv 702	135	25					yes	yes	255	318	cuy002		?	64	no
700	lv 703							yes	yes	253	296	cuy004		?	44	no
1500	133							?	no		352	cuy089	352 +/-5, between 347 and 357	1	82	yes
1500	188			521		328		?	yes			cuy096	344 +/-5, between 339 and 349	1	72	yes
1800	301			445		252		?	yes			cuy091	346 +/-5, between 341 and 351	1	45	yes
1800	303			488		295		?	yes			cuy092	371 +/-5, between 366 and 376.	2	63	yes
2000	045		20	501	21	308		?	no			cuy084	347 +/-max 5,between 347 and 352	1	90	yes
2000	080		32	515	72	322		?	no			cuy088	344+/-5, between 339 en 349	1	58	yes
2000	119		24	491	15	298		?	no			cuy086	366+-?	2	111	yes
3000	001	248	25	260	60	67	-181	no	yes	275	338	cuy039	after 338	2	64	no
3000	005	320	23	401	130	208	-112	no	yes	276	372	cuy038		3	97	no
3000	007	280	29	450	149	257	-23	yes	yes	258	317	cuy028		1	>60	no
3000	008	298	30	468	89	275	-23	yes	yes	270	308	cuy060		1	39	no
3000	011	301	32	420	25	227	-74	yes	yes	268	327	cuy056		?	60	no
3000	020	264	26	429	52	236	-28	no	yes	284	349	cuy034		2	66	no
3000	036	318	32	461	45	268	-50	yes	yes	275	317	cuy023		1	43	no
3000	038	225	29	436	40	243	18	yes	yes	266	298	cuy026		1	>33	no
3000	041	355	26	363	65	170	-185	no	yes	276	354	cuy058	after 367	2	79	no
3000	043	344	30	468	63	275	-69	yes	yes	259	323	cuy042		1	>65	no
3000	044	401	27	394	100	201	-200	no	yes	275	354	cuy033		3	80	yes
3000	046	384	31	395	85	202	-182	no	yes	314	387	cuy043		3	74	no
3000	047	262	29	408	80	215	-47	yes	yes	258	309	cuy024		1	52	no
3000	049	337	31	385	60	192	-145	no	yes	302	374	cuy051		3	73	yes
3000	070	327	27	316	53	123	-204	yes	yes	296	354	cuy059	after 349	2	59	no
3000	081	370	26	416	190	223	-147	no	yes	272	327	cuy061	after 327	?	>56	no
3000	082	411	23	426	180	233	-178	no	yes	280	352	cuy068		3	>73	no
3000	084	244	27	432	130	239	-5	yes	yes	261	307	cuy021		1	47	no
3000	088	320	29	460	130	267	-53	yes	yes	275	320	cuy063		?	>46	no
3000	091	281	29	452	110	259	-22	yes	yes	275	317	cuy027		1	>43	no
3000	100	377	29	457	55	264	-113	no	yes	307	374	cuy062		3	68	no
3000	lv92-09	258	26					no	yes	287	353	cuy035		?	67	no
3000	lv92-12	363	27					no	yes	299	343	cuy057		?	45	no
4000	001	265	31	479	131	286	21	no	yes	279	348	cuy036		2	>70	no
4000	002	280	25	473	150	280	0	no	yes	299	347	cuy077		2	>49	no
4000	003	106	18	323	14	130	24	no	yes	263	339	cuy037		?	77	no
4000	008	185	27	401	157	208	23	no	yes	289	347	cuy078		2	>59	no
4000	010	299	25	439	0	246	-53	no	yes	294	346	cuy072		2	>53	no
4000	013	222	27	283		90	-132	no	yes	314	350	cuy073		?	37	no
4000	016	240	29	500		307	67	no	yes	302	345	cuy067		?	>44	no
4000	019	291	29	411		218	-73	no	yes	290	323	cuy019		1	34	no
4000	022	170	27	325		132	-38	no	yes	283	336	cuy020		?	>54	no
4000	025	299	30	472		279	-20	no	yes	292	356	cuy049		2	65	yes
4000	026	296	28	462		269	-27	no	yes	304	352	cuy050		2	49	no
4000	033	311	24	476		283	-28	no	yes	283	342	cuy081		2	60	no
4000	044	189	27	328		135	-54	no	yes	257	367	cuy031	367-368 absolute autumn/spring	2	111	yes

Roman-Maas Bridge Cuijk-Mook the Netherlands 1992-93; Dated Piles (n=65 of 334)

