MAPUTO – KATEMBE BRIDGE

Quality Control of Pier Construction of Approach Bridges

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A meus Pais

The best preparation for tomorrow is doing your best today.

H. Jackson Brown Jr.

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ABSTRACT

This report was made in the context of the course "Dissertation", integrated in the final year of the Integrated Master in Civil Engineering (MIEC), of the Faculty of Engineering of Porto University (FEUP).

The work was conducted in a business environment, being the company GAUFF and the work taking place in Maputo, Mozambique, in which the Maputo – Katembe Bridge is being built. The author had the opportunity to intern from 7th of February until 7th of June 2016. This paper aims to convey knowledge related to the topic of the dissertation itself, as well as other aspects and relevant experiences, since it is a reference construction work. It is intended in this way to express the knowledge regarding the quality control procedures as well as the construction process of the piers and the construction work in general. These last topics are approached in Chapter 3 and a little on 4 and 5.

Planning and monitoring of the works in site is essential to ensure good control in all stages, ensuring the quality control of the concrete for the period of use of the suspension bridge. Therefore, there must be a control at every stage, from design, production, transportation, application and cure. Furthermore, the control of the hardened concrete properties has a special emphasis, being a final test of the overall quality of the concrete. The technologic content associated with all phases of the production cycle of the concrete is found in Chapters 5 and 6.

KEYWORDS: Concrete, Quality Control, Suspension Bridge, GAUFF, Piers Construction.

RESUMO

O presente relatório foi efetuado no âmbito da unidade curricular "Dissertação", inserindo-se no último ano de estudos do Mestrado Integrado em Engenharia Civil (MIEC) da Faculdade de Engenharia da Universidade do Porto(FEUP).

O trabalho foi desenvolvido em ambiente empresarial, na empresa GAUFF, na obra que decorre em Maputo, Moçambique, na qual se constrói a ponte de Maputo – Katembe. O autor teve a possibilidade de estagiar de 7 de Fevereiro a 7 de Junho de 2016. Este trabalho visa transmitir os conhecimentos relacionados com o tema da dissertação em si, bem como outros aspectos e experiências relevantes, visto tratar-se de uma obra de referência. Pretende-se desta forma dar conhecimento dos procedimentos de controlo de qualidade do betão, bem como do processo construtivo dos pilares e da obra em si, no geral. Estes últimos são abordados no capítulo 3 e um pouco no 4 e 5.

O planeamento e o acompanhamento dos trabalhos em obra é essencial para que haja um bom controlo em todas as fases, garantindo a qualidade do betão para o período de utilização da ponte suspensa. Desta forma, deve existir um controlo em todas as fases, desde o design, a produção, transporte, colocação e cura. Também o processo de controlo das propriedades do betão endurecido tem um ênfase especial, pelo que é um teste final à real qualidade do betão. O conteúdo tecnológico relacionado com todas as fases do ciclo de produção do betão encontram-se nos capítulos 5 e 6.

PALAVRAS-CHAVE: Betão, Controlo de Qualidade, Ponte Suspensa, GAUFF, Pilares .

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

CRBC – China Road and Bridge Corporation

PPWS – Prefabricated Paralell Wire Strand

SATCC – Southern Africa Transport and Communications Commission

SANS – South African National Standards

LEM – Laboratório de Engenharia de Moçambique

ACV – Aggregate Crushing Value

CM – Cimentos de Moçambique

SABS – South African Bureau of Standards

ACI – American Concrete Institute

NP EN – Norma Portuguesa English

Rebars – Reinforcement Bars

1
Introduction

1.1. MAPUTO BRIDGE AND LINK ROADS PROJECT

For a long time now, Mozambicans have been trying to make their country accessible from North to South, creating the connections for South Africa and Swaziland. With this project, a vital part of that vision will be created, providing Tourism infrastructure and therefore, more economical growth and employment for Mozambique.

The Maputo Bridge and Link Roads Project will create the largest suspension bridge in Africa and 54th largest in the world. It spans the entire entry area into the international seaport of Maputo and consists of a 1230m precast concrete element in the South Approach Bridge, a 1100m cantilever bridge on the North Approach and a main suspension bridge over the river with a total extension of 1224m and a central span of 680m, 60m above sea level.

This bridge is considered as the most emblematic construction in the South since the independence of Mozambique back in 1975. There is also the construction of adjacent roads with a total length of 170km. The main road will connect the city of Maputo to Ponta do Ouro, considered an attractive tourist destination in Southern Africa. This road of 115km will meet the need to connect these two cities, by eliminating the difficulties that always existed and by creating an easy access to the South African border. The second section of 65km is going to connect Bela Vista, located between Maputo and Ponta do Ouro, with Boane, facilitating the access to Swaziland border regions. Also in this second section there is going to be a rehabilitation plan regarding five bridges that cross the rivers Tembe, Changane, Mahubo, Boane and Umbeluzi.

The construction works started on August 2014 and will last 36 months in total. The employer is the Mozambique Government represented by Maputo Sul E.P., the construction company is CRBC (China Road and Bridge Corporation) and GAUFF Gmbh & Co. Engineering KG, working as a Consultant, is doing the construction supervision, design evaluation and is responsible for developing the Project Quality Management Plan.

It is important to add that due to the fact that some of the construction works takes place on living areas, many family houses will be destroyed, so the families will be rehoused in new apartments. It is also important to note that other benefits come with this construction, like the employment for local people on the construction site.

Fig.1.1 – Maputo Bridge Model

1.2. PERSONAL MOTIVATIONS

The realization of an internship like this one plays an important role in an Academic life. It brings the opportunity to apply all the knowledge from past years in a specific situation, promoting a new contact with a different reality.

Being Civil Engineering a practical field of studies, the opportunity to work in a project with such national and international importance, and to monitor the works with experienced professionals was very fullfilling and surelly was an important asset for the future. Being a part of GAUFF's team, providing technical assistance to CRBC, was an opportunity to gain experience in a more practical way, making possible the interaction with colleagues and workers from different nacionalities, with different perspectives and different ways of knowledge. This interaction provided increased learning, both in terms of Civil Engineering itself and experiencing day-to-day work in the different construction stages and situations.

Considering all of this, this internship was a formidable opportunity to complement the theoretical training received through the past Academic years by absorving as much knowledge as possible, considering the scale of the work developed in Maputo.

1.3. OBJECTIVES

The master thesis theme was chosen in accordance with the development of construction at the time of the beginning of my internship. Due to the reason that different teams from CRBC work with different methods in both sides of the bridge, it was decided that this work would only be about the South side (Katembe). At that time, all of the foundations in the South side were complete, so the pier construction, which was already on the way, was perfect to monitor during my staying in

Mozambique. Despite that, it is important to describe the works that occurred and the ones that will follow, so this paper will also focus on the entire project.

In order to make this paper a more embracing work, the main goals were the following:

- Understanding the construction sequence of a Suspension Bridge and associated construction methods;
- Describe the Maputo Bridge Project;
- Describe the methodology and the staging of a bridge;
- Describe the construction method for the piers in the South Approach Bridge;
- Describe the characteristics and the concrete composition in the South Approach Bridge;
- Describe all the concrete quality control procedures of the concrete manufacturing in the South Approach Bridge.

1.4. WORK BASES

This dissertation has been developed based in the following elements:

- Bibliographic research regarding suspension bridges;
- Client and contractor specifications, both general and technical;
- Project elements;
- Method Statements;
- Supervision Reports;
- Laboratory test results.

1.5. STRUCTURE OF THE DOCUMENT

This report is divided in 7 chapters. After this introduction, chapter 2 presents generally suspension bridges, explaining the concept and giving some examples all around the world with a special look to the ones in China, since the design and the contractor are Chinese and China itself has a considerable amount of suspension bridges, most of them built in the last 20 years.

Chapter 3 is about the Maputo – Katembe Bridge, with technical description of the main bridge. The infrastructures, site and geology are on focus, with the description of the work developed so far and the works to come. The South Approach Bridge is on focus, according with the technological part to come.

In chapter 4, the content is about the construction site, and consists of describing the construction site in Katembe, with an overview of the facilities, equipments, storage of materials and overall organization of the construction site in the South bank.

Chapter 5 is focused on everything there is about pier construction, since the concrete manufacturing and transport, the construction sequence of the pier body, the method statements, the design and construction of formworks, temporary platforms used, the reinforcement bars and installation of steel bars, concrete casting and curing. The necessary repair works regarding the pier construction are also in this chapter.

The following chapter, no. 6, is about the quality control of the concrete in pier body of South Approach Bridge. Concrete properties, mix designs, tests and complementary tests represent the major part of this chapter that has been finalized with acceptance criteria and discussion of results. Due to the location of this construction work, a comparison between European, American and local standards makes sense towards an understanding regarding the different perspectives and approaches that they represent, and therefore this comparison is also presented in this chapter.

The last chapter, no. 7, contains a reflection about the internship period and a personal opinion on the quality control system that has been implemented on site.

2
Suspension Bridges

2.1. BRIDGES – BIBLIOGRAPHICAL REVIEW

A bridge is a structure that spans horizontally between supports, whose function is to carry vertical loads. The basic principle consists of two supports holding a beam, with the supports holding the structure up and the span between the supports being strong enough to carry all the loads.

There are many different types of bridges, depending on the conditions or limitations that exist from different situations. Like in every Civil Engineering project, efficiency, design and costs represent the major principles. A good combination of these three areas often results in a good solution, which is very important considering that most of the times the bridges are built with public's money.

These construction works are designed for a long time span, wherein the return of the investment is achieved in the long term. For this reason, design and execution must be done very carefully so that the structure doesn't require any anticipated rehabilitation, like structural reinforcement for example.

In terms of classification, bridges are divided in six types:

- Beam Bridge;
- Truss Bridge;
- Arch Bridge;
- Cable-stay Bridge;
- Cantilever Bridge;
- Suspension Bridge.

The choice of the type of bridge to be adopted depends on several factors.

2.2. SUSPENSION BRIDGE – DEFINITION AND CHARACTERISTICS

Suspension bridge is an Engineering form with overhead cables supporting its roadway. Technically speaking, this type of bridge works by carrying vertical loading through curved cables in tension, which are then transferred to the vertical towers and to the anchorages at the banks. The vertical towers carry these loads through vertical compression into the ground, being the rest of the loads carried by the anchorage, which are normally embedded in either solid rock or concrete blocks. Inside the anchorage blocks, the cables must spread over a large area to distribute the loads, creating a safe structure capable of preventing the cables from breaking free and thus putting in jeopardy the structural safety of the bridge (see figure 2.1).

Like any other type of bridge or engineering work, this bridge has some advantages as well as disadvantages. Among the advantages, it clearly stands out the longer main spans that can be achieved than any other type of bridge, being the others the less material required, more capacity to withstand earthquakes and also the bridge decks can have sections replaced to widen traffic lanes, for example. The disadvantages, on the other hand, include the high stiffness or aero dynamical design that can be required to withstand high winds and the difficulty to carry heavy rail traffic due to reduced stiffness compared to others.

Stiffness and heaviness of a suspension bridge are a major concern due to the reason that the deck is hung in the air. Therefore, the bridge should be heavy, stiff or even both.

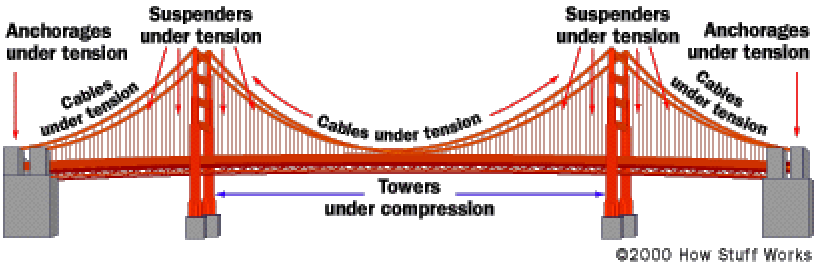


Fig.2.1- Distribution of forces in a Suspension Bridge [1]

2.3. HISTORY

Suspension bridges didn't always looked like nowadays, with high resistance materials and refined designs. Through time, this old engineering form evolved from rope, wood and twisted grass to high tensile strength cables, reflecting not only the evolution of engineering, but also civilization.

It´s not easy to track down and discover when was the first suspension bridge built, or where and by who, but there are many references of simple suspension bridges that go so far as the Han Dynasty, 220 B.C. travel stories when crossing lands close to the Himalayas, namely Hindukush, Gandhara and Gilgit. A simple suspension bridge is considered the first form of suspension bridges, being supported by anchors at both ends without any towers or piers. At that time people walked directly on the ropes, and only later the deck was added.

However, there is at least one more region where these structures were built by ancient civilizations. When the Spanish made their way across the Atlantic Ocean and into Peru, they ended up discovering an Inca empire connected by large hundreds of suspension bridges, some of them with unbelievable spans for that time.

The first modern suspension bridge is believed to be dated from 7th century in Central America, at the Mayan Capital city of Yaxchilan. The 100m bridge was the solution to traffic problems when crossing the river and the main span of 63m center span required two piers in the river.

Many years later, the year 1595 marks a page in suspension bridges engineering history. The Venetian Polymath Fausto Veranzio published a book containing the first designs of a modern suspension bridge. These drawings included a timber and rope suspended bridge and also a hybrid suspension and cable-stayed bridge using iron chains. Despite this, only in 19th century the iron chains bridges started to exist, with special emphasis for the British Menai Bridge (1826) which had a span of 176m.

Despite being only 0.45m wide, the first wire-cable suspension bridge was the Spider Bridge at Falls of Schuylkill (1816). After this and through the years, engineering evolved and many different structures were built, creating longer spans by the year, providing the solutions that many thought were impossible, creating iconic bridges like Manhattan Bridge (1909), the Otto Beit Bridge (1939) at Zimbabwe-Zambia border or the Golden Gate Bridge (1937) at San Francisco, United States of America.

Nowadays, China is leading by having four bridges in the top10 of the longest suspension bridges span, with several more planned.

2.4. SUSPENSION BRIDGES IN CHINA

2.4.1. XIHOUMEN BRIDGE

The Xihoumen Bridge is the largest suspension bridge in China, only surpassed by Akashi-Kaikyo Bridge in Japan (see figure 2.2).

Built on Zhoushan Archipelago and part of the Zhejiang Province, it connects Jintang to the Cezi Islands. The construction works started in 2005 and the opening date was on 25 December 2009.

The 5.3Km long bridge has a 2.6Km main bridge with a central suspension span of 1650m, being the total approaches a total of 2.7km. This Bridge was part of the second phase of a big project that started back in 1999 with the construction of three bridges. The main objective of this project was to link the Zhoustan Archipelago to the main island. Also in this second phase there was the construction of the 27km long cable-stayed Jintang Bridge that connects Jintang Island and Zhenhai, thus making five the total number of bridges in this project.

Fig. 2.2 - Xihoumen Bridge, China [2]

2.4.2. Runyang Bridge

The Runyang Bridge is a large infrastructure that crosses the Yangtze River in Jiangsu Province and its part of the Yangzhou-Liyang Expressway. This large complex was the solution find to give an alternative to the ferry services that operated across the river (see figure 2.3).

The total length of the bridge is about 36 Km and consists of two major bridges, being the south bridge a suspension bridge with a main span of 1490m, which was, at the time, the largest suspension bridge in China and third in the world. Nowadays it is the fifth longest in the world.

Among the technical characteristics, the height of the towers is 215m above water level and the main span is a streamlined orthotropic steel box girder with a depth of 3m. The width of the deck is 39.2m, containing six traffic lanes and a walkway at both sides for maintenance purposes. The maximum height for river navigation is about 50m.

