Edgar Cardoso's bridge at Quiamafulo, Angola. Design and Construction in the late 1950's of the third road viaduct across the River Cuanza.

José Luís Possolo de Saldanha
Department of Architecture and Urbanism, ISCTE – Lisbon University Institute. Researcher at Dinâmia-CET'IUL

Abstract

Designed by the leading Portuguese civil engineer Edgar Cardoso, the Quiamafulo Bridge was the third road viaduct to span the Cuanza River in Angola, and the one closest to the country's capital, Luanda, therefore shortening distances to its sparsely populated hinterland. Located upstream from where the Cambambe dam and hydroelectric facility was being constructed, the Quiamafulo Bridge remained in use until it became submerged in 2017, following the augmentation of that hydroelectric facility, and the resulting enlargement of its reservoir. This called for a fundamental study on this bridge, which eminently served the Angolan road network for more than half a century, focusing on its project and construction. Since bridges take part in larger systems – as river basins do - notes are given on other viaducts built across the Cuanza during the Portuguese colonial period in Angola. Research drew upon previously unpublished sources archived at Lisbon's Arquivo Histórico Ultramarino (AHU), and from Cardoso's engineering company; through delving into newspapers published when the dam and bridge were built; comparing this bridge with other structures from that period by Cardoso; and on-site visits.

Keywords

Quiamafulo Bridge; Edgar Cardoso; River Cuanza; Angolan Road Network; Cambambe Dam; hydroelectricity in Angola.

Introduction

The bridge across the River Cuanza, at Quiamafulo, municipality of Dondo, Angola, serving the road from Luanda to Nova Lisboa (presently, the city of Huambo), was designed by the most influential professional in the Portuguese Civil Engineering history, Edgar Cardoso. He was born in 1913, in the village of Resende, overlooking the Douro river, almost 100 km upstream from the city of Oporto, where he gained his degree in Civil Engineering in 1937. After graduation, he completed an internship at the Junta Autónoma das Estradas (the Portuguese road management body), in Lisbon.

Cardoso's experience in bridge design ultimately prompted him to establish his private engineering company in Lisbon, in 1944, which he ran until the time of his death, in the year 2000. By 1951, his growing reputation earned him the position of Professor in Bridge Design at one Portugal's foremost School of Engineering, the Instituto Superior Técnico,[1] part of the Lisbon Technical University (which merged into the University of Lisbon in 2013), which he held until 1983, upon reaching his retirement age.

Cardoso designed countless bridges on several continents, which became references in bridge design, particularly in Portuguese speaking territories. Across the Douro alone (on which left bank Cardoso was born), these included the easternmost bridge in Portugal on that river, at Barca d'Alva (to be referred further in the article), inaugurated on 22 June 1955; the Arrábida Bridge, in Oporto - built at the same time as the Quiamafulo Bridge - featuring a single 270 metre concrete arch which, at the time of its inauguration in 1963, was the longest span in the World;[2] the Mosteirô Bridge, designed in 1968 and inaugurated in 1971; Cardoso's final major opus, the São João railway bridge, in Oporto, which came into use in 1991.

Concrete bridges were being built many decades before Cardoso's most daring achievements. In Switzerland, the civil engineer Robert Maillart (1872–1940) had revolutionized the use of structural reinforced concrete, particularly with his designs using three-hinged arches and the deck-stiffened arches for bridges. The wonderful single-arch Salginatobel Bridge, built over a deep ravine in the Alps during 1929 and 1930, exemplifies his innovative ideas. As the main academic and designer of bridges in Portugal, Cardoso was well familiar with those accomplishments. However, it would be some time before these concepts were applied in Sub-Saharan Africa.

The most developed territories in that part of the continent, which came to integrate the Union of South Africa in 1910, saw the first use of reinforced concrete in bridge construction, in 1908. Built across the River Kowie at Port Alfred, in what was then the British Cape Colony, its rather stiff design was the work of engineer Frank William Waldron. Its use of 'a series of continuous girders supported on piles, would have been considered daring at the time if executed in steel, [however] in reinforced concrete it was considered shear lunacy'.[3] Several reinforced concrete bridges in South Africa followed, including the single-span Paul Sauer deck-arch bridge, designed by the eminent Riccardo Morandi. Built in the same decade as the one at Quiamafulo, 120 metres above the Storms River, it was at the time, the highest bridge in Africa. Nevertheless, multiple-arch viaducts in southern Africa built using reinforced concrete were quite scarce.

The remoteness of the Quiamafulo Bridge's tropical location evokes scenes from David Lean's classic Hollywood film, *The Bridge over the River Kwai* (1957). Set against the backdrop of war, a fate which Angola would also come to suffer after February 1961, the film was released in the same year that Cardoso made his first project to span the Cuanza. Located many kilometres from its source of building materials, the on-site technical options were limited, partly explaining why this Angolan bridge does not quite align with other cutting-edge designs of its day. Research showed the initial project by Cardoso was bolder (and, as usual with its designer, advocating a previously untried solution) than the one ultimately built, after successive circumstances imposed considerable changes to its design.

According to Cardoso, Angola had 'the first bridges in the country [Portugal],[4] of the spandrel-arch-deck compound type; one on the River Dange […] and the other on the Cuanza River, on the Dondo-Nova Lisboa road',[5] the latter being the one at Quimafulo – with an open spandrel – which was also the first sizeable multi-span arch bridge in Angola, entirely made of reinforced concrete. On the other hand, the territorial, social and political importance of the Quiamafulo Bridge is to be enhanced, as it shortened distances and opened new routes into the Angolan outback.

The Quiamafulo Bridge came into use in 1959, some 3.5 km upstream from where the Cambambe dam construction was starting. Cardoso had been aware, since 1956 – before he was commissioned to design the bridge – that the Cambambe hydroelectric facility was to be built, although it was expected at a slightly different stretch of the river. In fact, the Quiamafulo Bridge and the Cambambe dam were inextricably linked from their inception. Hence, this paper also deals with their relationship, particularly tracking the technical and political decision, from the late 1950's, to move the site of the hydroelectric facility some kilometres downstream, thus heavily encumbering the construction of the bridge. This structure is framed from the historical and typological point of view, particularly regarding the changes it underwent between its original July 1957 scheme; the version labelled 'provisional', from December 1957 and resumed in December 1958; and the one which was finally built.

The fate shared by this viaduct and the dam culminated with the increase of the latter's height in 2017, when its second hydroelectric power station started operating, to the elevation originally proposed in the late 1950's. This finally allowed its crest to be crossed, as expected back then, albeit too late for its integration in the modern Angolan road network. It also compelled the crossing of the Cuanza River by the Dondo-Huambo road, which had to be repositioned more than a kilometre upstream, where a new bridge was built to replace the one at Quiamafulo, now permanently submerged by the reservoir's enlargement. This was not the only structure by Cardoso to undergo such a fate, since his Abragão Bridge, in the Portuguese 'metrópole' (European Portugal), also became submerged by a dam. Conversely, Cardoso designed bridges across rivers, which had been enlarged into reservoirs for new dams: at Mosteirô or Vale da Ursa, also in present-day Portugal.

Historical and territorial background

The Cuanza is the largest river with its source and course entirely inside Angola's borders. Its lower stretch was historically the main route into the country's hinterland, since it was navigable up to the city of Dondo. Its key importance for the country even provided the name for the independent Angolan currency: the *Kwanza* (also spelled *Quanza*). The Cambambe waterfalls, however, blocked the river's navigation any further, ten kilometres upstream from the Dondo port, at the site where the eponymous Cambambe dam was built.