APPENDIX I The piles (continued)

excavation area	pilenumber	length	width	UHM	above riverbed	cm NAP height top	cm NAP height bottom	pileshoe	lifted	first ring	last ring	sample number	certain date AD	fase	number of tree-rings	sapwood
4000	048	268	28	454	180	261	0	no	yes	268	359	cuy029		2	92	no
4000	050	260	23	398	121	205	-55	no	yes	254	345	cuy040		2	92	yes
4000	052	273	29	460	116	267	-6	no	yes	296	347	cuy025		2	>52	no
4000	053	294	29	462	153	269	-25	no	yes	262	356	cuy044		2	95	yes
4000	055	324	28	474	155	281	-43	no	yes	299	352	cuy048		?	54	yes
4000	056	305	26	484	162	291	-14	no	yes	250	367	cuy030	367-368 absolute autumn/spring	2	118	yes
4000	057	253	28	439	126	246	-59	no	yes	301	366	cuy071		2	66	yes
4000	064	374	27	479	0	286	-88	no	yes	289	352	cuy054		2	64	yes
4000	066	304	27	482	0	289	-15	no	yes	258	331	cuy080		1		yes
4000	lv89-01	260	27					no	yes	303	352	cuy018		?	50	no
4000	lv89-02							no	yes	302	349	cuy070		2	48	no
4000	lv92-08							no	yes	291	368	cuy076		3	78	no
4000	lv92-10	440	27					no	yes	274	367	cuy041	367-368 absolute autumn/spring	2	94	yes
6000	010							?	no		309	cuy098	325+/-5, after 320	A	55	no
6000	017							?	no		373	cuy093	373, summer, autumn, absolute	B	93	yes
6000	047							?	no		321	cuy097	337+/-5, after 332	A	66	no
6000	048							?	no		358	cuy095	378+/-6, after 372	B	114	no

Roman-Maas Bridge Cuijk-Mook the Netherlands 1992-93; Dated Piles (n=65 of 334)

APPENDIX II The building stones (sorted by thickness)

findnr	thickness	length	width
cu X	18	39	26
4000cu200	21	54	52
2000cu307	24	49	33
4000cu265	24	57	55
cu F	25	76	47
4000cu269	25	54	48
2000cu318	28	48	44
2000cu365	29	72	45
2000cu321	30	65	62
2000cu323	30	74	44
2000cu333	30	70	70
2000cu319	31	63	52
2000cu363	31	97	59
3000cu502	32	58	38
3000cu506	33	95	63
3000cu530	33	86	73
3000cu592	33	102	96
2000cu356	35	88	77
3000cu529	37	69	65
2000cu314	37	64	58
4000cu204	38	88	60
2400cu503	40	146	75
cu N	40	83	53
2000cu355	40	90	50
2000cu324	40	64	69
3200cu601	40	76	45
2000cu306	41	110	81
cu M	41	90	45
cu O	42	93	75
3200cu603	42	89	59
2400cu533	42	75	67
2000cu326	42	74	74
1500cu337	42	78	55
3000cu515	43	102	76
3200cu605	43	87	73
4000cu268	43	90	72
4000cu267	43	93	79
4000cu201	43	98	60
cu K	43	90	76
2000cu330	43	70	70
4000cu203	43	101	63
3000cu534	44	100	56
2000cu315	44	75	70
2600cu003	44	66	72
2600cu002	44	98	79
2000cu325	44	79	59
cu P	44	78	69
3200cu612	45	91	84
4000cu263	45	107	88

findnr	thickness	length	width
3000cu586	45	87	69
2000cu316	45	74	74
4000cu205	45	85	80
2000cu310	45	70	69
4000cu210	45	86	76
3000cu593	45	90	58
2000cu311	45	97	50
2000cu357	45	79	67
3000cu507	45	80	60
3000cu505	45	86	65
2000cu304	45	95	73
2000cu359	45	53	44
2000cu320	45	75	72
cu L	45	95	55
3000cu527	45	80	63
3200cu614	45	95	76
3000cu525	45	85	57
3200cu620	46	80	73
cu A	46	78	70
2600cu001	46	89	53
cu H	46	90	60
cu E	46	90	65
3000cu-aa	46	88	63
3000cu585	46	92	81
3000cu538	46	72	71
3000cu516	46	75	72
4000cu262	47	91	78
3000cu596	47	95	74
3000cu508	47	73	68
3000cu514	47	80	77
3000cu597	47	84	55
2400cu536	47	85	56
3000cu504	47	75	72
2600cu004	48	56	65
4000cu206	48	110	70
3000cu598	48	90	60
2000cu308	48	78	78
4000cu209	49	89	61
2000cu313	50	68	43
2400cu540	50	65	55
3000cu531	50	92	80
1500cu339	54	57	56
2000cu317	55	75	45
1500cu336	56	75	69
1500cu341	60	68	56
2000cu362	60	70	60
2000cu332	70	40	59
2000cu302	74	74	42