Fig. 2.3 - Runyang Bridge, China [3]

2.4.3. Fourth Nanjing Yangtze Bridge

The fourth Nanjing Yangtze Bridge is located in eastern China, near the city of Nanjing and it was finished in 2012, being opened to traffic on exactly the 24 December of 2012 (see figure 2.4).

The Yangtze River is crossed by a large number of bridges, and the main structure of this particular one is a three-span continuous suspension bridge with a main span of 1.418m. The main span is considered to be the sixth longest in the world and third largest in China.

This twin tower bridge has a height of 229m above water level and a width of 34m, containing a dual six-lane carriageway design to maintain approximately 100-125 Km/h traffic.

Fig. 2.4 - Fourth Nanjing Yangtze Bridge, China [4]

2.4.4. Jiangyin Bridge

The Jiangyin Bridge is located in Jiangsu, China, and it is a suspension bridge over the Yangtze River that connects Jiangyin to Jingjiang (see figure 2.5).

The main bridge is a single span steel box girder suspension bridge, being the first bridge in China to have exceeded the 1000m long mark. When it was completed in 1999, it was the fourth largest main span in the world and first in China, but nowadays, even though the 1.385m main span is surpassed, it still has a place among the top ten longest bridge spans.

This bridge carries the traffic of the G2 Beijing-Shanghai Expressway, containing three lanes in both directions and also pedestrian sidewalks. The concrete towers are 190m tall and the main span is made of flat streamlined steel box girders, being the maximum height for river navigation about 50m.

Being a special structure among the Chinese, it is also important to say that the construction was planned to be executed in 1997, thus commemorating the 50th anniversary of the Chinese Revolution. It was awarded with numerous prizes, like the “First Prize for Highway engineering Excellent Design” in 2002, “China Civil Engineering Zhantianyou Prize”, “Eugene C.Figg Jr. Medal for Signature Bridges” by the International Bridges Conference and “Gold Prize for National Excellent Project Design” in 2004.

Fig. 2.5 - Jiangyin Bridge, China [5]

2.4.5. XIAMEN HAICANG BRIDGE (CRBC WORK)

Completed in 1999, Xiamen Haicang Bridge is the first three-span continuous steel box girder suspension bridge in the world (see figure 2.6).

Located in Xiamen, Fujian Province, China, this bridge has a main span of 648m and about 5.9km in length, being 32m wide. With this bridge, roller bearing loose cables saddle and main cable prestressed anchorage system were adopted for the first time in China.

The importance of this infrastructure is very high, linking Xiamen Island with the city's Haicang district, located in the main land by carrying six lanes of the 201 Provincial Road. It was awarded with "The First OVM Excellent Prestressed Engineering Design".

Fig. 2.6 - Xiamen Haicang Bridge (CRBC work), China [6]

2.5. OTHER BRIDGES IN THE WORLD

2.5.1. THE GREAT BELT BRIDGE

The Great Belt Bridge is part of a large infrastructure called “The Great Belt Fixed Link”. This large complex contains two other structures: a railway between Zealand and Sprogo and a Box Girder Bridge between Sprogo and Funen. This mega project was the solution found to replace the ferry service, which was the primary mean of crossing the Great Belt (see figure 2.7).

The suspension Bridge, officially known as “The East Bridge”, has the world’s third largest main span and the first outside Asia, with a total of 1624m. Built between 1991 and 1997, it is 6790m long and the two pylons have an impressive height of 254m above sea level, making it one of the highest structures in all of Denmark and the record holder for such structures, surpassing The Golden Gate Bridge Pylons by 26m.

Among the technical characteristics, the main cables have a diameter of 85cm and are spun by 18648 threads of 5mm in diameter. Between the two anchorages, the 2700m long road has a total of 57 bridge sections that weight approximately 1000t each and the width of the deck is 31m.

The Great Belt Bridge was designed to be the biggest suspension Bridge in the world but some delay resulted in losing the pretension for the title. Nevertheless, this is still considered the biggest construction work that Denmark has ever seen, changing the lives of millions of people and creating a connection to the mainland Europe to Sweden and to the rest of the Scandinavian countries.

Fig. 2.7 – The Great Belt Bridge, Denmark [7]

2.5.2. The Humber Bridge

The Humber Bridge is a structure located near Kingston upon Hull in England. Considered a historical Bridge, when it opened to traffic on 24 June 1981 was the longest suspension bridge in the world, and nowadays it's the seventh. It spans over the Humber, which is the estuary formed by the rivers Trent and Ouse, and connects East Riding of Yorkshire and North Lincolnshire.

With a main span of 1410m and a total length of 2200m, the Humber Bridge was a key project which was capable to solve road distance problems by reducing the distance between Hull and Grimsby by approximately 80km.

The height of the pylons is 155.5m above sea level and the clearance over high water is 30m. Each cable weights 5500t, with 37 strands of 404 wires each of cable, being capable of taking a load of 19400t. Each box section weights around 140t and the carriageways is a dual two lane.

This masterpiece of Civil Engineering has a design lifespan of 120 years and it is one of the most iconic construction works that took place in England, being recognized all over the world (see figure 2.8).

Fig. 2.8 – The Humber Bridge, England, UK [8]

3
Maputo – Katembe Bridge

3.1. PHYSICAL CHARACTERIZATION

Mozambique is a formal Portuguese colony, independent since 1975, and has a population of 21,397,000 inhabitants, according to the 2007 census. The country is located in Southern Africa, sharing borders with South Africa, Zimbabwe, Swaziland, Tanzania, Zambia, Malawi and the Indian Ocean. It has an area of 801,590Km^2.

Maputo, known as Lourenço Marques before the independence, is the capital and largest city of Mozambique, a Southern Africa Country. The population 1,766,184 according to 2007 Census and among others, the main exports are cement, cotton, sugar and hardwood.

Maputo is located on the Maputo Bay, where Estuário do Espírito Santo drains the flow from the rivers Tembe, Umbeluzi, Matola and Infulene. The bay is approximately 95Km long and 30Km wide and before the Bridge is completed, the only way to cross the bay to Katembe is through the ferry services that operate daily from 05:00 until 23:15. The total area of the Municipality of Maputo is 346Km^2 and it's surrounded at Northeast and East by the city of Matola, the districts of Marracuene to the North, Boane on the East and Matutuíne on the South.

Katembe, on the other hand, despite being part of the Maputo Province and enjoying the proximity of the country's largest city, is an underdeveloped city, mainly inhabited by local people with lack of good and modern accommodations. The demographic scenario will be forever changed when the new bridge is finished, increasing not only the accesses, but also the comfort and safety for a better life for all the population both in Maputo and in Katembe.

The population of Katembe is about 20,000 people and it is expected to grow to 400,000 inhabitants in the future, benefiting from the conditions of accessibility and all the infrastructures that will be created, following the construction of the bridge.

Fig.3.1 – Map of Mozambique and location of the Project [9]

3.2. CHARACTERIZATION OF THE CONSTRUCTION SITE

3.2.1. GEOLOGICAL CHARACTERIZATION

The geology is typical for this coastal region, being characterized mainly by medium-sized sands, mud stone and arenaceous sand stone.

Before the construction, a supplementary geological survey was carried out to evaluate the design values to be used for the foundation. The geological stratum revealed by the survey can be resumed as follows:

- Layer of imported fill of soil with a thickness of 2m;
- Medium-sized sands with a thickness below 10m;
- Mud stone – greyish brown, hypabyssal rock in mud texture, thin-medium thick, semi-rock semi-soil, extremely soft with an approximate thickness of 11m;
- Arenaceous sand stone – greyish yellow, hypabyssal rock in fine particle structure, thin-medium thick, semi-rock semi-soil, extremely soft. This material is characterized at the upper section by a thickness between 21.5m and 31.4m, which easily falls apart due to groundwater saturation to a thickness from 28.5m to 46.5m;

- Argillaceous siltstone – Grey, hypabyssal rock in mud texture, thin-medium thick, semi-rock semi-soil, extremely soft.

After this survey, a team from CRBC was capable of finding a drilling solution based on previous works with similar conditions, being decided that the drilling method for the piles and the execution method for the diaphragm wall would be performed with the support of a bentonite slurry.

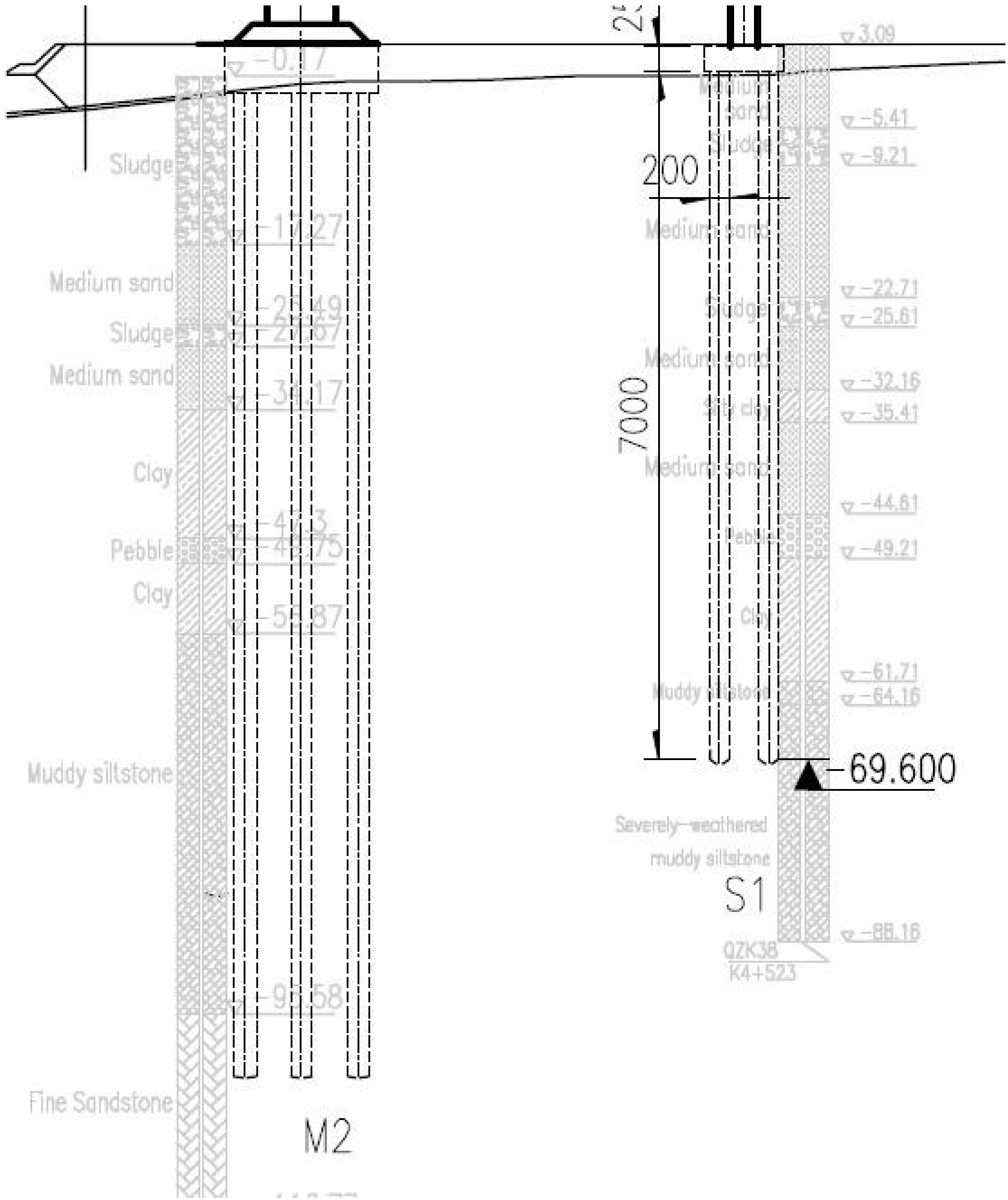


Fig.3.2 – Figure represents the relation between the different soil layers and the piers used to transfer the loads to the ground, going at approximately – 100 m deep

3.2.2. HYDROGEOLOGY

The surface water is the Maputo Bay Alkaline Seawater, with no other earth surface water source found.

The underground water of the area can be divided in three major types: perched water, pore phreatic water in the quaternary loose rocks and bedrock fissure water. The perched water can be found mainly in the artificial fill at both banks and receives the atmospheric precipitation and the vertical infiltration supply of water leakage from different sources such as water supply and drainage pipes. The pore water phreatic water exists mainly in sand and gravel layers, resulting in the major water-bearing stratum of the area. Finally, the bedrock fissure water mainly occurs in intensely weathered fine sand stratum where the bedrock in extremely soft and its joints are airtight, resulting in inadequate water.

In order to determine the water permeability of the stratums, pumping tests and laboratory penetration tests were mainly performed with drilling holes within the South and North anchorage foundation pit. The tests resulted in a moderate wide range, going from slight permeability in the artificial fill to extremely slight permeability of the argillaceous siltstone.

For the surface and underground water at the bridge location, water quality tests were conducted in order to determine the chemical characterists. According to the test results, samples were taken from 0.2m until 3m deep, resulting in a PH level that goes from 7.23 to 8.01. The tests resulted in a combination that determine the power of corrosivity for concrete and reinforced steel bars in concrete structures. Ultimately, the earth surface water is an alkaline water that produces strong and weak corrosivity for concrete structures and reinforced steel bars in concrete structures, respectively. The offshore well water in the South Bank belongs to alkaline water, producing weak and tiny corrosivity for concrete structures and reinforced steel bars in concrete structures, respectively. The offshore well water in the North Bank is the same type of the South bank, but due to different values in the composition, belongs to brackish water that produces tiny corrosivity for concrete structures and reinforced steel bars. Finally, the inland dune terrace spring water is the same type of water as the previous, but belongs to fresh water type, resulting in overall tiny corrosivity for the structure.

3.2.3. METEOROLOGICAL CONDITIONS

Maputo is in the Tropical Monsoon climate zone, being considered as a sub-tropical climate with an annual average temperature of 22.72ºC.

There are two big annual seasons: dry season and rainy season. The cool and dry season is from May to September and it has a monthly rainfall average of 0-30mm, being the temperature between 9ºC and 26ºC. The warm and rainy season is from October to April of the next year and the rainfall during that period is responsible for more than 80% of the whole annual rainfall. Also during that period, the monthly average is about 30-300mm with the temperature between 28ºC and 40ºC.

According to the statistics, there are 86.1 days with rainfall annually and the maximum single-day rainfall was 336.8mm on 7th of February in the year 2000, which is almost half of the annual average rainfall (798.9mm).

The maximum temperature can be as high as 44ºC-45ºC, while the minimum temperatures can be around 8ºC-9ºC. The relative humidity is approximately 76%, so in general it can be said that the weather conditions are good, resulting in beautiful landscape scenarios, which makes Maputo a tourist attraction. Regarding the Mozambique territory in general, the terrain is high in the Northwest and low in the Southeast with various rivers flowing into the seas in the Southeast. Due to the plainness of the terrain in the Southeast, there is also a possibility of flood disasters to occur in case of heavy rainfall and the other way around also happens when the rainfall amount is scan and the land ends up drought. In addition, due to the impacts of Subtropical climate, the country is also exposed to possible natural disasters such as rainstorms and hurricanes during the rainy season.

Regarding the wind, according with the Mozambique National Institute of Meteorology, the maximum speed is 32.5m/s and the speed values are average maximum wind speeds for 10 minutes at a height of 10m above the ground in Maputo. The wind measurement station is located in the Institution's headquarters, which are located about 3.7km away from the main bridge. In order to determine the return period for the project area, an extreme value GAMBEL TYPE I was adopted to figure out that the basic wind seed for 100 year return period is 35.8m/s and 31.5m/s for a period of 30 years.