The broadness and might of the Cuanza explain why it could only be crossed on barges. The first bridge to span it was built almost 1000 kilometres upstream from the river mouth, to the east of Camacupa (a village named 'General Machado' before Angolan independence), although it only served the Caminho de Ferro de Benguela (CFB - Benguela Railway Company). This is the only railway which connected Angola with the international African railway system, from its main station at Lobito – the largest sea port in Central Angola – to Vila Teixeira de Sousa (presently named Luau), on the frontier with the Democratic Republic of the Congo. It was a steel bridge imported from England, and assembled on the site where parts of the original structure can still be seen. It became damaged beyond repair during the 40 years that the railroad was out of use, when in 2015 the line was put back into service, and a new concrete bridge replaced it.

In 1932, the first road bridge, named 'Filomeno da Câmara', was built across the River Cuanza, to serve the road to Libolo, running southward from a junction on the Dondo to Malanje road. This structure is documented in the file *Pareceres do Conselho Superior de Obras Pública* (Technical Reports of the Public Works High Council) archived at Lisbon's *Arquivo Histórico Ultramarino* (AHU),[6] as well as the file 'Angola. Processos Antigos. Ponte sobre o Rio Cuanza' (Angola. Old Processes. Bridge across the Cuanza River), the former of which includes a report stating 'this bridge on the Cuanza is at the moment the most important work of engineering in Angola'.[7]

The Filomeno da Câmara Bridge was built in two stages: initially, it was meant to have a wooden deck set on timber beams, to be supported by three piers, and abutments made of massive squared masonry. However, during its construction, technical objections from the Superior Council of the Ministry of the Overseas Public Works and Mining saw its elevation heightened by 1.5 metres, to safeguard it against flooding. Furthermore, that supervisory body ordered three piers, with a more streamlined, hydrodynamic design, to be added to the structure, closer to the river´s left bank (as seen at the left of Fig. 1), to enlarge the bridge full span. This refined section of the structure also had a wooden deck, but supported on steel girders instead.

The second road viaduct to span the Cuanza, located at Porto Condo (near Cangandala), was built in the utter wilderness, for the road connecting the city of Malanje down to Cuíto, at Angola's geographic centre, more than 400 km upstream from the river's mouth. This partly explains its conventional design and construction. Inaugurated on 15 August 1951 by the Angolan Governor-General, José Agapito da Silva Carvalho,[8] it used the patented Monier bridge system. Patented in 1873 by the Frenchman Joseph Monier (1823–1906), this system closely emulates the tradition and shape of bridges built in stone, resorting to barrel vaults. Accordingly, the Porto Condo viaduct encompasses 14 spans of 18 metres apiece, and a fifteenth additional 32 metre wide span, to allow for larger boats to navigate under it (Fig. 2), all of which made with reinforced concrete barrel vaults, which formwork and steel rods may be seen in photographs of their construction kept at the AHU.[9]

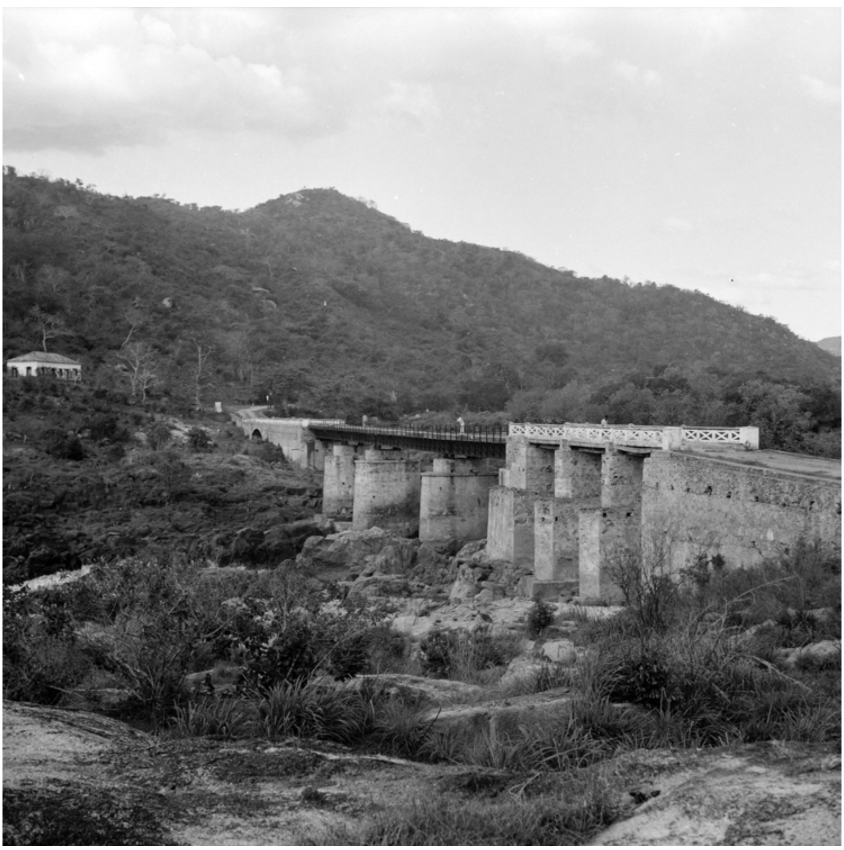

Figure 1. 'Ponte Filomeno da Câmara'. Credit Portugal, Arquivo Histórico Ultramarino – PT, AHU - Id: 14071, reference AGU/ECC/NC6943. Initial bridge section seen to right, and more streamlined stretch, to left.

Figure 2. 'Malange - ponte Dr. Oliveira Salazar', possibly taken upon its inauguration. Credit Portugal, Arquivo Histórico Ultramarino – PT, AHU - Id: 18125, reference AGU/PI 669.

For many years, the road bridge at Porto Condo was the longest bridge in Angola,[10] but it was badly damaged during the Angolan civil war, with the destruction of two of its arches in 1976. These were provisionally replaced by a steel structure, but in 1992, this temporary repair was also destroyed, along with the collapse of one of the pillars and of the three arches closer to the Cuanza right bank (including the 32 meter one). This rendered the structure unusable, until it was thoroughly renovated by the Armando Rito Engineering Company, during this century's first decade.[11]

The third bridge built across the Cuanza, at Quiamafulo, was to be positioned close to the village of Dondo (location seen in Fig. 3, along with those for the two previously built road bridges on this river). Its construction was first discussed in 1951, which is the earliest date it is recorded, in its official Overseas Ministry file archived at Lisbon's AHU.[12] An invoice by Edgar Cardoso's office for designing a bridge at Quiamafulo also dates from August of that year.

Along with the shortage of available materials and technical resources, the magnitude of river courses and other geographic difficulties also had to be tackled. Documents contained within the AHU files, on all cited bridges across the Cuanza, evidence the lack of trained designers and contractors in Angola at the time they were built, particularly at inland parts of the country. At an early stage, foreign engineers would be engaged for some of the work, such as the original railway bridge at Camacupa, imported by the CFB, which, by the way, was founded by the Scottish mining engineer, Sir Robert Williams (1860–1938), an associate of Cecil Rhodes (1853–1902), particularly with regard to developing railways. This difficulty was even greater with road bridges, since these were independently designed and built, outside those wider investments.

