

## = Bridge near Limyra =

The Bridge near Limyra ( in Turkish : K?rkgöz Kemer , " Bridge of the Forty Arches " ) is a late Roman bridge in Lycia , in modern south @-@ west Turkey , and one of the oldest segmented arch bridges in the world . Located near the ancient city of Limyra , it is the largest civil engineering structure of antiquity in the region , spanning the Alak?r Çay? river over a length of 360 m ( 1 @,@ 181 @.@ 1 ft ) on 26 segmental arches . These arches , with a span @-@ to @-@ rise ratio of 5 @.@ 3 : 1 , give the bridge an unusually flat profile , and were unsurpassed as an architectural achievement until the late Middle Ages . Today , the structure is largely buried by river sediments and surrounded by greenhouses . Despite its unique features , the bridge remains relatively unknown , and only in the 1970s did researchers from the Istanbul branch of the German Archaeological Institute carry out field examinations on the site .

## = = Field examinations = =

No information on the bridge survives from ancient sources . The first descriptions appear in European travellers ' accounts from the 19th century . The British archaeologist Charles Fellows was the first to explore the region of Lycia , and visited the bridge in May 1840 . Fellows , as well as T.A.B. Spratt and Edward Forbes , who visited the site two years later , describe it as having 25 arches . In 1882 , an Austrian expedition , including Otto Benndorf , interpreted the structure as part of an ancient road that connected Limyra with the city of Attaleia ( modern Antalya ) to the east . However , this mission failed to produce any plans or sketches of the site .

The first , and as of 2008 only scientific examination of the bridge was undertaken by the German archaeologists Wolfgang W. Wurster and Joachim Ganzert in two successive days in September 1973 , and completed through further visits in subsequent years . Their findings were published in 1978 in the Archäologischer Anzeiger journal of the German Archaeological Institute , with the express intent of bringing the imperiled state of the hitherto almost intact bridge into the spotlight :

Recently , citrus fruit plantations were created in this fertile bottomland ; greenhouses for early vegetables are now being built east of the bridge . The bridge is greatly endangered through the beginning of intensive cultivation in the vicinity . The locals strip the still intact bridge surface for stones ; bulldozers employed to build irrigation canals rip the structure apart and crush the stone pavement with their caterpillar tracks .

In 1993 , the civil engineer Colin O 'Connor summarized their report in his English @-@ language monograph on Roman bridges , and also emphasized the exceptional character of this bridge . No further scientific examinations of the Limyra Bridge are known .

## = = Location and situation = =

The bridge crosses the Alak?r Çay? stream , whose ancient name is unknown , 3 @.@ 2 km ( 2 @.@ 0 mi ) east of the ruins of Limyra ( distance measured from the city 's theatre ) and 3 @.@ 8 km ( 2 @.@ 4 mi ) north of the modern coastline , close to the modern road from Turunçova to Kumluca . The local topography is dominated by the foothills of the Toçak Da?? mountains , which blend here with the alluvial bottomlands of the Bay of Finike . In this transitional area , the bridge was built immediately above the point where the narrow river valley opens into the wide estuary plain , and where the crossing of the river during the rain period would be obstructed by high water . While the eastern end of the bridge levels off at the gravel plain , the western end abuts directly to the rising rock wall of the mountain , presumably for protection against floods . The resulting sharp bend in the course of the road could also be exploited in case of need to block the road . A modern dam , Alak?r Baraj? , was constructed upstream for irrigation purposes and flood protection .

Lycia did not , in contrast to other Roman provinces , possess a very developed road system . While the north ? south traffic was conducted primarily through the few river valleys , the east ? west routes led , unlike today , mostly on and along the mountain ridges . This particular road , leading from Limyra over the Alak?r Çay? and into the neighbouring region of Pamphylia and Attaleia , must

have been of special importance , since the two regions were united in a single province , Lycia et Pamphylia , until the 4th century . In comparison to the main arterial roads of the Roman Empire however , the roads of Lycia were , with 3 ? 4 m ( 9 @. @ 8 ? 13 @. @ 1 ft ) width , rather modest and confined to pedestrian and pack animal traffic . This is further corroborated by the fact that no wagon ruts are evident on the paving of the Limyra bridge , nor any traces of a parapet or breastwork .