3.2.4. TIDE

The Maputo-Katembe Bridge is located in Maputo Bay, which is also part of the Indian Ocean, being this way affected by tide changes. The width of the bay where the bridge is located is approximately 570m with a depth between 8m and 12m.

Tides are the rise and fall of sea levels caused by a combination of effects from gravitational forces exerted by the Moon, Sun and rotation of the Earth. The period of the tidal range change is about 15 days and most of them appear on the second, tenth, seventeenth and the twenty-fourth day of each lunar month. The tide in Maputo Bay is characterized by being a semi-diurnal tide, which means that it has two high tide and two low tide levels within one day, with a 12.5h repetition period for diurnal tide and the maximum tidal range at the bridge location is approximately 3.6m.

With the objective of knowing exactly how the tide could affect the project, a team conducted a combined measurement of water gauge and project elevation system of the Bridge at Maputo Port and the result was a 1.469m of water gauge, which equals to the project elevation. In addition to this measurement, an inquiry to local residents in the South bank was made to know the maximum water level during rainy season. The result was 2.3m, which is identical with the data in the document "Tide Forecast Table (Maputo Port) for 2012".

The design elevation for the bridge head at North Bank is 29.529m and at the South Bank is 7.473m, which, comparing to the 2.3m of tide elevation, can be concluded that the margin is substantial and the tide would not control the design for the vertical section.

3.3. TECHNICAL DESCRIPTION

3.3.1. GENERAL DESCRIPTION

As mentioned before, the construction works consist of a Suspension Bridge, a North and South Approach as well as the connections to the adjacent roads. The Suspension Bridge will be explained in general and since the scope is regarding the South Approach Bridge, from now on there will be more detail.

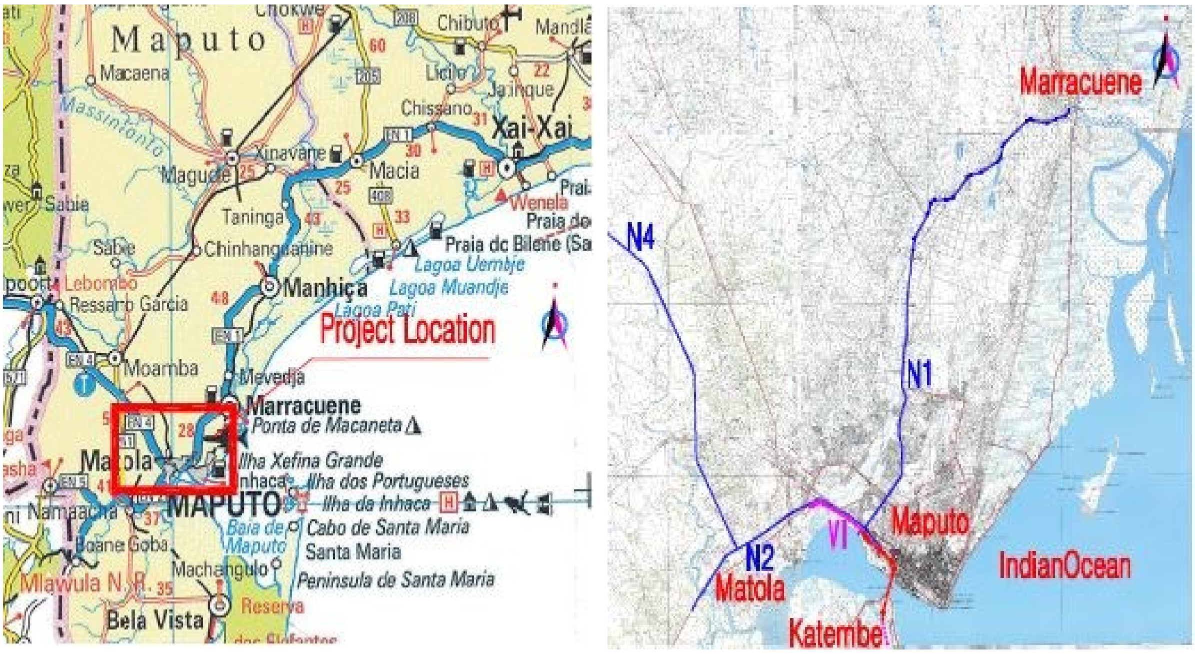


Fig.3.3 – Figure represents the implantation area with some aerial zoom [9]

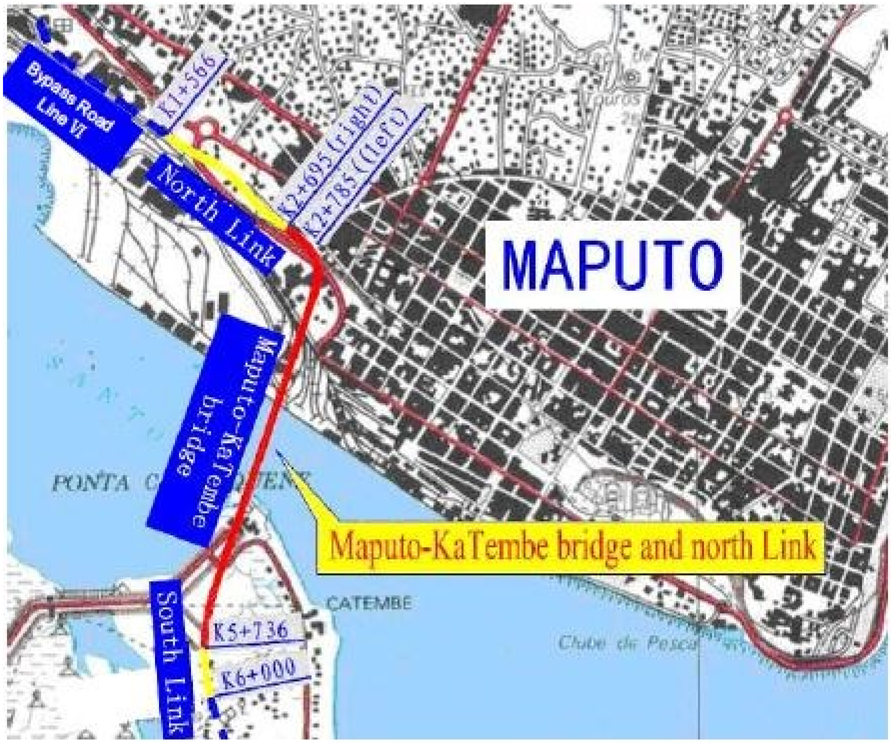


Fig.3.4 – Figure represents the implantation area with the suspension bridge, approach bridges and link roads [9]

3.3.2. THE SUSPENSION BRIDGE

The Maputo-Katembe Bridge is a single-span double-hinged suspension bridge and the span for the main cable is 260+680+284 m. Even though the lateral spans are considered when considering the technical design, the first pier from each bank are considered part of the approach bridges from a construction perspective.

The overall structure for the main bridge is a simply-supported system with vertical supports and transverse wind-resistance supports set between the cable bent pylon and stiffening girder. In addition, viscous dampers will be installed in both pylon girder joint, guaranteeing the energy dissipation for the dynamic loads caused by wind, braking and possible earthquakes.

Two main cables will be set for the whole bridge, with a transverse distance between them of 21.88m, which is the same distance for the transverse hanger. The distance from the nearest hanger to the center line of the pylon is 16m and the length of the shortest hanger is 3.2m. The structure type adopted for the pylon is gate-type.

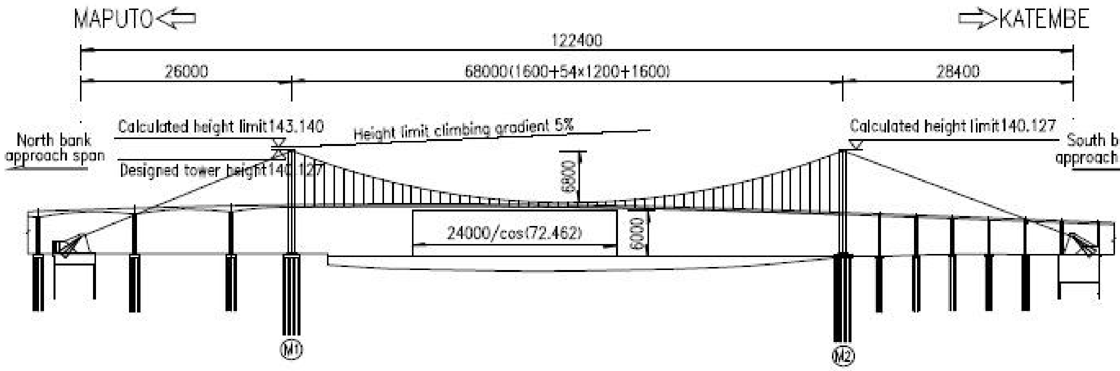


Fig.3.5 – Design for the main span [10]

3.3.2.1. Main Cable, Hanger and Cable Saddles

As said before, there are two main cables for the whole bridge and each one of them is composed by 91 galvanized high-strength steel wires with a diameter of 5mm and nominal tensile strength of 1670Mpa. The fabrication method for the main cable is a prefabricated parallel cable strand, known as PPWS (Prefabricated Parallel Wire Strand) and global diameter of the cable out of the clamp is 509mm.

Then, the cable strands are bound with fixed type strapping tape to ensure regular cross sections with a hexagon shape, using hot cast sockets for both ends. Each one of the cast sockets is composed by an anchor cup, a cover and wire divider plate and a zinc-copper alloy casted inside.

When finished, the design elevation of the main cable at mid-span is +70.627m, with a designed elevation of the intersection point of the main cable with the pylon top at +138.627m.

Regarding the hanger, galvanized high-strength steel wires will be used, forming 110 hangers in 55 hanging points. The standard distance between each hanging point is 12m and the distance from the center line of the cable bent pylon to the nearest hanging point is 16m. Each hanging point is equipped with two hangers composed by 61 parallel steel wires of 5mm diameter and a strength grade of 1770Mpa. Then, at both ends of the hangers, Y-shaped hot-cast sockets will be used for sockets.

Cable clamps are divided in two categories: the ones with hangers and the ones without hangers. They are divided into top and bottom halves and then connected with high-strength screws.

At the top of both Maputo and Katembe Pylon, main cable saddles will be installed. The material is steel casting with the support of a wholly casting structure. Also, a stainless steel plate bellow the saddle will be used to adapt to relative motions during the construction. Regarding the saddle groove, a vertical clapboard will be installed in order to increase the friction between the main cable and the saddle groove as well as for facilitate the positioning of cable strands. The saddle is divided into two halves in order to decrease the weight of hoisting and transportation, and they will be both connected with high-strength bolts.

After the positioning and adjustment of all cable strands, its top will be filled and levelled with zinc filler blocks, with bolts used to clamp the side wall of the saddle groove.

3.3.2.2. Girder

The girder will be a 3m high and 25.6m wide steel box girder with a standard segment of 12m long. To ensure the stiffness of the girder, an orthotropic plate streamline flat steel box girder is used, with the top plate being 14mm thick with an 8mm thick U-shaped stiffening rib. The bottom plate is 10mm thick with a similar shape as the top plate, only with 6mm thickness. Also, there are four diaphragm plates inside the box girder in order to reinforce the deck rigidity and reduce the adverse impact of the pavement layers. The diaphragm plates are 3m apart from each other and are 10mm thick at the hanger and 8mm thick for the rest of them. At the end beam segments, the diaphragm plate at permanent vertical support is 20mm thick and two longitudinal diaphragm plates will be equipped in this specific place.

Due to some factors such as length of the stiffening girder, transport conditions for the girder segments, hoisting capacity and so on, the manufacturing of the steel box girder will be divided into 57 girder segments. The connection between the girder segments will be assured by a whole cross section welding. The lengths of the girder segments, as said before, include a 12m standard, a 13m central segment and a 20.39m end beam segment.

The girder segments for the bridge will then be divided into thirty-one hoisting segments, namely one midspan hoisting segment, twenty-six standard hoisting segments, two closure segments and two end hoisting segments. The length of one standard hoisting segment, for instance, is 24m and results from welding two standard girder elements. On the other hand, for example, the length of the midspan hoisting segment is 13m and the closure segment is a standard girder segment of 12m long. The midspan segments will be hoisted first, followed by the other segments in both sides through a cable conveying, using a four-point hoisting system.

Finally, at both girder ends, multidirectional deflection comb plate expansion and contraction joints will be added to ensure a good connection and a stable girder.

3.3.2.3. Main Pylon

The main pylon is a gate-shaped frame structure composed of two beams (lower and upper) and two transverse girders (lower and upper).

The main pylon at Maputo, M1, is 135.1m high while M2, at Katembe, is 136.1m high. Among some specific characteristics, both pylon have a transverse center-to-center distance between the tops of 21.88m and each one of them has a different gradient, with a 100:3.7 for M1 and 100:3.3 for the M2.

The transverse section of the pylon body is a rectangular hollow box section, with a longitudinal width of 7.0m and a transverse width of 5.0m., while the transverse section of the lower and upper beam are 0.8x1.0m and 1.0x1.2m.

Regarding the foundation, 12 bored piles with diameter 2.2m are used as a pile group for each side of the pylon, being connected to each other through a tied beam. Each side pile cap has a dimension of 21.45x15.7m with 5.0m thickness. Then, on the top of each pile cap, a 2.0m high pedestal is the base for each column, with a 12x14m bottom size and 8x10m top size.

Fig.3.6 – Pylon M2 under construction

3.3.2.4. Anchorage

The anchorage at both banks are located in the Maputo Bay landform region, which means, as was approached previously on 3.2.1, that the subterranean bearing capacity is relatively low (400Kpa), belonging to extremely soft rocks. Therefore, with that information in mind, gravity anchorages were used to resist the tensile force of the main cable.

The confined water head is approximate to the water level of pore water at Katembe, which is approximately 1.0m higher than the water level of pore water at Maputo. The existence of high water implicates a relatively large impact on the design of the anchorage foundation. Other conditions such as the proximity to railway and railway station at Maputo bank also needed to be considered, with large-scale pumping and drainage measures avoided in order to prevent affecting the balance of underground water. At the South bank, the proximity to the sea resulted in water-blocking measures to ensure the safety during and after the excavation.

Both anchorages foundation at Maputo and Katembe are within a 50m wide circular underground diaphragm wall with a 1.2m thickness. A ring type reinforced concrete lining supporting structure was adopted to the anchorage foundation, which is composed by underground diaphragm wall, cap beam, lining, setting plate, top plate and filing core materials. The construction time for the panels of the walls were planned for 8 months, each one reaching 54m deep. The circular wall is divided into 22 sections and was executed in the following sequence: first, cement stabilized piles in the upper part were used to build the guide wall and for soil improvement, then the guide wall was constructed and the panel element was excavated, cleaned by airlift, removing all sand from the slurry. After this, a test for verticality and shape was performed by ultrasonic means and after the test results, a reinforcement cage was placed, followed by concrete casting using a tremie pipe. Finally, after 7 days, an integrity testing of concrete was performed to determine the quality of the inside panel and between panels.

Fig.3.7 – South Bank Anchorage under construction

3.3.3. THE SOUTH APPROACH BRIDGE – GENERAL DESIGN

3.3.3.1. Horizontal Alignment and Cross Slope

The horizontal alignment for the South Approach Span is a straight line followed by a right skewed circular curve with a parameter R=2500m, an easement curve with a parameter A=450m and a left skewed circular curve with a parameter R=1300m. The normal cross slope for typical cross section is 2.5% and the superelevation is calculated with a linear principle, being the maximum 2.5%.

The traffic lanes of the South Approach Span are four in total, each one 3.5m wide, with a median divider that includes a guard wall of 0.6m wide, a hard shoulder of 2x1.5m, side guard wall of 2x0.5m and a maintenance roadway of 2x0.64m. The pavement of the South Approach Bridge will be a bituminous concrete of 10cm thickness.