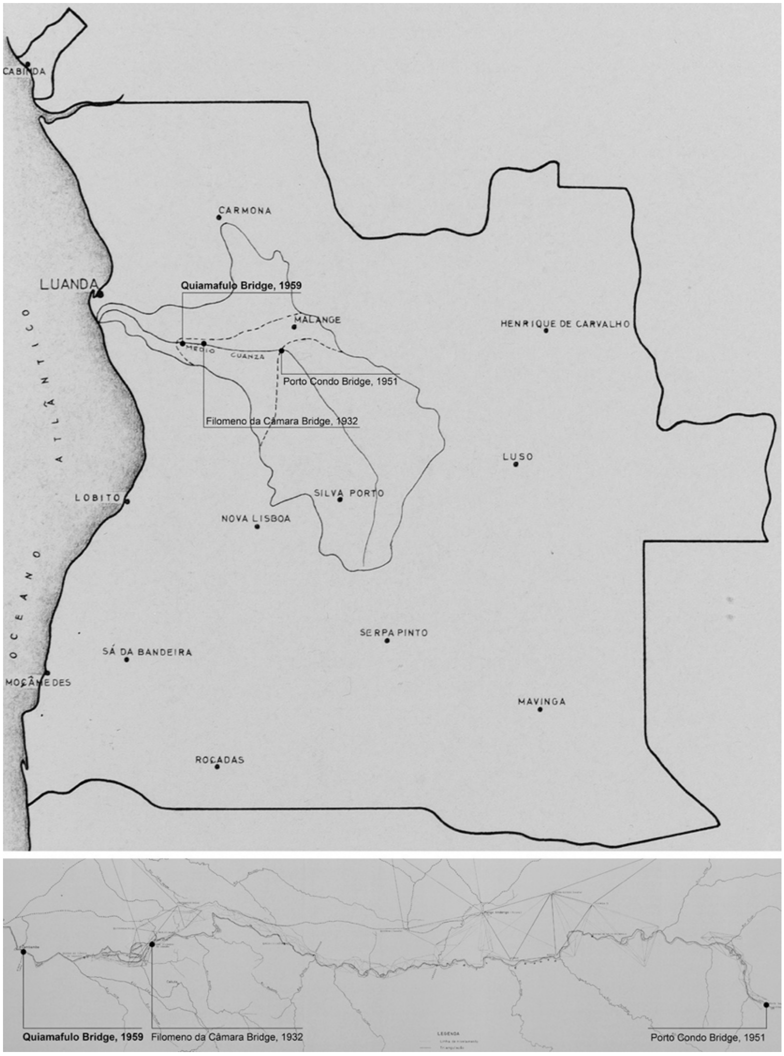

Figure 3. Location of Cuanza road bridges, pinpointed on excerpts from drawings 1 (above) and 39 (below), from 'General Plan of the Middle Cuanza'. Credit Portugal, Arquivo Histórico Ultramarino – PT, AHU file PT/IPAD/MU/DGOPC/GE/12495, 1962.

In 1944, the Minister of Colonies, Professor Marcelo Caetano (who would succeed Oliveira Salazar in 1968, as the last Prime-minister of the Estado Novo dictatorship), introduced legislation establishing the Gabinete de Urbanização Colonial (Colonial Urbanization Office), in Lisbon,[13] to overcome the shortage of specialized designers in the Portuguese Colonies.

Although the legislation prescribed that the Office should be headed by an engineer, it mostly focused on public buildings, urban planning and infrastructure. Engineering projects were usually designed locally, on the initiative of the General-Government of the colony, even if it had to be endorsed in Portugal. The designers would belong to provincial, or regional, departments of government, which were often ill-equipped, and somewhat empirical in their approach.

The Filomeno da Câmara Bridge was designed at the Angolan Public Works Directorate, but its construction was freely adapted, on site, by the Circumscription Administrator, Mr. Raúl Lima. This explains why the Public Works and Mining Superior Council, in Lisbon, appointed a new official body – the Angolan Road Brigade – to take over the work, and finished it with the previously mentioned additional piers. The bridge at Porto Condo, on the other hand, was the work of engineer António Pais, who was provisionally heading the Malanje Provincial Public Works Detachment, and oversaw its construction, under engineer Mendonça Lopes.[14]

The number of professional engineers working in Portuguese colonies was boosted when citizens from those colonies returned home after graduating at universities in the so-called 'metrópole', as university education was not authorized in the major Portuguese colonies of Angola and Mozambique, until 1962.[15] They were eventually joined by a few European colleagues, who immigrated to Africa during the economic boom in those territories, in the late 1950's and early 1960's. Collectively, they generated a larger body of professionals capable of answering most engineering challenges. However, major projects in Angola, such as hydroelectric dams or large transportation investments (like the ore terminal at Saco do Giraúl, Moçâmedes, also by Edgar Cardoso), would remain the work of professionals based in Portugal, even if they regularly visited the worksites, as shown in photograps of Cardoso, in the Quiamafulo Bridge files.[16]

The Quiamafulo case-study attests to the hierarchical gap between engineers operating in the colonies, and those based in Portugal. The project for the bridge was the responsibility of the Angolan 1st Road Brigade, on which, as a Board Member of the Fundo de Fomento Ultramarino (the Portuguese body supervising overseas investment funding), Cardoso was asked to produce a technical report. After identifying many faults with the project, he ended up having the Angolan Governor-General and the Undersecretary of State of the Overseas recommission it to him![17]

Edgar Cardoso's July 1957 Project for the Quiamafulo Bridge

Edgar Cardoso was well known for a catchphrase: 'In every river, there is a place meant to get a bridge'.[18] In this sense, Quiamafulo was not all in all a specific spot on the Cuanza, even though its name was given to a sandy beach accumulating along its right bank, after the Cambambe dam was finished, making it a popular venue for locals daring to bask in the Sun and bathe in the crocodile infested waters. Consequently, as Martin Heidegger once put it, *Quiamafulo* was not quite there before the bridge was:

> Before the bridge stands, there are of course many spots along the stream that can be occupied by something. One of them proves to be a location, and does so because of the bridge. Thus the bridge does not first come to a location to stand in it; rather, a location comes into existence only by virtue of the bridge.[19]

The July 1957 project for the bridge at Quiamafulo, by Cardoso, includes a file with a descriptive document, justifying calculations, specifications, worksheets, cost estimations (reasoned at 5,277,341 escudos), as well as a set of drawings and graphics, and a separate dossier for larger scaled drawings.[20]

The descriptive document includes photographs of models, which were typical of Cardoso's conceptual processes (Fig. 4). It describes the project as a bridge to be erected on the river Cuanza, close to Dondo, at Quiamafulo, on the 1st Class National Road nr.5, downstream from where the great Cambambe dam was expected to be built. It stated that the construction of this hydroelectric facility would not be started before 1959. Therefore, the bridge to be built on the dam's crest, which would enable the crossing of the river, was not expected to be completed before 1961 or 1962. Cardoso added that, for that reason, it had been decided at the highest political level, that it would be most convenient for the construction of the dam, if the Quiamafulo bridge was completed, two or three hundred metres downstream from the dame, some time during 1959.