= = Construction = =

With a length of 360 m ( 1 @, @ 181 @. @ 1 ft ) , the Limyra Bridge qualifies as the largest surviving engineering achievement of antiquity in Lycia . The bridge stands on 26 uniform segmental arches consisting of a double , radially laid course of bricks . At the eastern end , the original 27th arch has been replaced by two smaller , semicircular arches of later construction . The latter are built with a single course of bricks . Traces of the original , flat beginning of the collapsed arch are still visible on the piers .

At the time of Wurster 's and Ganzert 's visit to the site , the entire bridge was buried by river sediments up to the springing line of the vaults . No efforts to dig them up were undertaken by Wurster and Ganzert . Only two of the 28 arches were exposed enough so that direct measurements of the clear span and the pier width could be undertaken . It was , however , possible to calculate the dimensions of the remaining bays from their exposed sections .

= = = Architecture = = =

= = = = Arches and piers = = = =

The spans of the arches ranged from 11 @. @ 60 m ( 38 @. @ 1 ft ) to 14 @. @ 97 m ( 49 @. @ 1 ft ) ( arches 2 and 26 respectively ) . Based on the size of the spans , one can distinguish four groups , with the following median values :

11 @. @ 60 ? 12 @. @ 30 m ( 38 @. @ 1 ? 40 @. @ 4 ft ) for four arches ( Nos. 2 , 3 , 7 , 21 )

12 @. @ 75 m ( 41 @. @ 8 ft ) for fourteen arches ( Nos. 5 , 9 ? 15 , 17 ? 19 , 22 ? 24 )

13 @. @ 10 m ( 43 @. @ 0 ft ) for four arches ( Nos. 1 , 4 , 6 , 8 )

13 @. @ 60 m ( 44 @. @ 6 ft ) for three arches ( Nos. 16 , 20 , 25 )

The reason for this grouping is unclear ; they certainly cannot be attributed to an attempt to match the lay of the river bed . The differences however could point to the repeated use of differently @-@ sized falsework structures in the construction of the barrel vaults ( see animation below ) .

Only in a single case , between arches 26 and 27 , were Wurster and Ganzert able to determine the breadth of a pier : 2 @. @ 10 m ( 6 @. @ 9 ft ) . Subtracting this value from the common arch span of 12 @. @ 75 m ( 41 @. @ 8 ft ) , a clear span of 10 @. @ 65 m ( 34 @. @ 9 ft ) remains . Since all arches have a rise of ca . 2 m ( 6 @. @ 6 ft ) , the Limyra Bridge has an unusually large span @-@ to @-@ rise ratio of 5 @. @ 3 to 1 . Such flattened arches were very rare at the time for stone bridges , and were not matched and surpassed until the reappearance of segmental arch bridges in 14th century Italy . For the largest arch in the Limyra Bridge , the ratio is even greater , spanning a width 6 @. @ 4 times its height . The two later arches , in contrast , are , with a ratio of 2 @. @ 7 : 1 , quite ordinary semi @-@ circular arches .

= = = = Height = = = =

The total height of the bridge could not be determined because most of the structure is silted up . However , the distance between the arches ' abutments and the pavement surface could be determined at only 3 @. @ 25 m ( 10 @. @ 7 ft ) .

The surface level is almost horizontal : the roadway lies at a height of 20 @. @ 05 ? 20 @. @ 55 m ( 65 @. @ 8 ? 67 @. @ 4 ft ) above sea level between arches 1 to 20 , and falls slightly in its eastern

section , between arches 21 and 26 to a level of 19 @. @ 94 to 19 @. @ 66 m ( 65 @. @ 4 to 64 @. @ 5 ft ) . Since there is no indication of a later sinking of the structure , this nearly uniform height indicates careful levelling and the existence of solid pier foundations . In contrast , the lengthwise axis of the bridge displays often significant deviations from arch to arch .

===== Statics =====

Remarkably , the support line of the structure 's dead load is almost identical with the curve of the vault arch . The statical analysis of the bridge proves the structure 's great load capacity :

In modern classification , the bridge would be able to support loads of a Class 30 bridge ( per DIN 1072 ) ; this would mean , that it could support a 30 @- @ tonne vehicle on one arch and additionally on the remaining surface of the arch a load of 500 kp / m <sup>2</sup> . The bridge was thus very safe for ancient traffic .