Item		Unit	Indicator
Designed speed		km/h	80
Number of lanes			Two-way 4 lanes
Subgrade width		m	19m for subgrade section, 25.6m/20.88m for bridge section
Width of traffic lane		m	3.5
Recommended radius without superelevation		m	≥600
Maximum longitudinal gradient		%	5.0 (recommended value) 6.0 (limiting value)
Minimum longitudinal gradient		%	0.20%
Minimum slope length		m	200
Ordinary minimum radius of vertical curve	Convex	m	1800
	Concave	m	1500
Pavement structure			Bitumen Pavement
Designed return period of flood			1/300 years for Maptuo bridge, 1/100 years for other bridges
Main Bridge navigation Clear height		m	60

Fig.3.8 – Table of critical design parameters [11]

3.3.3.2. Vertical Curve and Longitudinal Slope

For the vertical alignments, two parts were considered. The first is located in the straight line and has a parameter i=-4% while the second vertical alignment is located in the vertical curve with a parameter R=5000m and parameters of i=-4% and i=0.3%.

3.3.3.3. Bridge Span Arrangement

The starting chainage for the South Approach Bridge is at K4+472, which connects to the main Bridge, and is divided into 9 different segments. Pre-fabricated T-beams are adopted for the span, and the final arrangement is the following: 4x45m T-beam for the first three segments, 5x30m T-beam for the next three segments and 4x30m T-beam for the final two segments. The last beam after the T-beams is a pre-casted standard beam of 30.45m span.

The length of the pre-fabricated T-beams has a direct relation with the pier heights. Following this thought, 45m T-beam will be used for the piers that exceed 30m height, while the 30m span T-beam will be used for the piers that have a height smaller than 30m. The overall width for the T-beams will be 20.88m.

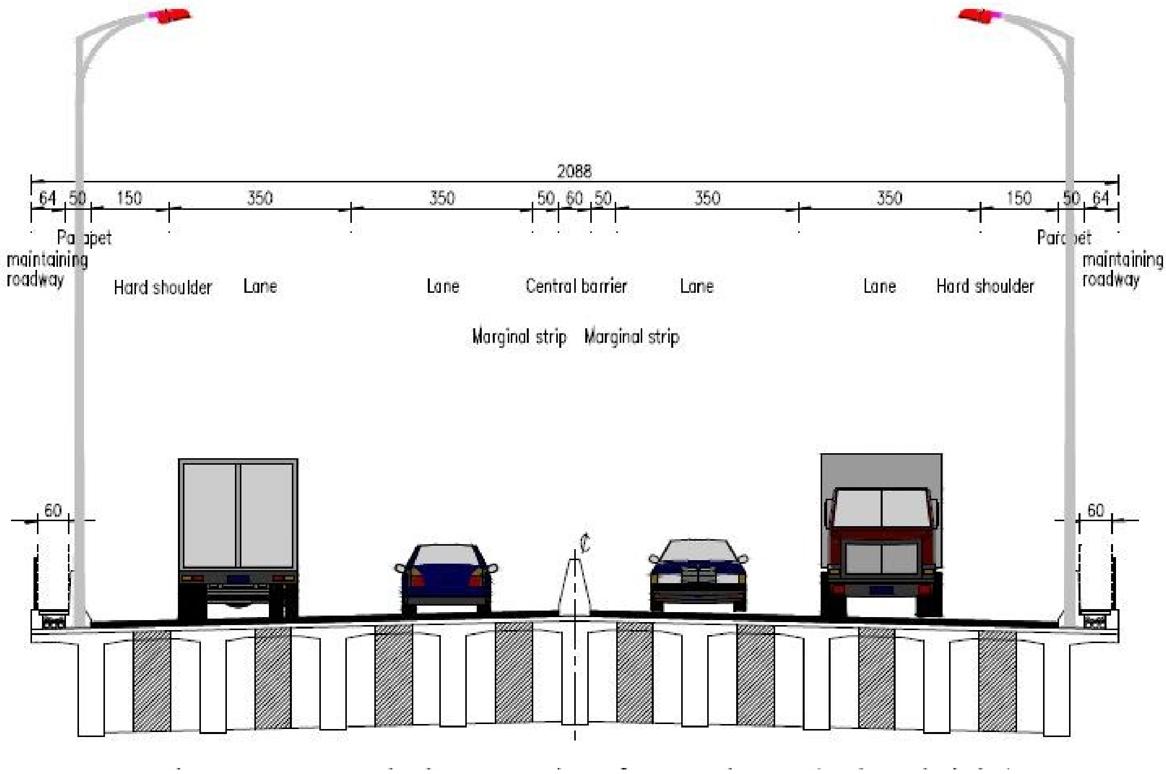


Fig.3.9 – Standard cross section for the South Approach Span [12]

3.3.4. SOUTH APPROACH BRIDGE - KEY DESIGN ELEMENTS

3.3.4.1. Superstructure

The superstructure of the T-beams are post-tensioned members with a height of 2.7m for 45m span and 2.0m for the 30m span. Cast-in-situ parts will naturally be adopted with 70cm width parts between the nearby beams and at the top of the mid-pier, resulting in a whole superstructure for the precast beam. The pre-casted beams on the horizontal curves will be casted as a straight line, and in order to assure a smooth alignment, the outside boundary of the T-Beams will change according to the road horizontal curves.

3.3.4.2. Substructure

Regarding the substructure, different types of piers are used, reflecting conditions such as different spans, the height of the piers and the geological conditions. All the foundations for the piers are bored piles with an integrated pile cap connecting to the pile group.

The final arrangement for the piers can be separated into three big groups: hollow piers with double chamber, solid piers and circular column piers. The piers are numbered from S1 to S35, thus facilitating to differentiate from the piers at the North Bank, that are named as N instead of S. Tshaped beams will be adopted as Bent Caps for all the piers from S1 to S34. The detailed information and construction method of the piers will be approached in chapter 5.

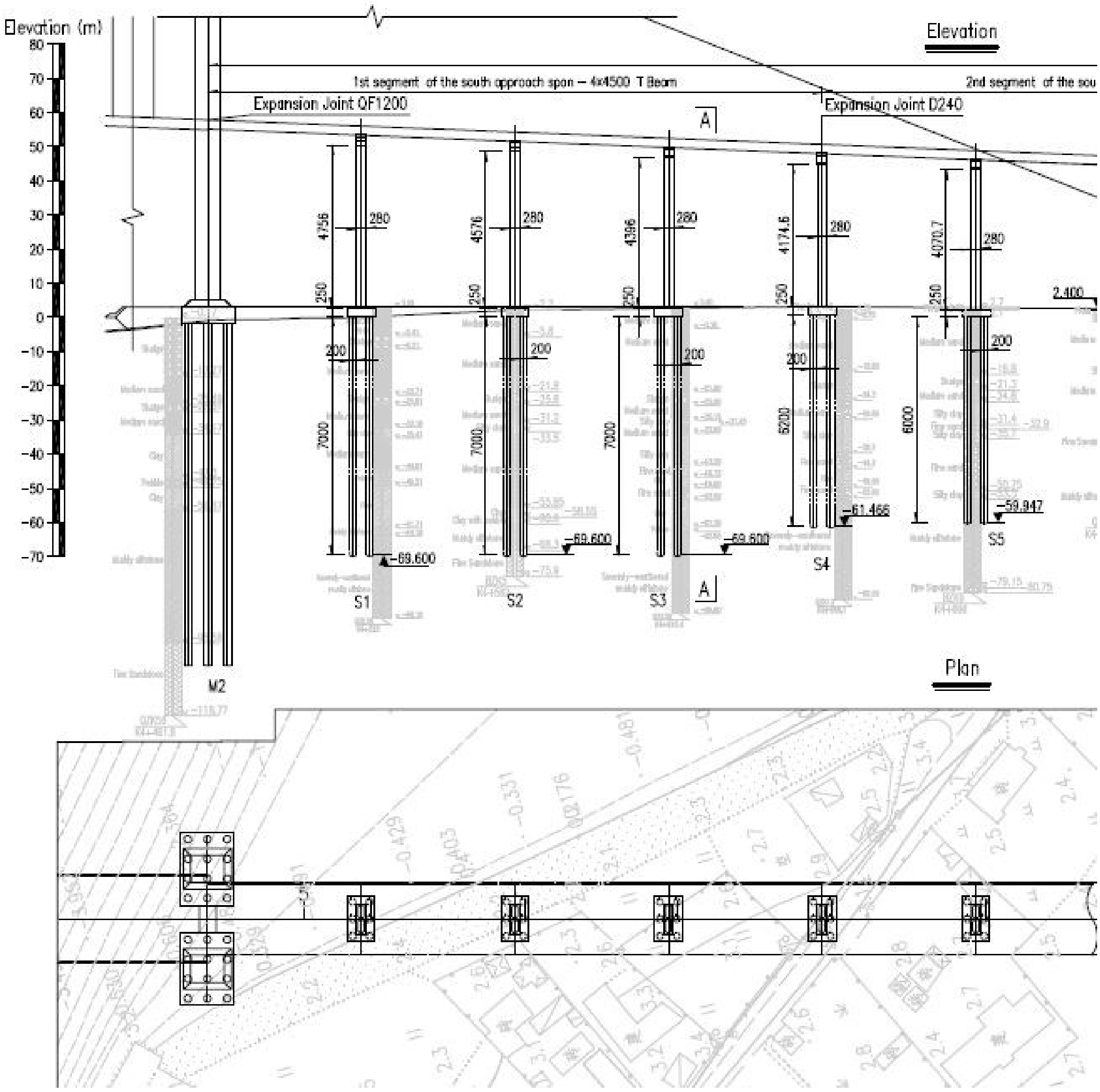


Fig.3.10 – Profile and plan view from M2 to S5, with piles, pile cap and the piers

Nevertheless, the pile cap and bored piles are different from one group of piers to another. From pier S1 to S5, the pile cap is 2.5m height with six bored piles of 2.0m diameter each. In the next segment, from pier S6 to S12, despite different pier dimensions, the pile cap and bored piles are the same as the previous group, thus resulting in the same foundation from S1 to S12, which are all hollow piers. The next group of piers goes from S13 to S27 and are all solid. In this case, the pile cap has a 2.0m height with five bored piles of 1.5m diameter. From S28 to S34, the piers are circular columns with a connection of bored piles with a diameter of 1.5m. In this case, since there are four columns, the same number of bored piles are considered, with a pile top connection provided by a 1.0x1.2m tie beam. Finally, S35 is a rib slab type of Abutment, in which three ribs slab are set, each one connecting to one pile cap with plan dimensions of 2.5x6.3m and a height of 2m. At the bottom of each pile cap, two bored piles with a diameter of 1.5m are set, resulting in a total of six bored piles for S35.

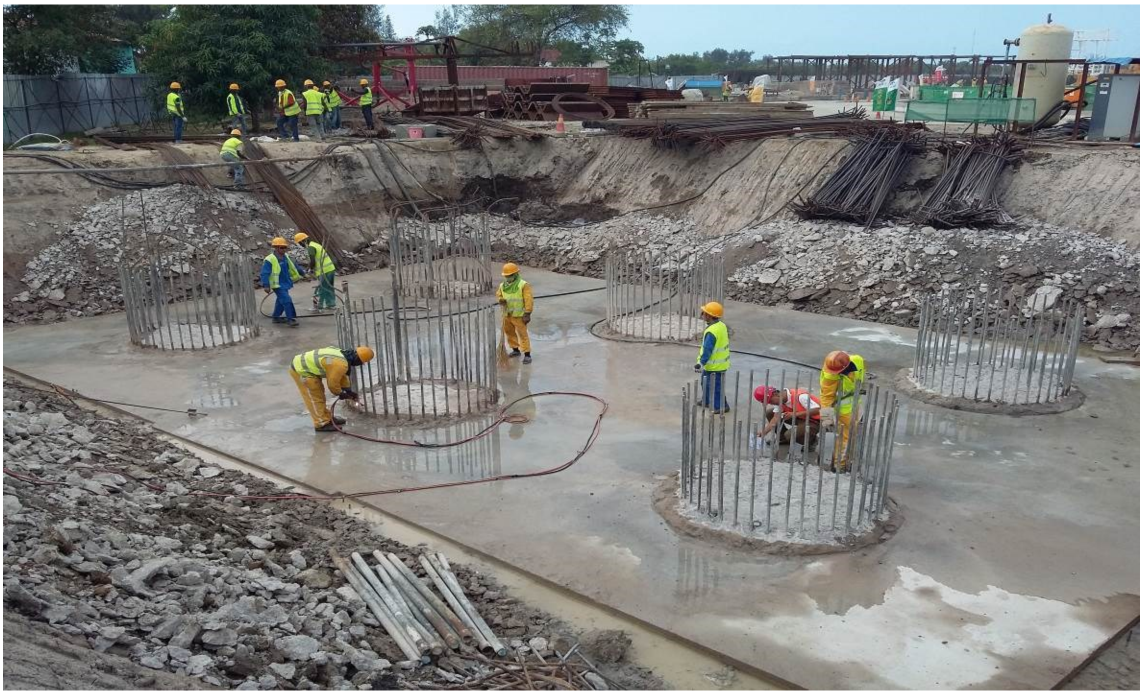


Fig.3.11 – Pile Head regularization for installation of Pile Cap Reinforcement – Pier S5

4

Construction Site

4.1. KATEMBE CONSTRUCTION SITE

A well-planned construction site is an indispensable tool towards the final goal, which is to obtain success of the construction project. The type and scale of the organization is determined by a number of factors, and in this particular project there are two main construction sites. Since there are two main areas of work, Maputo and Katembe, different teams from the contractor were assigned to each bank, being responsible to manage everyday problems and challenges independently from the other bank. This paper will focus exclusively on the Katembe Construction Site since the scope is about the South Approach Bridge.

4.1.1. OVERALL DESCRIPTION

The Katembe construction site is a closed camp, benefiting from low density occupation caused by the dispersed population. Generally speaking, this particular situation results in an incredibly good organized space, thereby allowing the weekly personnel to have both great working and living conditions. The camp is divided in two main areas, and the only reason that there is a separation is because of a local road that is close to pier S4.

The Chinese camp is a closed space controlled by guards day and night. In this facilities, all the buildings are pre-fabricated with identical areas, for the exception of two buildings that serve as the general bathroom and the other for the curing room. Since many Chinese expatriates are working on this project, dormitories are provided to everyone, as well as a social cantina and some minor sporting facilities to ensure a good adaptation and quality of living. Regarding the working facilities, meeting rooms and personal offices can be find in the entrance of the camp. GAUFF personnel have their own offices and a different eating/lounging area as well as the client Maputo Sul.

Fig.4.1 – View from Pylon M2 with the site entrance, the batching plant on the left and the Chinese camp on the right

4.1.2. TECHNICAL LABORATORIES

In terms of technical facilities, different laboratories are used for the tests that are performed during the day, whether they are concrete tests, structural steel bars test or aggregates tests, for example. These site laboratories are established for all the Maputo Bridge infrastructure, providing quality and continuous control for the materials used in the construction works. Being a specific area with plenty of different specifications and standards to follow, it is a daily challenge to handle all the tests, results, records, certificates and documentation. With this in mind, and quoting the Chinese, "Quality attributes are precision, accuracy, specificity and sensitivity", meaning that the laboratories must have qualified people handling the everyday work, assuring that the test and the results are as trustful as they could be. The laboratories are fully equipped and capable of running all the necessary tests for the construction works but one, the chemical reaction test, which is performed by LEM (Laboratório de Engenharia de Moçambique).