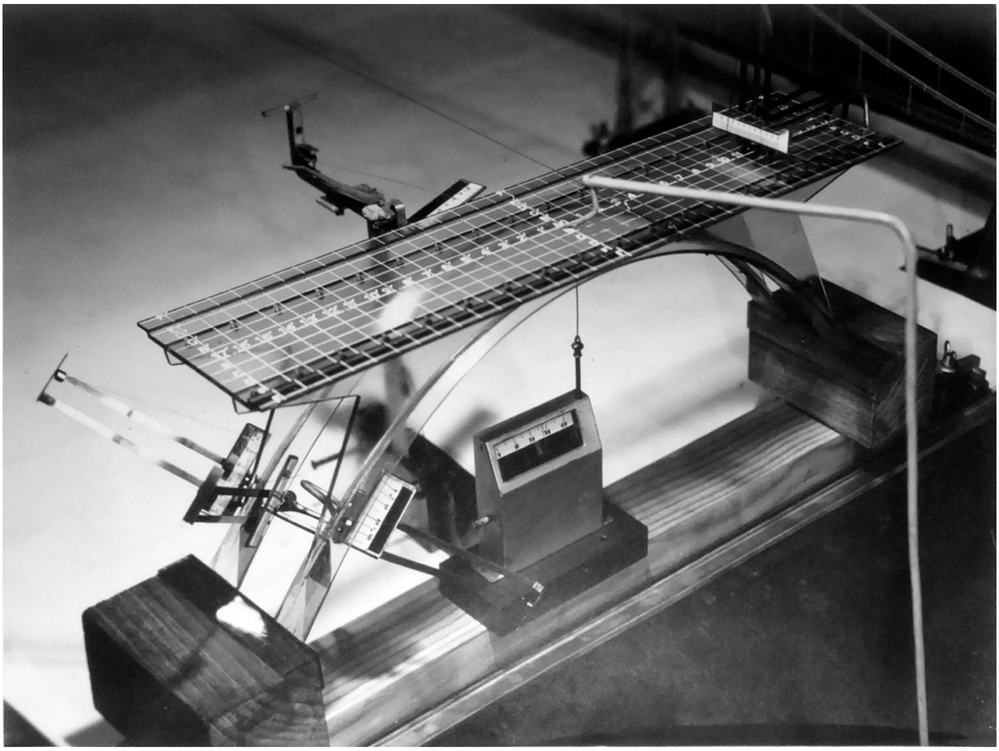

Figure 4. Quiamafulo Bridge test model. Credit Portugal, Arquivo Histórico Ultramarino – PT, AHU file PT/IPAD/MU/DGOPC/DSPE/1773/17461.

The bridge was designed with five reinforced concrete spans, in an arch, supported on four pillars of mass concrete with a hydrodynamic profile, spaced at 36 metres between axes, and on two lightweight abutments. It should have a straight usable span of 170 metres, with an elevation difference between the grade line and the dry season waters of some 21 metres, from where the Cambambe dam should be seen in all its might. According to Cardoso, the high elevation of the grade line called for the arch solution, while all pillars and abutments should be executed in the dry. As the waters in the dry season ran through a narrow canal less than 20 metres across, coffer dams could be avoided. Considering the river profile and the site conditions, Cardoso suggested that the guidelines followed in the construction of the bridge he had recently built at Barca d'Alva, on the river Douro, would also be suitable. At Quiamafulo, Cardoso preferred a dihedral angle section for the rib-arches, instead of the rectangular section followed at Barca d'Alva, which was to facilitate the casting of concrete, while requiring less steel reinforcement.

The drawings for this project date from July 1957, and a photograph of a model of it may be seen on the cover of the 13 December 1957 issue of the newspaper *O Comércio de Angola*. In that opening page, an article also declared that, at the 'until then deserted Cambambe scrub, a small town should arise, where thousands of workers building the mighty dam should dwell'.[21]

The descriptive document for the bridge indicates that a criterion was established for the cost of the superstructure to equal that of the foundations, piers and abutments (substructure). This followed the principle of rejecting heavy work with massive sections and materials of lesser quality, rather advocating a solution with minimal material, although of a higher quality.

The solution executed on the Cuanza is quite similar to the one at Barca d'Alva indeed, which had been completed in 1955, although the distance between its abutments lies around 225 metres, whereas at Quiamafulo, it was set at 178.62 metres. Consequently, the bridge at Barca d'Alva received an additional sixth arch, while its piers stand 37 metres apart. Its spans also include three parallel ribs, whereas at Quiamafulo, each span should have only a pair, to be biarticulated at their bearings, with sections formed by two oblique obtuse-dyhedral folds, with a varying width from the crown to the bearings. Each arch rib in the Angolan bridge was to be composed by the 250 millimeter thick spandrels, set on two parallel arches at each side of the bridge. The pair of arch/spandrels, along with the deck slab, should form a compound structure, with an inverted-U shape (as seen in cross sections of *'Superstructure steel reinforcement details'* drawing - Fig.5).

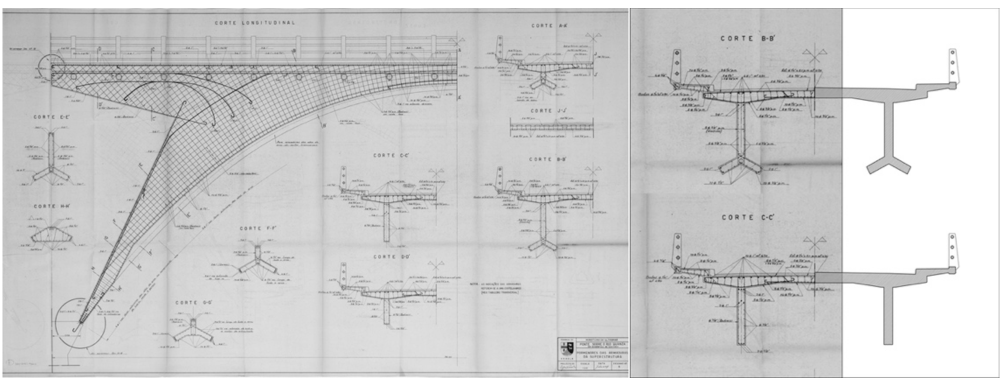

Figure 5. 'Superstructure steel reinforcement details'. July 1957 project, drawing 5. Credit Portugal, Arquivo Histórico Ultramarino –PT/IPAD/MU/DGOPC/DSPE/1773/17462 (left), and detail of compound spandrel-arch-deck and spandrel-deck sections, with mirrored, filled-in half by article author (right).

Both bridges show clear resemblances, although the piers at Barca d'Alva follow a planimetric geometry, whereas at Quiamafulo, they are more complex and hydrodynamic hefty blocks of mass concrete, with a section formed by two juxtaposed half-ellipses and a central rectangle, lying on elongated conical cutwaters (Fig. 6). The load transmission from the arches to the piers is achieved, in both cases, onto concrete blocks consolidated with the pier imposts. The foundations at Quiamafulo were executed directly, with mass concrete footings built off the bedrock, with their upper surfaces levelled with the riverbed, so as not to disturb the free water flow.

The Quiamafulo Bridge should have a 6 metre-wide wearing course, just like the Barca d'Alva bridge, and identical one-metre side footpaths made of concrete, with a tooled-joint square grid surface set at a 45° angle. The similarity between bridges is also in evidence in the deck's edge beams, on which the reinforced concrete acroteria lie, to receive the guard-rails. Unlike the Barca d'Alva bridge, where the three arches are interconnected by cylindrical beams, at Quiamafulo, no transversal braces between arches were expected, because, once the construction was complete, and the various carrying elements in the superstructure interconnected (arches, spandrel walls and deck), the whole system would resist the applied actions. These included stresses derived from, the vertical loads, the temperature variation, the concrete shrinkage, the braking actions, and particularly the wind loads. No seismic actions were considered.