===== Materials =====

The Limyra bridge was built in a composite manner of brick , stonemasonry , and rubble .

===== Arches =====

The bricks of the segmental arches are made of yellow @- @ red clay , mixed with fine brick fragments . The bricks are rectangular plates , measuring ca . 40 cm x 50 cm ( 15 @. @ 7 in x 19 @. @ 7 in ) and 5 cm ( 2 @. @ 0 in ) thick . They are placed with the shorter side upright facing outwards , so that the total thickness of the arches measures ca . 80 cm . The bricks are bound with grout of lime mortar mixed with brick shards and fine gravel , forming 4 cm ( 1 @. @ 6 in ) -thick joints . The two later semi @- @ circular arches were built with smaller bricks , although surviving bricks from the original arch were re @- @ used at places . The abutment stones are dressed limestone ashlar blocks , and form a sloping surface to support the arches .

The double @- @ layer technique facilitated a more effective use of the falsework , since they could be removed and used elsewhere as soon as the lower course was finished :

The construction of the two layers of the double brick @- @ arches in two separate phases had two advantages . In the first phase , the falsework only had to carry the weight of the lower course , so that it could itself be of lighter construction . In the second phase , the weight of the upper layer could be already borne by the lower vault ; the falsework was thus already available for use in a different arch .

===== Superstructure =====

As far as can be determined , between arches 2 to 21 , the outer facing of the superstructure consists of four layers of brick , followed by layers of rough stonemasonry bound with mortar . In contrast , between arches 22 and 26 , as well as in both ramps on either end , the facing consists of ashlar blocks . The two repaired arches 27a and 27b are differentiated from the earlier work through the use of smaller unworked stones and the incorporation of irregularly placed brick tiles . In arch 26 , the lower side of the arch still features a projecting bearing used for the placement of the falsework .

The interior of the superstructure consists of a combination of unworked masonry blocks and large river boulders , bound with lime mortar .

===== Pavement =====

The bridge surface is located only 30 ? 40 cm ( 11 @. @ 8 ? 15 @. @ 7 in ) over the arches ' apex , is 3 @. @ 55 ? 3 @. @ 70 m ( 11 @. @ 6 ? 12 @. @ 1 ft ) wide , increasing towards either end at 4 @. @ 30 m ( 14 @. @ 1 ft ) and projects ca . 10 cm ( 3 @. @ 9 in ) over the superstructure on either

side . It is paved with large and irregular limestone cobblestones , although smaller pebbles have been used in the repairs at the two semicircular arches .

= = Dating = =

The exact chronological placement of the Limyra bridge is difficult due to its unique place within Roman engineering tradition and the lack of comparable structures . Wurster and Ganzert used following characteristics as a starting point :

- multiple arches of same width , and horizontal deck level with only small @-@ gradient ramps on either end

- very flat segmental arches built with double , radially layered brick courses

- the use of mortar in the stonework

- exterior facing primarily rough masonry with interspersed bricks , partly dressed ashlar blocks

- exceptionally large paving stones .

In contrast to these , most Roman stone bridges were faced with ashlar and rested on voussoir arches , a method which is dominant in other vaulted structures in Lycia too . Compared to the massive and tall semicircular @-@ arched bridges that are typical of Roman architecture , the Limyra bridge , with its flat segmented arches , offers a markedly lower and more elongated appearance , so that Wurster and Ganzert offer a " provisional " late dating , approximately during the reign of emperor Justinian I in the 6th century , during which the use of mixed brick and stone is attested in other structures of the region .

On the other hand , this mixed technique is already present in the 3rd @-@ century AD aqueduct of Aspendos , and the Romans certainly knew how to build segmented @-@ arched bridges , as attested by surviving examples , three of which are listed by Wurster and Ganzert themselves . An earlier construction date in the 2nd or 3rd centuries AD cannot therefore be excluded . The case for an earlier construction date has been strengthened in recent years with the discovery of further seven Roman segmented arch bridges . The remnants of the nearby Kemer Bridge over the river Xanthos , which dates to the 3rd century and has some architectural similarities with the Limyra bridge , could further reinforce that case .