In total, there are six laboratories and one curing room in the South Bank. The concrete standard curing room exists to store the concrete cubes with the perfect temperature and humidity conditions. The six laboratories are the following: Concrete, Mechanical, Geotechnical, Concrete Chloride Ion Detection, Cement and Aggregate. In these technical spaces, a well-organized and capable technical team performs all the tests needed, thus guaranteeing the following of the Quality Management Plan that is implemented for the Maputo Katembe Bridge project. More detail about the equipment and some tests comes in chapter 6.

Fig.4.2 – Cement laboratory

4.1.3. BATCHING PLANT

A computerized Batching Plant is dedicated to all concrete works performed in the South Approach Bridge. With a capacity of 120m^3/h, this facility is located in the middle of the construction site, providing a fast and safe transportation to all the elements to be casted. The batching plant balances for cement, water, sand, aggregates and admixture and it was calibrated before being officially in use. In order to verify the proportions of the concrete mix, trial mixes were conducted and approved. The transport for the concrete from the batching plant to the elements to be casted are provided by concrete mix trucks with a capacity of 10m^3, but for safety reasons the limit load for each truck is set to 8m^3.

Fig.4.3 – South Bank computerized batching plant

4.1.4. PYLON WORKING AREA

In order to provide for safety excavation works for the pylon foundation and a landing port for the boats coming from Maputo, a temporary platform was used. This platform is still in use today, with an adjacent area to perform all the works related only to the pylon. So, in this area, a team of workers works every day on putting together the steel cages and process all the steel bars for the reinforcement works. Also in this area, the formwork for the pylon body gets often cleaned or repaired. Among the equipment used in this area, two tower cranes are assigned to the pylon, each one to both sides of the structure. In order to facilitate the access to all the workers, two elevators were installed in mid-March, providing a safe and fast access.

Fig.4.4 – View from Pylon M2 with the Pylon Working Area

4.1.5. OTHER FACILITIES

The area where the batching plant is located is also the area where there is storage of materials, as well as other working areas. Attached to the batching plant, a closed area is organized with all the sand and aggregates used for the concrete, as well as a closed warehouse that stores formwork, cement, curing materials, Sika products, among others. Also on this area, but on the other side, an open space is used to park the concrete trucks and all the other vehicles that are used on a daily basis, such as trucks, dumpers, stackers and so on.

Since large quantity of machinery is operated every day during the construction works, a mechanical workshop exists on the Southwest end of the construction site in order to assist and provide all the reparations that need to be done from time to time to the equipment existing on site.

Fig.4.5 – Vehicle and machinery parking area (Part of the South Construction Site)

4.2. ORGANIZATION FOR PIER CONSTRUCTION

4.2.1. LABOR/MACHINERY ORGANIZATION

In such a big construction, the quantity and type of labor and equipment has to be suited for the different elements to build, ensuring the quality of the final product.

In order to guarantee a good organization, three different teams are in charge for the pier body work, with one extra team only with reinforcement staff. The other personnel involved in the process are drivers, electricians and a maintainer.

The equipment used, which includes machinery, are truck cranes, crawler cranes, tower crane, mixing plant, concrete trucks, trailer pumps, excavator, loader, platform trailer, forklift, cantilever template, formwork, submersible pump, generators and transformers.

4.2.2. WATER AND ELECTRICITY

When planning the construction process, must exist serious consideration regarding the water, and specially the electricity. In an undeveloped African country, power cuts are frequent and this can disturb the ongoing works and compromise the overall quality and safety of the works. With this in mind, three different transformers with a range of 500kVa to 630kVa are used to distribute the power, with two 500kW generators prepared to act in case of emergency.

A network of water supply system is used to distribute the water to each pier.

5

Materials and Pier Construction Process

5.1. CONCRETE IN MAPUTO-KATEMBE BRIDGE- MATERIALS AND COMPOSITION

5.1.1. CONCRETE MIX DESIGNS

Concrete Mix designs are used in Maputo-Katembe Bridge to obtain a concrete of C20, C30, C40 and C50. In order to fit them as required by the employer, specifications, requirements and procedures are used in detail, following Chinese Standards, SATCC standards and also the Eurocodes for concrete structures. Since the location of the bridge is in a very exposed environment, criteria like chemical aggressiveness and service life of 100 years for the structure had to be considered, having the different elements different exposure classes to avoid the corrosion of steel in concrete and concrete itself. So, for this particular project location, the "Condition of exposure" is very severe or extreme condition, depending on the element location. Since this thesis is focusing on Pier construction, these structural elements were classified under SATCC standards as being in a very severe environment , with "concrete surfaces exposed to the abrasive action of water, sea water spray or a saline atmosphere" and "all exposed surface of structures within 30km from the sea", resulting in a 60mm cover for C40 concrete class. [13]

The different mix designs for the concrete were developed and tested in the Maputo CRBC laboratory, ensuring that the concrete would reach the characteristic strength on site as designed. An example of C40 class concrete mix designs can be found on attachment C.

The concrete in the South Approach Bridge is distributed as follows:

- C20 – Base Slab, Top Slab and Cushion;
- C30 – Bottom sealing for Pile Cap (Bearing Platform);
- C40 – Pile Cap, Cap beam, Anchorage and Piers;
- C50 – Pylon saddle house, Pylon body, both Pylon beams, Prefabricated T-Beam, Box Girder, Hollow Slab Beam, Pylon Pillar and Cantilever Traveler.

5.1.2. CONCRETE PRODUCTION

Concrete is a material composed by different materials – cement, aggregates, water and sometimes adjuvants – and the dosage of the mixing varies depending on the structural behavior to be achieved.

In a construction as big as the Maputo Bridge, which accommodates different structural elements with highly functional differences, there is a production of different types of concrete with distinct characteristics. Since this work has a defined scope, the focus will be on the concrete production regarding Pier Body executions.

All the 35 Piers in the South Approach Bridge are of the class C40, which was previously studied and tested in order to determine the correct dosage for the projected design strength. The characteristic strength of the concrete mix is 40Mpa, with the target design strength of 48Mpa.

The laboratory design strength is to ensure that the concrete will reach the characteristic strength on site as the level of control of the contractors varies between levels good, average or poor. So, in this case, CRBC batching plant is considered good and therefore we have the following calculation mode:

- TS= CS+(SD*1.65) [14] (1)
    - TS=Target Strength (Mpa);
    - CS=Characteristic Strength (Mpa);
    - SD=Standard Deviation for the conditions on site, with Good=5, Average=8 and Poor=11.

5.1.2.1. Aggregates

Aggregates are inert particles that derive from the crushing of rocks and are a component of composite materials like concrete. The aggregate function is to add strength to the composite material, thus improving the dimensional stability of the concrete with the advantage of reducing the cost of the concrete.

The source of this materials normally comes from the mining of mineral deposits, but it can also be obtained from the waste of iron and steel manufacturing and the recycling of concrete itself. In this case, all the aggregates come from mining.

Aggregates can be divided into two big groups depending on the size. These two groups are divided by whether the material passes the 4.75mm sieve or not, resulting in sand or stone, respectively.

Aggregates are a very important component both in fresh and hard concrete. Among the characteristics that are needed, the workability of fresh concrete must be good and the hard concrete must be strong, durable and dimensionally stable. Generally speaking, the aggregates should be stable, strong, clean and free from other particles, namely organic materials that can interfere with the quality of the final product, the concrete. Therefore, the aggregates must be carefully selected in order to fulfill the design requirements.

Some constructions benefit from the location of the project and are able to extract some aggregates from quarries. In this case, all stone aggregates come from the district of Boane. Homogenous results were obtained from a number of tests, thus satisfying the requirements for producing acceptable aggregates to use in the production of concrete. Regarding the water absorption test, the aggregates indicated a value of +/-3%, which results in a slightly porous aggregates, but according to the SATCC the value is ok, since the requirement for water absorption limit is only considered in case of a freeze-saw environment, which is not the case. Concerning the strength, and using the ACV “Aggregate Crushing value”, the aggregates were considered to have a good resistance to crushing. The remaining chemical tests were performed at LEM, such as the Alkali-Silica reactivity and shrinkage tests and they showed that the aggregates had little or no reaction, performing well within the maximum limits.

Sand aggregate is also used and comes from the district of Moamba. The sand is mined from the Moamba river, benefiting from the good characteristics of Sand River like cleanliness and free from clay and also the round shape that normally characterizes this type of sand, which lowers the water demand of the concrete, resulting in improved permeability, shrinkage and durability. On the other hand, the lack of fine particles could be a problem, leading to bleeding if the water content is too high in low concrete classes (less than C40), but the amount of cementitious fines and pozzolans eliminates this risk.

5.1.2.2. Hydraulic Binder

The hydraulic binder is the element in the concrete that performs the agglomeration between the aggregates through setting, and it is normally a mix between cement and other substances, depending on the final purpose. In this particular case, the choice was fly ash.

The cement used on the Maputo – Katembe Bridge is of the type CEM II 42.5 A-LN and is supplied by CM – Cimentos de Moçambique, which has a factory located in the suburbs of Maputo, in the city of Matola. Regarding its composition, the cement is a Portland Limestone Cement comprising between 80-94% clinker and between 6-20% limestone. This particular type of cement is capable of ensuring a strength between 42.5 Mpa and 62.5 Mpa.

Table 5.1 – Type of cement used

CEM II 42.5 A-LN	
CEM II	Portland Ciment mix
42.5	Class of Strenght
A	Aluminum Oxide (AL_2O_3)
L	Limestone
N	Normal

When the cement is mixed with water forms a reaction called hydration, and during this process Calcium Hydroxide is produced. This inorganic compound does not contribute to the overall strength, but raises the pore water PH level to 12.5, which results in a layer of ferric oxide forming on the reinforcement bars, preventing them from rusting. On the other hand, the addition of a pozzolan material like fly ash results in the consuming of the Calcium Hydroxide but results in a further strengthening of the concrete cement past after 90 days.

Fly ash is a substance that cannot react directly with water, so it reacts with the Calcium Hydroxide in the cement pore gel. Its incorporation in the concrete has innumerous advantages both in fresh and in hard concrete, and they are as follows:

- Fresh Concrete – Improves the workability of the paste and reduces the water requirement for a given slump; Slightly retards setting;

- Hard Concrete – Slightly reduces rate of strength development; Increases later age strength; Reduces the rate of chloride diffusion though concrete; Enhances the reinforcement resistance to chloride attack; Refines pore structure and reduces permeability; Prevents or retards the alkali-silica reaction; Improves sulphate resistance; Reduces rate of heat generation caused by cementing reactions; Reduces the risk of thermal cracking.

Even though the advantages of using fly ash surpass the disadvantages, without adequate knowledge and careful preparation and consideration, misuse of this element can result in problems in mixing, setting time, strength development and ultimately in the durability.

5.1.2.3. Adjuvants

Adjuvants or chemical admixtures are substances that are added to the concrete in its mixing phase to impart certain properties. Nowadays the use of this products are well studied and spread, resulting in an important element in the composition of conventional concrete.

There are a large number of adjuvants with multiple use, so it is necessary to study and perform tests to verify which ones are to be used and its quantity in order to give to the concrete the correct properties and behavior. The adjuvants should never be used as a substitute for high quality, materials, a good mix design or even good workmanship.

In the South Approach Bridge there is the use of one chemical admixture for the concrete production and its name is PCA Concrete Superplasticizer, which comes directly from China. This admixture is a superplasticizer water reducer with a retarder and the benefits of using this product in the concrete production are: increased fluidity by enabling the concrete to penetrate through congested reinforcement, excellent workability required for self-compacting and self-levelling concretes, W/C ratio reduced resulting in high strength, improved durability and reduced shrinkage.

5.1.2.4. Mixing Water

The quality of the water is always important to consider for the concrete mixing. Even though its quality has little or no effect on the final characteristic product, it can have effect on the setting time, strength development and long-term durability.

Water is an essential part in concrete by making it workable while in its fresh phase and also by reacting with the cement through hydration, forming strengthened components. Before being used, the water must be tested and checked for special parameters like PH level, presence of chlorides, sulphates, carbonates and bicarbonates. Normally, when a water is classified as potable, it fits perfectly with the requirements for a good mixing water.

The mixing water used in the South Bank batching plant comes from five boreholes in the Marinha. The water was extensively tested in Laboratório de Engenharia de Moçambique, where it was found suitable for using in the concrete mix.

5.1.2.4. Concrete Composition

Different mixed designs were used to C40 concrete, depending on which element to be casted. On this case, the C40 concrete used has two different mix designs. The first one is called PHB C40-4 and it was used since April, 2015 until late March this year, 2016. The change was motivated by a new supplier for the fly ash, which, as was expected, has different characteristics compared to the previous one. The new mix design in use is called PHB C40-6 and it has the same composition in quantity as the previous mix.

The concrete composition for the Piers in the South Bank is as follows:

Table 5.2 – Concrete composition for Piers Mix Design

PHB C40-6 : Concrete composition for 1 m^3	
Constituents	**Quantity (Kg)**
Cement	273
9.5 mm nominal Stone Aggregate	195
26.5mm nominal Stone Aggregate	782
Sand Aggregate	738
Mixing water	164
Additive	5.04
Fly Ash	147

Considering this concrete composition, the water/cement ratio is 0.39 and the sand has a proportion of 43% of total aggregates, with 11% for 9.5mm nominal aggregates and 46% for 26.5mm nominal aggregates.

5.2. PIER CONSTRUCTION PROCESS

5.2.1. SOUTH APPROACH PIERS DESIGN

As briefly approached in chapter3, hollow piers, solid piers and circular column piers are respectively used by span value, pier height and geological conditions.

The arrangement for the piers design is described in table 5.3:

Table 5.3 – Pier Arrangement for the South Approach Bridge

Pier Arrangement for the South Approach Bridge		
Pier Number	Type of Pier	Plain Dimensions
S1 to S5	Hollow pier – single box with double chamber	9m x 2.8m
S6 to S12	Hollow pier – single box with double chamber	9m x 2.5m
S13 to S27	Solid pier	8m x 1.8m
S28 to S34	Circular column pier	1.4m
S35	Abutment with a rectangle trustum of a pyramid	-

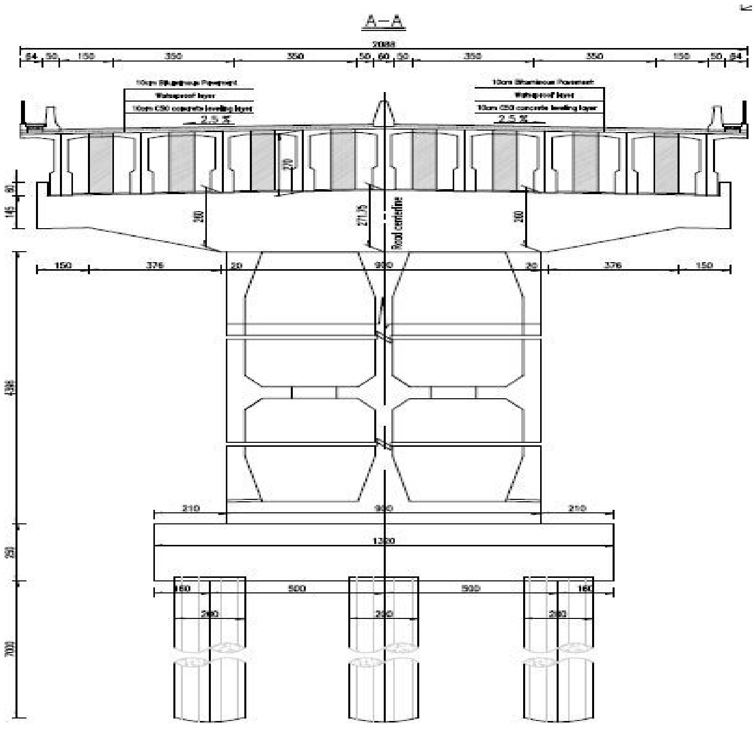


Fig.5.1 – S3 Hollow Pier with all the piles, pile cap, bent cap and the T-Beams

5.2.2. CONSTRUCTION PREPARATION

After the piling, a pile cap gets installed and casted. In the pile cap reinforcement there are the starter bars for the first layer of the pier, so when the installation of reinforcement is finished, it must be clear that the starter bars should be in the correct position and also with the correct amount and shape in order to ensure the quality of the next construction step. (See Figure 5.1)

Fig.5.2 – Pile Cap S1 before backfilling and with the starter bars for the first layer of pier body reinforcement

5.2.3. PIERS CONSTRUCTION METHODOLOGY

Like in every construction, equipments are frequently used to provide better work conditions and safety. There is a set of equipment used in the South Approach Bridge as mentioned before in 4.2.1., and its distribution is according to the needs and specific elements to be built.