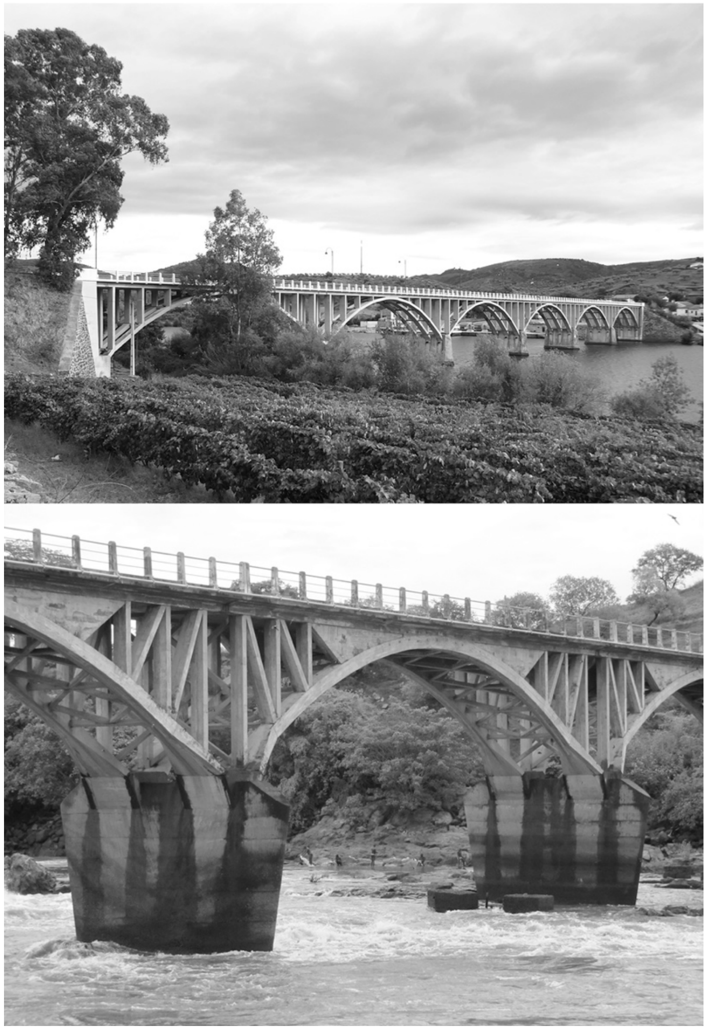

Figure 6. Barca d'Alva (above) and Quiamafulo (below) bridges seen from river right banks (Photographs: J. Saldanha, Sept. 2020, and courtesy A. Rito & P. Cabral, Dec. 2009). Notice people on opposing bank of the Cuanza, for scale.

The spandrels would be hollow above the piers, producing a 5.50 metre span cantilever (Fig. 5), to reduce the wind thrust and facilitate the system's performance. The peculiar appearance of the design (Fig. 7), confirms that Cardoso hardly ever repeated himself, and what he usually said about his bridges: 'I don't make a bridge like another, because each work is a moment for innovation and search for new, more rational and economical solutions'.[22]

The hinges of the rib-arches were accomplished with lead plates embedded in reinforced concrete blocks in the arches, piers and abutments. The bridge deck would have expansion joints (Fig. 8) at the piers and abutments, designed so as to allow for free horizontal expansion, while arresting any differential vertical thrust. These devices forced the cantilever extremities to the same rise, so, both cantilevers collaborated in the absorption of the major concentrated loads.

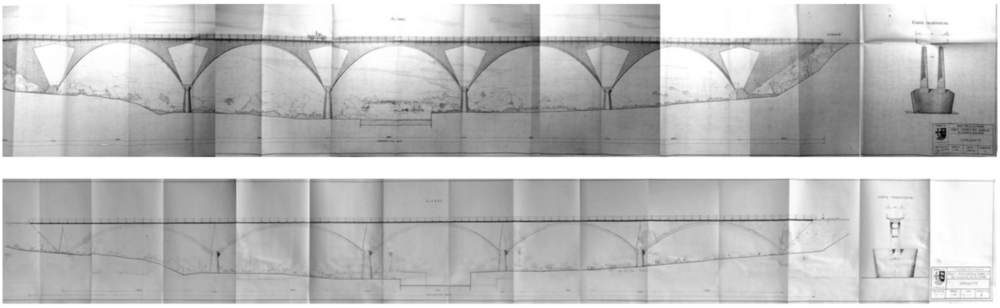

Figure 7. Elevations of Quiamafulo bridge in July (above) and December 1957 (below). The latter's superstructure to be set on piers cast for the former. Credit: Portugal, Arquivo Histórico Ultramarino – PT/IPAD/MU/DGOPC/DSPE/1773/17461 and PT/IPAD/MU/DGOPC/DSPE/1773/17464.

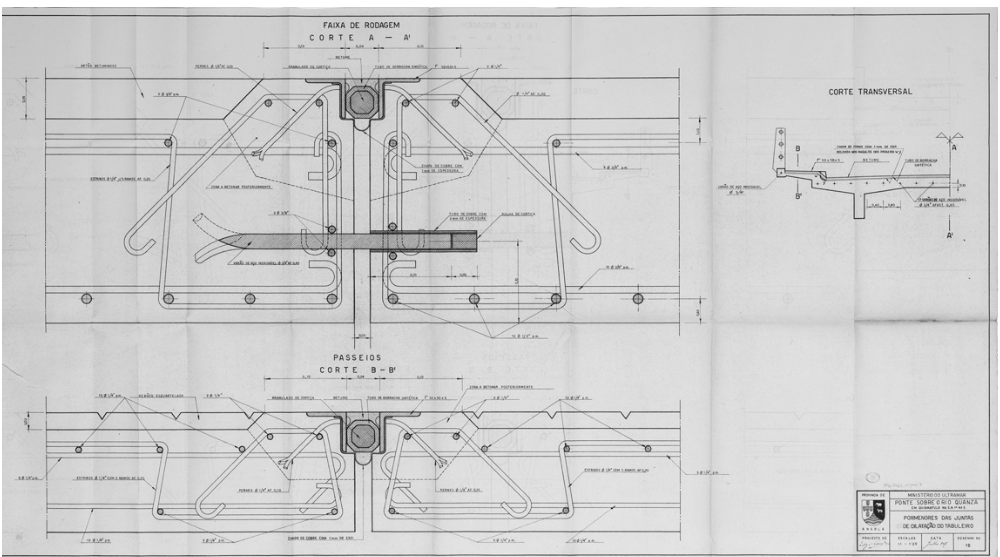

Figure 8. 'Details of deck expansion joints' [for wearing course - above - and sidewalks - below]. July 1957 project, drawing 10. Credit Portugal, Arquivo Histórico Ultramarino – PT PT/IPAD/MU/DGOPC/DSPE/1773/17461.

The Sonefe Cuanza Middle-Stretch Concession

The Quiamafulo Bridge was not built according to the July 1957 plans produced by Edgar Cardoso. The proposed deck elevation, set at 120 metres, was abandoned when the position for the Cambambe dam was moved some 5 kilometres downstream from the site initially selected by the American Hydrotechnic Corporation.

According to the 21 April 1958 issue of the Lisbon newspaper *Diário Popular,*[23] the preliminary appraisal of the hydro-agricultural and hydroelectric potential of the rivers Cuanza, Bengo and Lucala had been included by the Portuguese Government in the group of projects to be supported by the

European Recovery Program, in 1951. This plan, set up by the United States Secretary of State, General George Marshall (1880–1959), regulated the United States' financial aid policy for the economic reconstruction of Western Europe following the Second World War. The *Marshall Plan*, as it came to be known, was to be implemented between the 1949 and 1952. Although Portugal had not entered the conflict, the country was still included in the programme, thus benefiting from funding from the second and third 'Marshall years' (1949/50 and 1950/51). This enabled Portugal to balance its deficit and encourage its incipient process of industrialization, and the construction of hydroelectric dams.[24]

A commission headed by engineer Arnaldo Pereira de Carvalho was established in Portugal,[25] to determine which investments should be financed by the Marshall Plan. Pereira de Carvalho, with the aid of the Economic Cooperation Administration (which administered all Marshall Plan funds), prompted the engagement of the Hydrotechnic Corporation for delivering the initial plans for the hydraulic usage of the rivers Cuanza, Bengo and Lucala, in northwest Angola, during a 10 month term to begin on March 1954.[26] As a result of its work, the American company proposed that seven dams be made along the Cuanza, five of which should be run-of-the-river facilities.[27] According to the *Diário Popular* article, the preliminary project for the Cuanza hydraulic system's lowest step, to be set at Cambambe, was also designed by the Hydrotechnic Co. These studies were followed in greater detail by the *Cuanza, Bengo and Lucala Brigade*, set up by the Angolan General Government, which followed – with slight variations – the strategy outlined by Hydrotechnic Co., of which the hydro-agricultural usage was a cornerstone.

The Brigade presented two solutions: Solution I, also advocated seven dams, for the middle stretch of the Cuanza; Solution II suggested only five dams, which highest step should be its largest, and the only one with a substantial reservoir.[28] The latter would also have its lower step at a small dam, where its waters were to be withheld some 5 kilometres upstream from the historical ruins of the Cambambe Fortress, by a concrete dam with an average height of 17 metres, and a 225 metre length central body (which should include its flood discharge), continued by lateral extensions penetrating both riverbanks.[29]

The facility's general plan would suffer a radical change, however, when the Portuguese State granted a license for the exploitation of the Middle Cuanza – with effects on the river stretch between Cambambe and the cited Porto Condo Bridge – to *Sociedade Nacional de Estudo e Financiamento de Empreendimentos Ultramarinos SARL* (Sonefe), which had been established in Lisbon in the previous year.

Sonefe's contract for the Cuanza concession, signed on 18 September 1957, was controversial at the time, as it enabled the private sector to exploit the largest river running entirely inside the Portuguese Empire. With a drainage basin of 152.570 km², it justified what was then the construction of the biggest dam built anywhere by Portuguese engineers.[30]

Sonefe then commissioned the Cambambe dam project from *Hidroeléctrica do Zêzere* (HEZ), which departed from the principles set by the Hydrotechnic Corporation (closely followed by the Cuanza, Bengo and Lucala Brigade). The opposing possibilities of a public vocation of the dam, or of a venture by private enterprise, created a dispute inside the *Conselho Superior de Fomento Ultramarino* (CSFU – Overseas Funding Superior Council), the governing body for policy of all major overseas investments, whose approval was needed for the project to go ahead.

A first group of CSFU board members, which included Edgar Cardoso, followed the Hydrotechnic ideas based on agriculture, for vast irrigation expansions, and the support of the fertilizer manufacturers. The second group, argued in favour of a great hydroelectric facility, with a large power capability to supply energy at competitive rates. Cardoso fought every argument with all his grit, always questioning, as a bottom line, the quality of Sonefe's project and the geological data for the site, especially as the dam had been moved from its original location, towards a river bend where the flood waters would increase its energy output.[31]

The CSFU was presided by engineer António Trigo de Morais, whose position in the debate is interesting. He was the central figure in the Portuguese hydraulic investment policy (especially in its overseas territories), and had been the first president of the *Junta Autónoma das Obras Públicas de Hidráulica Agrícola*, the state agency for hydro-agriculture public works in Portugal. Trigo de Morais accordingly had an inclination towards hydro-agricultural investments, which saw him head the development plans for the rivers Cunene (in Angola) and Limpopo (Mozambique), then the largest irrigation enterprises developed in Portuguese territories. Nonetheless, he sided with those preferring power generation at Cambambe, as the dam's single purpose.

Between the signing of the contract of concession to Sonefe, in September 1957, and July 1959 (the decisive moment at the CSFU), the preliminary works for the execution of Cambambe started. The provisional deviation of the river was achieved at the end of 1959's dry season,[32] around August. There were, therefore, great expectations about the decision on the project's fate, so that the construction at Cambambe - which had mostly dismissed all the work done by Hydrotechnic and the Project Brigade for the Cuanza, Bengo and Lucala - might at last advance at full-speed.

Fallback solutions for the Quiamafulo Bridge

When Edgar Cardoso became fully aware of the changes in the dam and its location, he discovered that the bridge he had designed for Quiamafulo, in July 1957, would fall upstream from that development after all (Fig. 9). Since the bridge grade line was planned at 120 metres, this meant it would no longer be useable once the reservoir level reached that elevation. Furthermore, the structure designed by Cardoso was already being built, which concerned its designer, the officials in Angola, and those at the Ministry for the Overseas Territories, because Sonefe's plans would result in a complete loss of the investment already spent on the bridge.

Cardoso and the State officials' concerns can be observed in another file on the bridge, also archived at AHU, for a 'Provisional Bridge on the River Cuanza - reinforced concrete solution of an arch type', designed by Cardoso, and dated December 1957.[33] This variant was to be supported by parts of the substructure that had already been built, which explains why it very much resembles the initial bridge design (Fig. 7). The budget estimate for that solution indicated that some piers were already built, as well as part of the bridge abutments, while the formwork for the rib-arches for two of the spans had already been assembled on-site. Meanwhile, the dam project by HEZ also went through a number of stages, of which the initial version, from January/March 1958, was most ambitious.[34] It proposed an arch-dam with a 110 metre height, with a spillway over its central blocks at the 140 metre elevation, and a top crowned by a deck at 162 metres, for the road from Luanda/Dondo to Quibala and Nova Lisboa (presently named Huambo).

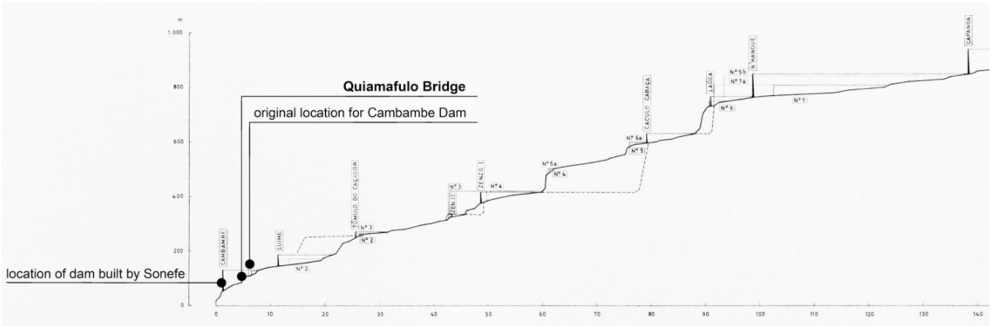

Figure 9. Detail of magnified-elevation profile of river, from 'General Plan of the Middle Cuanza' displaying expected dams, drawing 12: 'Comparative scheme of solutions', 1966. Credit Portugal, Arquivo Histórico Ultramarino – PT, AHU, file PT/IPAD/MU/DGOPC/GE/12495.

On 28 May 1958, the Director of the Service for Bridges and Structures of the Ministry of Overseas Territories, engineer Armando Girão, requested Edgar Cardoso to urgently send the revised plans for the bridge, so they might be forwarded to Angola, as it was expected that its piers should be completed within 30 days. Cardoso dryly replied that the said design had been finished for some months, but its plans had not been sent to Angola because Sonefe's Development Plan for Cambambe, which interfered with the bridge grade line, had still not been approved by the authorities.