Since there are different pier heights, there must be a good consideration regarding which equipment to use in hoisting, and from S1 to S13 there is the allocation of two sets of tower cranes for repetitive use. In the end, one tower crane should be allocated to S1, one to S2 and S3, one to S4 and S5, one to S8 and S9, one to S10 and S11 and another one for S12 and S13. Piers S6 and S7 will be constructed with a different tower crane that is allocated to the anchorage construction. Except for the anchorage tower crane, the other two sets of this equipment adopt a fixed substructure that is connected between the bottom of the tower crane and to steel pipe pile foundation. From S14 to S35, since the heights are lower and easier to work, the equipments used for hoisting are truck and crawler cranes.

To better access the pier working areas on high levels, a rolling ladder is installed in each pier column. This installation also needs service efficiency since the equipment goes from each pier body to the next. Each pier column formwork has two sets of rolling ladders pedestal, with the South Approach allocating in total 200m of rolling ladder and six pedestals for repetitive use. In order to ensure the safety of this equipment, some preparation must be done before its installation. Among the works, there must be a backfill on the pile cap and a backfill soil compression followed by a C30 concrete casting for the foundation of the rolling ladder, with four supports of 40cm x 40cm x40cm dimensions. For the lateral support of the rolling ladder, embedded parts in the pier body are used every 4.5m and the connection between the ladder ad the formwork is provided by a safe wood plate.

Fig.5.3 – Pier S12 with the rolling ladder and the tower crane installed

5.2.4. CONSTRUCTION SEQUENCE

A well-defined construction sequence is a good step towards the overall organization and it is divided in two different sequences, being one for the rectangle piers and the other for the cylinder column piers.

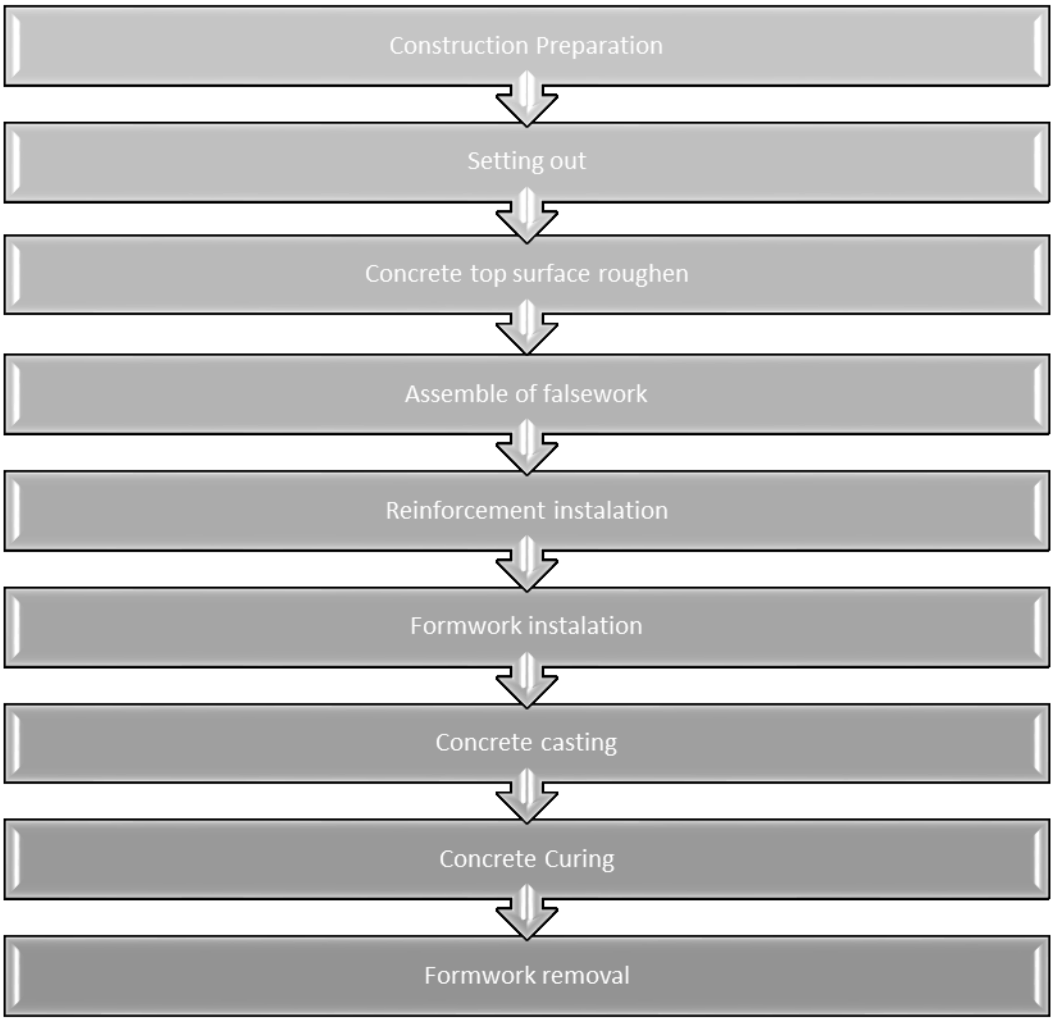
In the case of the rectangle pier body construction technology, there is a division in layers, with each layer varying and reaching to a maximum of 4.5m height. For each layer, the sequence applied is as follows:

Table 5.4 – Construction sequence for Piers S1-S27

1. Construction Preparation
2. Concrete top surface roughen
3. Setting out
4. Stiffen frame instalation
5. Reinforcement instalation
6. Stiffen frame removal
7. Embedded parts instalation
8. Formwork and platform instalation
9. Concrete casting
10. Concrete Curing
11. Formwork removal

For S28 o S34 cylinder piers, the construction sequence is different, since they are built and casted as a unique single piece. The construction sequence is as follows:

Table 5.5 – Construction sequence for Piers S28-S34



5.2.5. Processing and installation of reinforcement

The manufacture and installation of reinforcement can be divided in three groups, which are from pier body S1-S27, S28 to S34 and finally, S35.

5.2.5.1. Processing and Installation of Reinforcement on S1 to S27 Pier Body

In pier body S1-S27, since the pier dimensions are considerably bigger, the organization and requirements are more straight and defined through a three topic organization: reinforcement process, reinforcement assembling operation platform and reinforcement assembling and installation.

In the reinforcement process there must be special attention to the cleanliness of the bars, which must be free from surface oil, rust and other particles.

When it comes to the operation platform, it has a 4.9m height divided into four layers horizontally. The operation platform is fixed on the embedded part of the cantilever formwork platform. The operation platform adopts a total of eight steel pipes of diameter 219mm and it is assembled as a whole in the processing area, being installed with the help of the cranes.

In the reinforcement assembling and installation, the reinforcement should meet the design requirements when it comes to diameter, number and spacing. The range of the rebar diameter goes from 12mm to 28mm, with 16mm and 20mm rebar also used. When there is intersection of reinforcement, two options exist. The first option is to bind the rebars using a 0.7-2mm steel wire and the other option is welding, being that normally the first option is the most used. When there is overlapping of rebars, welding is used to bind the pieces together, with a weld length of at least 10d mm for one single side and 5d mm when welding both sides, with d representing the diameter of the reinforcement bar. All the intersections must be at inside the concrete, ensuring that the concrete cover is respected. In every layer of reinforcement there are also embedded parts, which need to be placed and fixed according to the design requirements. Regarding the vertical reinforcement bars, there must be also careful consideration regarding the next step of reinforcement because of the couplers, since they cannot be all at the same height, being the limit 50% of total amount of rebars. An example of a supervision report for Pier S9 can be found on attachment A.

Fig.5.4 – Pier S8 with the operation platform settled

Fig.5.5 – Pier S8 with the reinforcement installed

5.2.5.2. Processing and Installation of Reinforcement on S28 to S34 Pier Body

Since these specific piers are cylinder columns casted in one layer, the steel cage is completed as a whole in the steel plant and then transported to the implantation place. The reinforcement should be, as before, clean and free of any substances or particles that can damage or affect its overall condition. In this particular case, all the intersections were welded.

The diameter, number and spacing of the rebars and the concrete cover should be as designed and the diameters used are 10mm and 28mm.

5.2.5.3. Processing and Installation of Reinforcement on S35

The reinforcement of S35 abutment is once again processed differently, with a single platform used to process the rebar assembling. The reinforcement manufacture and installation is identical to the pier bodies S1 to S27.

In this case, since the structure is a different assembled element with different pieces like the abutment wing wall and the abutment back wall, the range of the reinforcement bars goes from 10mm to 32mm, but also with 12mm, 16mm, 20mm, 25mm and 28mm.

5.2.6. FORMWORK DESIGN AND CONSTRUCTION

Like in 5.2.7., the formwork design and construction also varies with the different pier type, so from S1-S27, from S28-S34 and finally S35, there are three different solutions for the formwork. All the formwork systems were design and processed by a professional formwork company.

5.2.6.1. Formwork Design and Construction for S1-S27

On the square piers, three sets of cantilever template system are used. Since S1-S12 are hollow piers, there is a need for two sets of inner formwork system and wellbore platforms.

The adopted formwork system is a cantilever movable formwork structure that can be characterized in three sections such as: formwork system, embedded part system and support bracket system. The formwork system is composed by wood templates with a wooden beam, back arris, back arris fastening and wooden connection claw. The embedded part system is composed by embedded plates, high strength screws and bolts and the support bracket system is composed by load-bearing tripod, setback device, main, middle platform and lifting platform.

Since it is a structure that is going to be used in height, safety must be the first priority and the construction process should be well prepared, ensuring that the cantilever movable formwork can be used correctly.

The first step in the construction process, after the installation of the reinforcement and the embedded parts, is to assemble the formwork, followed by the formwork installation. After casting and curing, the formwork is removed and a tripod is assembled together with a setback device. The next step is to install the main platform of climb cone, followed by the installation of the top and middle platform. After this, reinforcement is assembled on the next section of the pier body, followed by the installation of the formwork, which at this point has the main, middle and top platform installed. After this step, the embedded part of climbing bracket is installed, with concrete casting and curing next. The third and final step is to install the third section of pier body reinforcement, followed by a formwork setback which allows the formwork to move up and then the lifting platform is installed as well as the embedded part of the cantilever formwork, enabling he third layer concrete casting and curing. An example of a supervision report for S8 formwork can be found in attachment A.

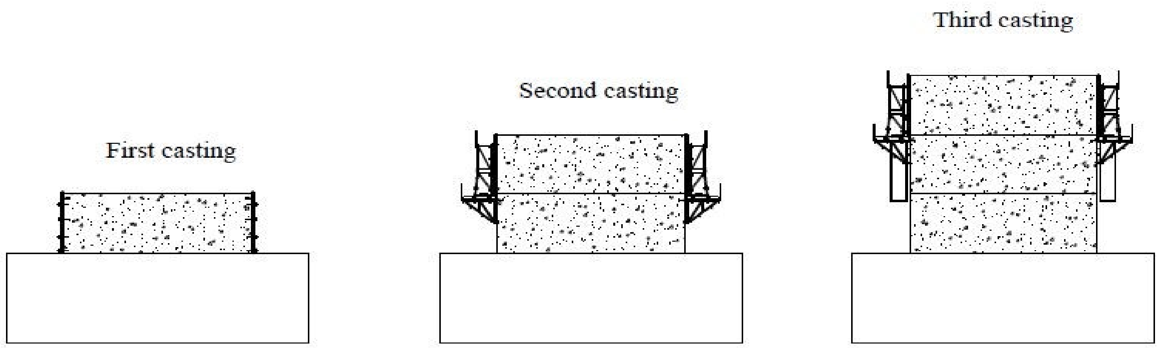


Fig.5.6 – Cantilever movable formwork process for solid piers

Fig.5.7 – Pier S10 with the formwork installed and ready for concrete casting

5.2.6.2. Formwork Design and Construction for S28-S34

The cylinder pier column formwork adopted is a 6mm thick steel formwork. This formwork is divided into two semi-circular structures, being connected with a flange. The adopted formwork is a very simple structure, installed with the help of the tower crane in one time. Nevertheless, it must have the same precautions and preparation as before, with special attention to the steel plate surface cleanliness. After the installation, the verticality of the formwork should be adjusted in order to ensure the formwork stability and the pier body final shape.

5.2.6.3. Formwork Design and Construction for S35

Regarding the S35 abutment, since it is a different structure with different layers and shapes, the adopted formwork is a timber formwork with bamboo plywood and square wood. The fixation is guaranteed by the use of PVC tubes. The casting is divided by four times, with the first being for the Pile Cap, the second for the three main rib plates, then the bent beam and finally the back wall and wing wall, thus dividing the general design of the abutment formwork in this four different formats.(See figure 5.8)

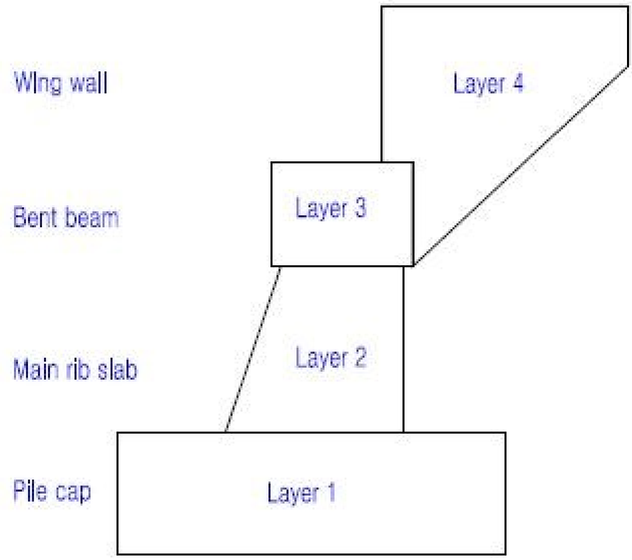


Fig.5.8 – S35 abutment casting scheme

5.2.7. CONCRETE CASTING

Once again the concrete casting methods change with the different types of pier. From Piers S1-S27 the casting is divided by layers that are previously approved and don't exceed the 4.5m height maximum. Piers S28-S34 are casted in one time, while S35, as mentioned before, is casted in four layers.

Before the casting, the surface should be cleaned and moistened with water to ensure the adherence to the bottom layer. The concrete transport is provided by two concrete mixer trucks with four other concrete trucks prepared in case of emergency. After the arrival of the truck to the pier area, the concrete is poured using a steel hopper carried by a tower or crawler crane. When concreting high layers such as 4.5m height, the height of the concrete fall must be controlled in order to avoid segregation or damages in the formwork, resulting in a 2m height free drop when the drop is concrete-concrete or 0.5m height when the drop is concrete-reinforcement. This control is ensured by the use of steel funnel.