In September 1958, the Quiamafulo worksite was inspected by the Angolan Governor-General, Horácio Viana Rebelo, after a visit he paid to the Cambambe dam's preliminary works and comemorate the first year of the signing of the Sonefe concession contract. On that occasion, this colonial official voiced the wish that the Quiamafulo Bridge, which would shorten the road from Luanda to Nova Lisboa by some 170 kilometres, might come into use in May of the following year.[35]

In November 1958, HEZ produced a less ambitious second version of the dam design, which included lowering its top/road and spillway by 30 metres, dropping to 132 metres and 110 metres each, for a maximum reservoir level set at 130 metres, and a four turbo-generator power station.[36] These elevations still exceeded the grade line of the bridge originally designed by Edgar Cardoso, which construction was proceeding at any pace, as demonstrated by the December 1958 cost estimate for finishing the structure. During the preceding 12 months, 630 m^3 of concrete had been poured there, along with the placement of 4.000 kg of steel reinforcement. One gathers that the two remaining piers of the bridge had also been erected, even though no final solution for the superstructure had yet been settled.

A provisional bridge would mostly be a fallback solution for saving the face of the investment already made. The AHU records include numerous papers which display the whole procedure leading to the solution that was finally implemented. A handwritten note, dated 12 December 1958, sent to the Undersecretary of State for the Overseas, Carlos Krus Abecassis, by the Governor-General Viana Rebelo (both of whom were engineers) suggested that an old iron structure located nearby might be reused for the bridge superstructure. The Governor was of the opinion that, building a concrete bridge, to have it submerged within three years, should be avoided. Moreover, a steel bridge was preferable, even if it turned out to be more expensive, as public opinion considered that a concrete bridge was the same as a 'stone bridge'. Hence, an apparently lighter solution would be better accepted. Edgar Cardoso, however, objected to having a superestructure formed with steel beams, as indicated in his 'Instruction regarding the provisional bridge on the river Cuanza, on the National Road 5, in Angola', dated December 1958.

He reverted to the concrete-arches variant he had produced in December 1957, to be supported on the piers which were already made up to the 108.00 metre elevation, enabling its grade line to be raised to the 115.00 (5 metres above the one made from the available steel parts). Cardoso added that, according to Sonefe's plan, the dam should reach the 132.00 elevation before the end of 1961, after which vehicles might drive across its crest.

Cardoso also remarked that the spillway gates could possibly be installed only one year later, so the reservoir level would not rise above the 110.00 metre elevation at once, plus the two-or-three metre water blade running over its spillway. Cardoso suggested, therefore, that if its deck elevation was increased by two or three metres, with the heightening of the piers' imposts, its grade line would turn out two or three metres above the spillway lip. Meanwhile, Cardoso also considered resorting to a superstructure of prestressed concrete girders, with a grade line at 133.00, which he presented as a supplement to his 'Instruction'.[37] Cardoso remarked that this solution (Fig.10) would resemble the bridge he designed to cross the Guadiana River, at Mértola, Portugal, under construction at that moment, and completed in 1961.

Figure 10. December 1957 Quiamafulo project for pre-stressed concrete variant (above) to set on existing piers, Credit Portugal, Arquivo Histórico Ultramarino – PT/IPAD/MU/DGOPC/DSPE/1773/17464, and Mértola Bridge. Notice slender mass concrete pillars (Photograph: J. Saldanha, Apr. 2021).

The beams and pier extensions proposed by Cardoso, were to be set on the piers and foundations already cast at Quiamafulo, and are very similar indeed to those at the Mértola Bridge, even though the latter has eight spans of variable widths, for a distance between abutments of some 225 metres (identical to that at Barca d'Alva). The Cuanza Bridge should have a 9 metre width, whereas the one at Mértola is 12 metre wide, and therefore has an additional pre-fabricated beam per span. Cardoso prescribed piers of mass concrete, which is surprising, considering the hydrodynamic shape they display, both in their drawings as in the latter bridge, to be seen on site. This prestressed-deck variant did not proceed at Quiamafulo, however, so the 'concrete arch hypothesis with a wooden deck' was the key for the structure ultimately built at Quiamafulo, upstream from the dam.

The 'provisional' bridge at Quiamafulo

Following the Undersecretary of State for the Overseas Funding's dispatch of 5 December 1958, Edgar Cardoso produced an Instruction No. 165, named 'Provisional Bridge over the River Cuanza, on National Road 5. Concrete arches hypothesis with a wooden deck', dated 15th December. Cardoso proposed the bridge arches to be executed on the existing formwork, with a slight modification to reduce their rise. Over each of the ribs, a carrying spandrel should be made (hollow, partly trussed or filled-in), to receive a wooden deck made from rough beams, to be reused from the formwork and scaffolding.

The main features of the final design for the bridge at Cambambe are the rib-arches, which were executed with a rectangular section, simpler than the one originally designed, and cast with a lower rise. This became visible in their discontinuity with the springing blocks positioned on each side of the pier tops, as these were designed to receive arches with a higher rise, according with the initial design (July 1957). The spandrel framing was also simplified, resorting to triangular trusses of reinforced concrete, which became the main aspect in which the bridge departs from its December 1957 design. Slender trussed beams were also introduced, to brace the parallel arches, possibly because the 'provisional' solution expected a wood deck on wood beams, which would not provide for the consolidation of the opposing arches through a reinforced concrete deck. The parallel arches stood apart more than the 4.40m proposed in the July 1957 original project, because the expected cantilevered outside part of the deck would not be executed after all.

On 31 January 1959, Cardoso finally sent an Instruction No. 178 to the Head-Engineer of the Overseas Ministry Services for Bridges and Structures, with the original drawings on tracing paper for the construction of the provisional bridge at Quiamafulo, as well as two blueprint sets made from them. On 9 February of the same year, the Director-General of Public Works and Communications of the Ministry for Overseas Territories, engineer Eugénio Sanches da Gama, sent the Governor-General of Angola the drawings Cardoso had delivered him, so the work might be finished.

The solution followed at Quiamafulo resembles the original December 1957 design, which is not surprising, since it springs from the piers built for it, while also retaining many similarities with the Barca d'Alva bridge. Both are open-spandrel structures, although in the Angolan case, most pillars springing from the arches are diagonally braced, and the sections close to the arch crowns are filled in (Fig. 11). Unfortunately, attempts to locate the plans for the built structure were unsuccessful, either at the AHU or at the Cardoso's firm - which is still operating - in Lisbon.

Figure 11. Bridges at Barca d'Alva (left) and Quiamafulo (right). The latter's piers built according to original July 1957 version, and superstructure following January1959 project (J.Saldanha, Sept. 2020, and courtesy A. Rito, P. Cabral, Dec. 2009).

The pressure to finish the Quiamafulo Bridge as quickly as possible might explain why the original drawings were sent to Angola, along with the blueprints made from them, without retaining any copies at the engineer's office in Lisbon. This procedure, unusual at an engineering or architecture practice, together with the turmoil of Angolan archives during the Colonial War, and the ensuing Angolan Civil War, may have resulted in the loss of the final plans for the bridge.

Bedrock faults at Cambambe and the Quiamafulo Bridge as a lasting solution

The 1959 edition of the *Angolan Chorographical-Commercial Dictionary* notes that the bridge on the river Cuanza, at Quiamafulo, was inaugurated that year. It was 'a reinforced concrete structure with 5 spans, each with 2 extremely light arches, placed side by side, with the tops joined by the deck slab […] and cost 3.1 million escudos',[38] which considerably reduced travelling time between Luanda and the country's second largest city, Nova Lisboa (today's Huambo). This means that the simplified 'provisional' bridge which actually was built, turned out to be cheaper than the cost expected for the wider, more complex, original project by Cardoso (as exposed in this paper's part titled 'Edgar Cardoso's July 1957 Project for the Quiamafulo Bridge').

The precise date the Quiamafulo Bridge came into use could not be found, nor whether it had a formal inauguration, usually to be expected. The ceremony may have been dismissed because it was considered to be a temporary structure, only to last until the dam's construction was accomplished. Nevertheless, the bridge designed by Cardoso remained in use for almost 60 years.

In July 1959, HEZ had concluded the final plans for the biggest dam to be built by the Portuguese Engineering, until that moment, at Cambambe, a full copy of which is archived at AHU.[39] The main features of the former year's November plans were retained, such as its 132.00 elevation, a reservoir maximum at 130.00 m, and a spillway at 110.00 m.

The dam project approval at the CSFU allowed the main contractor, *Sociedade de Empreitadas Moniz da Maia & Vaz Guedes*, associated with the Swiss *S.A. Conrad Zschokke* (the company which built the first European river powerplant in 1911, at Rheinfelden, on the German-Swiss stretch of the Rhine), to start its major undertaking at Cambambe. Before then, it had been mostly restricted to ground preparation, excavations, the dam's diversion galleries, the preliminary cofferdam, and the concrete cofferdam following it – the latter of which was finished on December 1959. That same month, however, previously undetected bedrock faults were exposed during the excavation for the dam's foundations, which required additional geological probing, before the concrete casting commenced.[40] The situation justified the appointment, by the Portuguese Government, of a 'restricted commission', presided by engineer Trigo de Morais, and including the very Edgar Cardoso, to decide how to solve the uncovered problems. These were so significant that the *Ultramarina de Sondagens* Company, from the Portuguese Group *Teixeira Duarte*, who had been awarded the contract for the groundworks, and stabilizing of the dam foundation, in association with the French *Bachy*, declared its inability to derive an adequate solution for them.

In the first days of December 1960, a first visit to the site by the commission took place, which confirmed the adverse geological conditions identified at the new dam location. These vindicated Cardoso's original objections to the location, and solution, chosen for the dam. A prolonged halt, before the work could restart, inevitably ensued, with a revision of the whole project. This seriously encumbered the development, and resulted in the downsizing of the dam's height.[41]

Morphologically, the most significant consequence of the dam project's alteration was the decrease of its elevation, with the interruption of the concrete casting at the 105 meter height for its seven central blocks, and a 110 meter elevation in its lateral blocks. This solution would also accommodate an adaptation to 'economical conditionings still to be met'[42] – a euphemism for the financial hardships Sonefe was enduring. The dam's height was lowered, in order to reduce the hydrostatic pressure acting on the dam wall. The level of the water it withheld was limited to 105 metres, above which the waters could freely run over the lip of the spillway. This established the dam's characteristic looks for more than half a century, but also put an end to any crossing over its top.

Apart from the geotechnical imperatives, the change allowed the economically stressed Sonefe to postpone its financial commitments, such as doing without the discharge gates. The adaptation of power to be installed at Cambambe to the evolution of the electricity consumption, also led to the subdivision of the equipment at its power station into two phases, of two generating groups each, with a unitary output of 65 MW.[43]

As a consequence of the changes with the dam, Cardoso's 'provisional bridge' ceased to be so. The maximum level of the dam fell below the bridge's grade line, and the decrease of the dam elevation was accompanied by the omission of the road expected to top it, thus impeding its crossing by National Road 5. As the bridge's designer, Cardoso must have been pleased that it should play a part in solving the Cambambe issue after all, and to endure an extended service life.

Viana Rebelo's concerns about a bridge *made of stone* were also met, since the bridge at Quiamafulo should only become submerged if, and when, the dam was heightened. In any case, the most comprehensive book on bridges built in the Portuguese Overseas provinces, published in 1968, stated that the Quiamafulo Bridge was a 'temporary bridge to be replaced by the dam when the second stage is completed' and that 'the road will then be carried by the crest of the dam'.[44] At the end of the 1960s, the bridge 'was being improved and strengthened so as to increase the effective width of the carriageway from 3.00 to 6.00 m',[45] which definitely established its appearance. The widening of its wearing course probably coincided with the replacement of the bridge's wooden deck with a full reinforced concrete slab.

Incidentally, the bridge built across the Cuanza after the one at Quiamafulo is a cable-stayed structure, likewise designed by Edgar Cardoso, and completed, just above the river's inlet, in 1975.

Interviews carried out with those engaged in the Sonefe enterprise revealed that at moments of great dispute, the relationship between the Cambambe worksite staff and Edgar Cardoso was strained. However, given the standing and technical prominence of those involved, once the works were concluded, those differences of opinion faded away. So much so, that by 1965, when Cardoso presented a lecture entitled 'Civil Engineering in the Portuguese Overseas Territories' at Lisbon's Instituto Superior Técnico (IST), he highly praised those very colleagues he had squabbled with, around the dam built at Cambambe.

Cardoso's IST lecture, which was published in that Institute's Journal in 1965,[46] specifically emphasised the outstanding hydraulic, irrigation and colonization enterprises around the Cunene (Angola) and Limpopo (Mozambique) rivers, 'prizes of the distinguished engineer António Trigo de Morais', as eloquent examples of the Portuguese engineering capability, while signalizing the Chicamba (in Mozambique) and Cambambe dams, as exemplary of the Civil Engineering practice in the energy field, and attesting the merit of the country's designers and builders. The article includes a photograph of the Quiamafulo Bridge carrying a revealing caption: 'Provisional Bridge over the Cuanza River, on the Luanda-Nova Lisboa'. As we have seen, it remained in use, after all, for more than half a century.

Conclusions

The territorial and strategic relevance of the third road bridge built across the Cuanza matched the importance of the largest river to flow entirely inside Angolan borders, and its meaning for Angola was also celebrated in an airmail stamp for that country, included in a set issued in 1965 displaying ten of the most noteworthy engineering works in that Portuguese colony (Fig. 12).[47] Designed by the most important professional in the history of Portuguese Civil Engineering, Professor Edgar Mesquita Cardoso, this engineering structure was historically and typologically assessed, particularly regarding the changes it underwent between its July 1957 original version; the one, labelled 'provisional', from December of that same year, and resumed in December 1958; and the one finally built.

Researching the Quiamafulo Bridge seemed all the more necessary, since the plans sent to Angola in January 1959 for completing its construction have apparently been lost. Its remoteness also explains why this is a less known work by Cardoso. Moreover, its recent submersion, owing to the heightening of the Cambambe Dam in 2017, might plunge the bridge into full oblivion. Research into this kind of subjects in Angola is also still at its incipient stages, so this paper provides definitive information on this engineering structure, especially for Angolan and Portuguese researchers and engineers.

Figure 12. 1965 Angola airmail stamp of Quiamafulo Bridge. Source: author's property.

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The Author

José Luís Possolo de Saldanha is an architecture graduate of FAUTL (1989) and holds a PhD in Architecture from the University of Seville (2003). He is an Associate Professor at the Department of Architecture and Urbanism of ISCTE – Lisbon University Institute, where he was the Pedagogical Council President during 2013 and 2014, and head of department from 2016 to 2019. He is a researcher at Dinâmia-CET'IUL, and has been an author of books, book chapters and papers on subjects in history of architecture, urbanism and territory. He has also privately designed projects for several architecture programmes.

Contact details
Avenida das Forças Armadas, 1649-026 Lisbon, Portugal.
Email: jose.saldanha@iscte-iul.pt

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