When casting, the concrete must be poured into several discharging points with 30-50cm layers. Then, vibrators of 50mm diameter are used to vibrate the fresh concrete, serving as a mechanical compaction method, allowing the air trapped inside the concrete to escape. This vibration process is very important for the final result and must be carried out with specific instructions that ensure the quality of vibration. Among the instructions, the vibrators should be inserted vertically at points between 450mm and 550mm and must be completely immersed. The insertion should be quick so that the concrete is compacted from the bottom up, allowing the air to escape and the removal should be slow, ensuring that the hole is closed behind the head of the vibrator. The vibration time is undefined, being finished when there are no more air bubbles breaking on the surface, avoiding excessive compaction that often tends to cause stone to settle and mortar to be brought on top.

When casting, there must be a special attention to the concrete temperatures, and since the temperatures in Maputo are frequently high, there must be control of the temperature. With this in mind, the concrete should be casted and poured in low temperatures and it should not be more than 28º

C. When extremely hot temperature is a factor, the aggregates temperature should be decreased by watering, and the cooling machine system in the batching plant can be used to decrease the water temperature used in the mixing. When it comes to transporting the concrete, the concrete trucks are also protected with textile that is watered with cold water, and the concrete tank should keep a slow rolling of 2-4r/min before the concrete unloading. When concreting high volumes of concrete in the South Bank, a cooling system is used, but since the 4.5m maximum layer high is used for the pier construction, it makes no sense to use it when casting these elements. An example of a supervision report for S8 can be found in attachment A.

Fig.5.9 – Pier S18 with the preparation for casting

Fig.5.10 – Pier S19 being casted

5.2.8. CONCRETE CURING AND FORMWORK REMOVAL

After the final concrete pouring, vibration and surface regularization, the curing process begins. The curing works are carried with the use of geotextile and watering adopted to the exposed concrete surface, keeping it wet and trying to avoid wet/dry cycles. The geotextile should be carefully applied and not damage or pollute the concrete surface.

From S1-S27 the curing method is the one previously described plus the use of curing agent. When it comes to S28-S34 cylinder column piers and S35 abutment, the curing work is done with the help of a plastic film, with a water box on top to water it.

The curing time should not be less than 7 days. It was agreed between the client, contractor and consultants that the removal of all formworks should be done in a period not inferior to 24 hours. The formwork must not be removed before the concrete strength reaches 2.5Mpa, which normally, after 24hours, is way higher than the specification limit. Also during that time, the pier body should not be subjected to any kind of external load.

After the formwork is removed, it is cleaned and prepared for the next section, which can be on the same pier or moved to other construction area. All the formwork pieces are inspected regularly when the final body acceptance is made, and when is not used for some time, it must be stored in good conditions to prevent damage or deformations.

5.2.9. REPAIR WORKS

All works performed need some final reparations in order to assure quality, even when sometimes the elements don’t require that much work.

There are plenty of steel embedded components in this project that are installed in concrete to support climbing formworks and other types of templates, so protective measures must be taken to ensure anticorrosion protection for steel plates and other mortar structures, for example. Generally, regarding repair works in the South Approach Bridge, if the concrete cover of embedded components is enough and according to the specifications, common concrete is used to seal it and it’s applied to cover the grooves left by the embedded components. On the other hand, if the concrete cover of embedded elements is less than required, Sika products are used to repair the grooves.

Sika products are known and used worldwide as building construction products used for sealing, dumping, reinforcing, bonding and protecting all kinds of elements. Regarding the specific products used, they are three: Sikadur 32 Normal, Sika Monotop 612 and Sika Monotop 620, with the first one being liquid and the two other solid material. All of these products are certified and applied using the specifications of EN 1504-4. Concerning its application, it varies with the works to be performed but some overall procedures regarding its application and storage are equal to every work. For example, all Sika products should be kept unopened, dry, protected from direct sunlight and at temperatures between 5ºC and 30ºC. Also, when it’s applied, the surface of the concrete or the steel parts should be clean from other substances or particles that can contaminate and jeopardize the procedure. After all the procedures, the curing process begins and it should be cured in a minimum time of 3 days, thus ensuring full cement hydration and the avoidance of cracking.

After formwork striping, every layer of the pier body needs some minor reparation in order to guarantee its final quality and a good looking surface. In the end, and generally speaking, the surface must be clean, free of gravel accumulations and without cracks, and if there are any cracks, they must be examined to find out its extension and how they can damage or not the final result, and then corrected. The holes that were used to support the formwork but are not part of the cantilever movable formwork are also repaired, with the PVC pipe cut and the hole filled with Sika material with cement finishing. After this, the surface should not present any cracks. Another critical point is the joint from one layer to the next, since it is normal to have some minor deviations that need to be corrected in order to perform a smooth surface transition between pier body layers. An example of a supervision report for pier body acceptance can be found on attachment A.

Fig.5.11 – Pier S9 with the formwork stripped

Fig.5.12 – Pier S9 with the repair works finished

6
Quality Control of the Concrete in Pier Construction

6.1. CONTROL METHODOLOGY

This current chapter has the purpose to present the inspection plan and control methodology adopted for the quality control of the concrete produced at the south bank batching plant. Regarding the concrete, CRBC designers gave CRBC laboratory the design strength for each element, and the laboratory staff, together with GAUFF, developed the mix designs for concrete.

Among the specifications, the compressive strength class, class of exposition, maximum dimension of aggregates and chlorates content class were considered. Since the south bank has the laboratories fully equipped to perform the required tests for the inspection plan, every one of them is made on site whenever it is necessary.

The supervision of the concrete production is made by the CRBC laboratory technicians and GAUFF is responsible for monitoring the quality plan, by developing and implementing it on site, as well as supervise all the works related to concrete.

Like most constructions, the analysis of the test results and its verification is made by the supervision company, since the concrete composition was made with the consultancy of GAUFF Engineers. In the end, GAUFF materials department is responsible to assure the concrete quality and its conformity with the requirements.

6.2. INSPECTION PLAN AND TESTING

For the control of concrete in the Maputo-Bridge, an inspection testing plan was developed in order to organize all the necessary procedures. In this document, the required tests, the technical specifications, testing methods, sample sizes, testing frequency and tolerances are the main topics and in the next sub-chapters all the tests related to concrete production, application and post-application tests are approached and explained. On attachment C can be found the inspection plan for the element.

6.2.1. ELEMENT

6.2.1.1. Cement

Whenever there is a new batch of cement, a series of tests are conducted in order to fulfill the requirements, making sure that the product has the correct characteristics for the concrete production.

All the cement tests are made according to the technical specifications in SABS EN 197-1 [15], except for the chemical analysis that follows SANS 50196-2[19], whose certificate is supplied with the delivery note. The cement that doesn't comply with the standard should be rejected.

The tests performed for cement are synthesized in the following table 6.1.

Table 6.1 – Testing required for cement, with standards and requirements

Testing required	Standard	Testing Method [16] [17] [18]	Specification requirements
Compressive tests after 2 days	SABS EN 197-1	SABS 196-1	≥10 Mpa
Compressive tests after 28 days	SABS EN 197-1	SABS 196-1	≥ 42.5 ≤ 62.5 Mpa
Rupture strength after 2 days	SABS EN 197-1	SABS 196-1	≥ 3.5 Mpa
Rupture strength after 28 days	SABS EN 197-1	SABS 196-1	≥ 6.5 Mpa
Setting time - initial	SABS EN 197-1	SABS 196-3	≥ 60 min
Setting time – final	SABS EN 197-1	SABS 196-3	≤ 600 min
Fineness	SABS EN 197-1	SABS 196-6	≤ 10%
Chemical analysis	SANS 50196-2	-	-

Fig.6.1 – Represents the image of a mixer used in the laboratory to mix water with cement

6.2.1.2. Fly Ash and Chemical Admixture

Like in the last sub-chapter, every time a new batch of fly ash is delivered from South Africa, a set of tests is performed. The technical specifications followed in the case of fly ash are from SANS 50450-1, with a chemical analysis certificate supplied with the delivery note. Regarding the chemical admixture, no tests are made in the laboratory since the product comes from China with all the proper documentation and certificates. The tests performed for the fly ash are synthesized in the following table 6.2.

Table 6.2 – List of tests required for fly ash, with standards and requirements

Testing required	Standard [20]	Specification requirements
Loss of ignition	SANS 50450-1	Max. 5%
Chloride content	SANS 50450-1	Max. 0.1%
Sulfuric anhydrite	SANS 50450-1	Max. 3%
Free calcium oxide	SANS 50450-1	Max. 2.5%
Calcium oxide	SANS 50450-1	Max. 10%
Fineness	SANS 50450-1	Max. 12%
Activity index	SANS 50450-1	Min. 75%
Soundness	SANS 50450-1	Max. 10mm
Water requirement	SANS 50450-1	Max. 95%

Even though there is a control of every test in the table above, only three of these tests are performed in CRBC laboratories, being them loss of ignition, fineness and water requirement. As mentioned before, during the internship period there was a change of the fly ash supplier, so some comparison can be made between the suppliers when it comes to the results of the three tests performed. During the month of February, two new batches of 200tons each were delivered, with four deliveries also in March and three in April and May. The results were analyzed and an average of each supplier was calculated for each test, being the result as follows. (See table 6.3)

Table 6.3 – Comparison between two suppliers of fly ash

Testing required	Old Supplier Results	New Supplier Results
Loss of ignition	1.368%	1.578%
Fineness	8.675%	6.925%
Water requirement	94.4%	85.95%

Fig.6.2 – Represents the view of the machine that performs the “loss of ignition” in fly ash

6.2.1.3. Aggregates

When testing the aggregates, it was defined that they can be separated between coarse and fine aggregates. Nevertheless, the sample size in each test is 50kg and the testing frequency is $3m^3/250m^3$ for every test except for the Alkali reactivity and Sulfate determination, which are made whenever there is a new source of supplier. These tests are fundamental since the aggregates play an important role when it comes to the overall strength of the concrete. All the tests, standards and specifications can be resumed in tables 6.4 and 6.5, being separated between coarse and fine aggregates.

Table 6.4 – List of tests required for coarse aggregates, with standards and requirements

Testing required	Standard	Specification requirements
Grading of large aggregate nominal size	SANS 3001- AG1 [21]	passing 13.2 mm 100% 9.5 mm 85-100 % 6.7 mm 0-55 % 4.75 mm 0-25 % 2.36 mm 0-5 %
Grading of small aggregate size	SANS 3001- AG1	passing 37.5 mm 100% 26.5 mm 85-100 % 19.0 mm 0-50 % 13.2 mm 0-25 % 9.5 mm 0-5 %
Soundness of Na_2SO_4	SANS 3001- AG1	≤ 12
Potential Alkali Reactivity	SANS 3001- AG1	Non-reactive
Aggregate crushing value	SANS 3001- AG10 [22]	≤ 29
Sulfate determination	SANS 3001- AG1	2000 mg/l
Fineness modulus	SANS 3001- AG1	1.2 to 3.5
Dust Content	SANS 3001- AG1	5% to 10%
Clay Content	SANS 3001- AG1	Max 2%
Flakiness Index	SANS 3001- AG4 [23]	Max 35%
Water absorption	SABS 843/844 [24]	Max 1%

Table 6.5 – List of tests required for fine aggregates, with standards and requirements

Testing required	Standard	Specifcation requirements
Grading of sand	SANS 3001 – AG1	passing 4.75 mm 90-100% 2.36 mm 75-100 % 1.18 mm 60-90 % 0.60 mm 40-60 % 0.3 mm 20-40 % 0.15mm 10-20% 0.075mm 5-10%
Clay Content	SANS 3001 – AG1	Max 2%

6.2.2. FRESH CONCRETE PROPERTIES

The inspection testing plan for the Maputo Bridge also specifies some demands regarding the concrete fresh properties, which are mostly evaluated on site.

For the inspection plan testing there are two tests who are performed in order to evaluate the fresh concrete properties, being them the air entrainment and the fresh concrete slump test. The first one is only performed when required by an Engineer on site, and the second one is made every time there is a new truck with a new batch leaving for site. More details are presented on sub-chapter 6.3, where the control on the application is approached.

6.2.3. HARDENED CONCRETE PROPERTIES

To ensure the correct production of concrete in the South Bank batching plant, hardened concrete properties are also checked through the test of concrete cube strength determination. This test is performed whenever there is concrete casting and it is made under the SANS and SATCC standards. For the testing itself, the standards are from SANS5863 [25] and the number of samples to be taken are from SATCC standards [26], where it is defined according to different amounts of casted concrete. For the concrete mold it was used a plastic cubic mold that guarantees that all cubes have the same dimension for testing. (See table 6.6)

Table 6.6 – List of tests required for concrete strength determination, with standards and requirements

Testing required	Standard	Dimension of the cubes	Samples taken
Concrete cube strength determination	SANS 5863	15cm*15cm*15cm	0-20m³ = 3 21-40m³ = 6 41-70m³ = 9 71-100m³ = 12 100-150m³ = 14

The samples taken are for 28 days testing, and normally an additional 3 samples are taken for early strength tests after 7 days and 3 samples are taken for 90 days testing. Whenever there is a situation on site that requires a fast testing for strength determination after one day, for example, the cube should be taken from this additional ones. This situation can happen for example to determine if the contractor can remove the formwork after casting.

During the internship period, several concrete cubes were made and tested under the supervision of the author. When making the concrete cubes, if they are made in the batching plant, they are produced with the help of a vibration table that ensures the correct distribution of the concrete in the cube mold, but when the cubes are made on site, the method changes and the workers carefully fill the cube mold and try to ensure the correct concrete distribution without directly compacting it. (See figure 6.3)

Fig.6.3 – Concrete cube samples on the vibration table

When determining the concrete cube strength, the tests were always performed by a CRBC laboratory Engineer with the supervision of GAUFF personnel, and then the official report was submitted and ultimately approved with the concrete cube results. The cubes are brought from the curing room, correctly identified like in the fig. 6.4, and then they are weighted and tested. The tests so far have been very positive.

The presentation and discussion of the results is presented in the sub-chapters 6.2.3.1.

Fig.6.4 – Two concrete cubes with the correct identification

Fig.6.5 – Compressive test to determine the concrete cube strength

6.2.3.1. Presentation of Results

Since the internship period of the author was only 4 months, some piers in the South Approach Bridge were already finished, some were incomplete and some had not even started to be executed. So, during the period between 10/02/2016 and 20/05/2016, 28 pier body layers (as of 25/5/2016) were casted and concrete cubes were produced to test them according to the standards. Unfortunately, not all concrete cubes from this period can be tested and presented in this report, since some 28 days results are still not available for the latest castings. Tables 6.7 and 6.8 represent the list of pier body layers analyzed for concrete cube samples testing.

Table 6.7 – Concrete samples analyzed for the 7 days compressive test results

Concrete cube samples analyzed for 7 days			
February	March	April	May
S12L2	S12L4	S12L6	S10L3
S11L1	S18L6	S12L7	
S12L3	S19L5	S10L2	
S11L2	S11L3	S11L5	
	S17L6	S11L6	
	S19L6	S8L1	
	S12L5	S9L1	
	S17L7	S8L2	
	S11L4	S9L2	
	S10L1		

Table 6.8 – Concrete samples analyzed for the 28 days compressive test results

Concrete cube samples analyzed for 28 days			
February	March	April	May
S12L2 S11L1 S12L3 S11L2	S12L4 S18L6 S19L5 S11L3 S17L6 S19L6 S12L5 S17L7 S11L4 S10L1	S12L6 S12L7 S10L2 S11L5 S8L1 S9L1	-

For every test performed, a collection of data must be organized in order to guarantee a good sequence of results and its overall organization. So, in every test record it needs to be identified the element, grade, casting date, test date, age of testing, specimen size, specimen number, mass, density, crushing load, strength and ultimately the average strength. An example with some data used for the analysis of results is presented as follows in tables 6.9 and 6.10.

Table 6.9 – Example for S10L1 concrete samples analyzed for the 7 days compressive test results

7 days cube testing for pier S10L1 – Casted on 27/03/16 – PHB C40-6					
Size (mm^2)	Mass (g)	Density (kg/m^3)	Load (KN)	Strength (Mpa)	Average Strength (Mpa)
22500	7748	2296	936.4	41.6	41.8
22500	7786	2307	939.9	41.8	
22500	7759	2299	946.4	42.1	

Table 6.10 – Example for S10L1 concrete samples analyzed for the 28 days compressive test results

28 days cube testing for pier S10L1 – Casted on 27/03/16 – PHB C40-6					
Size (mm^2)	Mass (g)	Density (kg/m^3)	Load (KN)	Strength (Mpa)	Average Strength (Mpa)
22500	7796	2310	1281.5	57.0	56.7
22500	7779	2305	1283.8	57.1	
22500	7819	2317	1255.0	55.8	
22500	7774	2303	1244.4	55.3	55.5
22500	7765	2301	1240.4	55.1	
22500	7793	2309	1256.1	55.8	
22500	7784	2306	1225.3	54.5	55.3
22500	7699	2281	1251.5	55.6	
22500	7771	2303	1264.2	56.2	

For the analysis of the results, two different tests were performed. Like seen above, the samples taken for 7 and 28 days were considered and analyzed in order to determine the overall strength quality and accordance to the standards. Even though the SATCC standards don't have any requirement for 7 days testing, tests are performed in order to evaluate the early concrete strengths for 7 days, being the target value of 36 Mpa, per design. So, for every group of 3 concrete cubes, an average was calculated and introduced in the table for calculations. After that, an overall average was calculated as well as the standard deviation. To better analyze the results, a line that contains 95% of the results was introduced. This type of descriptive statistic helps to identify more easily the concrete cubes that are not that good as well as to have a better idea of the results as a whole. This calculations and graphics were made for 7 and 28 days and the results are as follows. (See figures 6.6 and 6.7 and tables 6.11 and 6.12). The calculations can be found on attachment D.

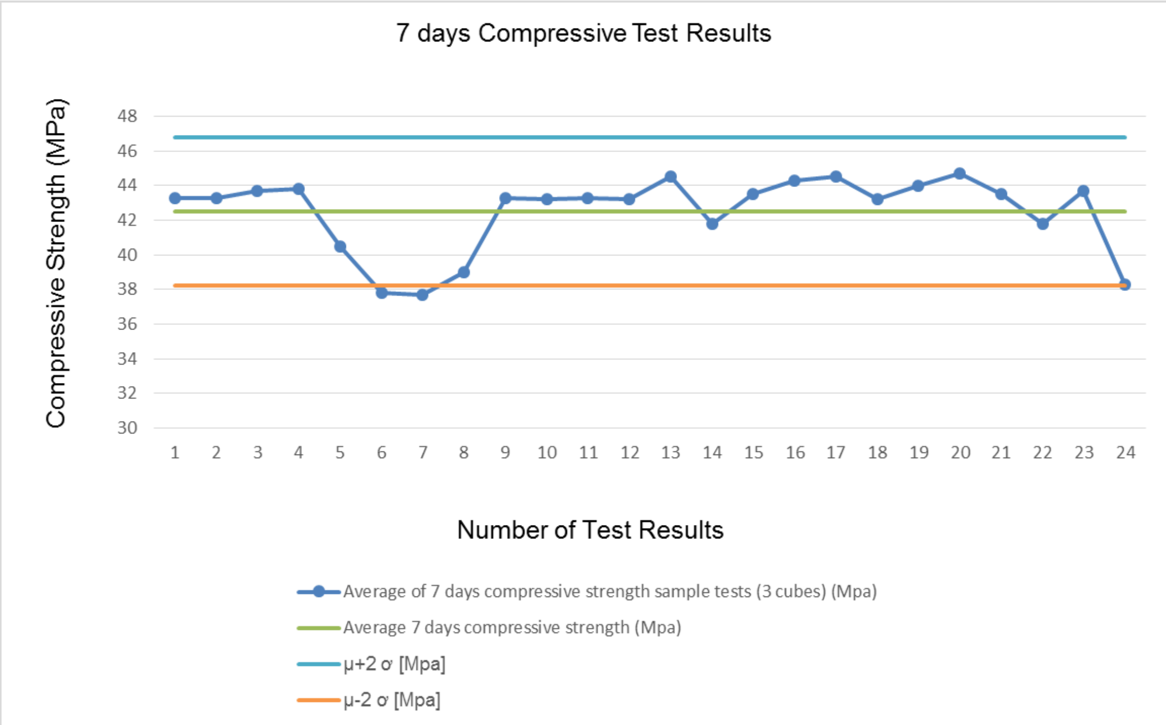


Fig.6.6 – Graphic with the 7 days compressive test results

Table 6.11 – Key values for the 7 days compressive test results

7 days Compressive Test Results				
Number of samples	Average (µ) MPa	Standard deviation (σ)	µ+2 σ (Mpa)	µ-2 σ (Mpa)
72	42.5	2.13	46.76	35.23

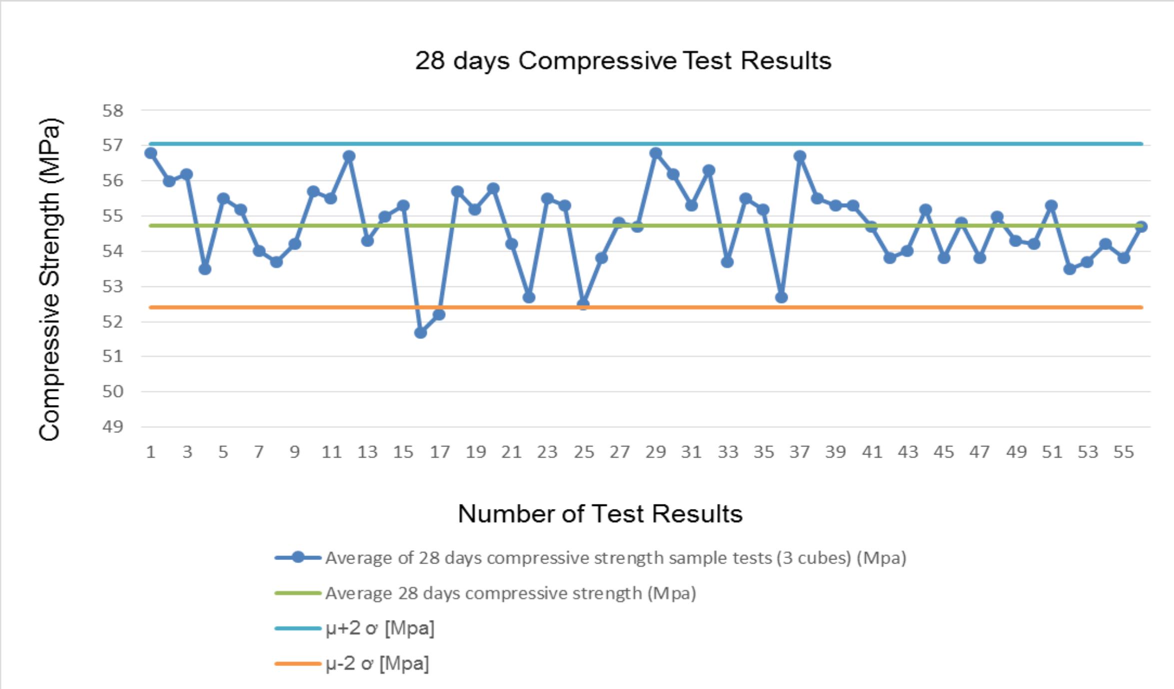


Fig.6.7 – Graphic with the 28 days compressive test results

Table 6.12 – Key values for the 28 days compressive test results

28 days Compressive Test Results				
Number of samples	Average (μ) MPa	Standard deviation (σ)	μ+2 σ (Mpa)	μ-2 σ (Mpa)
168	54.73	1.16	57.06	52.41

6.2.3.2. Discussion of Results

Even though not many cubes were tested considering the amount of concrete casted so far, a total of 240 cubes (72 for 7 days and 168 for 28 days) were analyzed in the above graphics, and they represent a good sample that can be used to evaluate the concrete performance for the pier construction.

By comparing directly the two graphics for the compressive test results, the first thing that stands out is the number of samples. Just like mentioned before, most of the concrete cubes tested are for 28 days, so it is normal that the sample size is bigger for 28 days compressive test results comparing to the 7 days.

Analyzing the results for the 7 days compressive test, it clearly stands out that the concrete reaches really high strength within the first days after casting. With an average of 42.5 Mpa, it means that 88.5% of the target design strength for 28 days is reached in the 7 days results. The line that contains 95% of the results also helps to identify only two sets of samples below this value, which only means that they are a bit out of line compared with the other results. The values are 37.8 MPa and 37.7 Mpa, which means that they are 78.75% and 78.54% of the target strength, which still are impressive results.

SATCC specifications gives the acceptance criteria used in the South Bank 28 days compressive test results through the values presented in table 7205/5 [27]. In this table it is specified, according to the number of cubes taken for testing, the requirements when it comes to the characteristic strength. So, according to these specifications, we have the following calculation mode for the average:

- $X \geq L_S + \Delta_A$, where: (2)
  - X – Mean value for the 28 day compressive test results;
  - L_S – Characteristic Strength (CS), which in this case is 40MPa;
  - Δ_A – The applicable value given in table 7205/5.

Following the same line of thought, no value must be lower than the value obtained from:

- $L_S - \Delta_B$, where:
  - L_S – Characteristic Strength (CS), which in this case is 40MPa;
  - Δ_B – The applicable value given in table 7205/5.

For example, for a set of 15 cube samples for a C40 concrete class, we have:

- An average of 40 + 2.7 = 42.7 MPa;
- No value below 40 – 5.8 = 34.2 Mpa.

Analyzing the results for 28 days compressive test results, it can be said that the target strength of 48 Mpa is easily surpassed in each sample. Regarding the acceptance criteria above, the average of 42.7Mpa is also surpassed and no value is below 34.2Mpa, being the lower value 51.7Mpa. The average strength for the analyzed samples is 54.73 Mpa, which means that the compressive strength of the concrete cubes has an average of 14% higher than the target strength. Analyzing the line that contains 95% of the results, it can be stated that the dispersion in not relevant and both values under the line that are 51.7Mpa and 52.2Mpa are still 7.7% and 8.75% higher than the target strength.

Analyzing the results globally, the compressive strength for the C40 class, specifically the PHB C40-5 and the PHB C40-6 mix design, is really good. Not only the target strength is achieved but also the acceptance criteria is respected and the samples taken comply with the requirements. When it comes to the composition, one can foresee that cement and fly ash could be reduced and still the values would be acceptable when it comes to the compressive strength.

6.2.3.3. Comparison with European and American Standards

Since the project is in Southern Africa and follows the SATCC and SANS standards, a comparison can be made with other foreign standards in order to evaluate the overall quality of the concrete and to help on validating the quality of the work performed, globally speaking. This comparison is only made for the 28 days compressive test results.

When comparing with European standards, the adopted standard was the NP EN 206 [28], which is the Portuguese version of the European norm. In this document, all the information regarding concrete composition and behavior can be found. Since the comparison is only for the compressive test results, the first challenge was to adapt the C40 class of the project to the European concrete class. This C40 is equivalent to a European C35/45, in which 35 Mpa is the minimum characteristic compressive strength of a cylinder ($f_{ck,cyl}$) and 45 Mpa is the minimum characteristic compressive strength of a cube ($f_{ck,cube}$), which is the one that matters in this comparison since the compressive test results were only made for cube samples.

According to the standards, for a continuous production we have [29]:

- Criterion 1: Mean of results - $(f_{cm}) \geq f_{ck} + 1.48 * \sigma$; (3)
- Criterion 2: Any individual test result $\geq f_{ck} - 4$. (4)

Applying criterion 1, $f_{cm} \geq 45 + 1.48 * 1.16 = 46.72$ Mpa. Comparing with the average of 54.73 Mpa calculated before, the conclusion is that the cubes comply with the European requirements regarding the mean of results, with a result 17% bigger than the required value.

For criterion 2, in which any individual test result should be according to the above formula, it makes sense only to calculate it for the lower value observed in the cube samples. So, the minimum value should be equal or above $f_{ck} - 4=45 - 4= 41$ Mpa, and since the minimum value is 51.7Mpa, the conclusion is that the compressive test for cubes comply with the requirements when it comes to the individual test results. The result for the cube with less compressive strength is 26% higher than the minimum required.

The comparison can be finalized by comparing the SATCC standards with the standards from ACI (American Concrete Institute), a technical society and standard organization that works to develop a consensus knowledge when it comes to concrete and its uses.

In the document ACI 211.4R-93, which is a “Guide for Selecting Proportions for High Strength Concrete with Portland Cement and Fly Ash” [30], it can be found the required average strength for a concrete of C40 class. When it comes to high-strength concrete proportion based on field experience, which was the case, the calculation mode is the larger of the two following calculation mode:

- $F_{cr}' = f_c' + 1.34*s$ (5)

  And

- $F_{cr}' = 0.9*f_c' + 2.33*s$ with: (6)
  - F_{cr}' = Average strength in Mpa;
  - f_c' = Design compressive strength;
  - s = Standard deviation.

Solving the first equation, $F_{cr}' = 40 + 1.34*1.16 = 41.56$ Mpa and solving the second, the result is $F_{cr}' = 0.9*40 + 2.33*1.16 = 38.7$Mpa, which lead to the adoption of the first one, since it is the larger of the two. Since the average for the 28 days compressive test results is 54.73Mpa, once again the results are higher than the requested average, thus complying with the ACI standards. The results are 31.7% higher than required.

Analyzing the results after the comparison with foreign standards, the compressive test results are valid and present a good result, validating the work done when it comes to the concrete composition and the supervision methods, both in production and casting.

6.3. CONTROL ON THE APPLICATION

Control on the application is an important task to perform in order to guarantee that the concrete transported from the batching plant and casted has the correct properties. After the mixing at the computerized batching plant, two concrete trucks are prepared to transport the concrete to the element to be casted.

In order to organize this process, a team from the laboratory is responsible to fill the casting record with technical information such as the truck number, the arrival and leaving time on the batching plant, the air temperature, concrete temperature, slump test results and the concrete cubes.

Regarding the slump tests, they are an indicator of the quality of the fresh concrete and the standards followed are from SANS5862-1 [31]. The test is performed through a metallic mold with a thickness of at least 1.6mm and an internal smooth surface. The overall dimensions and shape must be according to the standards, with two holdings on the wider end to ensure steadiness and another two handlers on 2/3 of its size to facilitate the lifting procedure. Before making the test, the equipment must be clean and free from all sorts of particles that can compromise or modify in some way the slump results. After the sample is collected from the concrete truck, the mold is filled in three layers and between each of them, a compaction is made with a help of a metallic tamping rod. For each layer, 25 strokes are applied, guaranteeing the correct distribution of the concrete throughout the mold. After the mold is filled, its top is regularized and every piece of concrete outside the mold is removed, assuring the cleanliness of the base. When all the previous steps are finished, the mold is carefully and slowly removed in a vertical position and with minimum lateral or torsion movement. Immediately after removing the mold, the slump result can be read with a ruler like in the following figure 6.8.

Fig.6.8 – Slump test performed for S10L1 casting

The slump results must be in between 140 – 220 mm. This values were defined per design when producing the mix designs for the South Approach Bridge. Slump tests are performed per truck and if the result is not within the accepted range, a new mix must be done. Normally only one test is made per truck before concrete pouring, but if for any reason a truck is on wait for more than one hour with the concrete inside, a new slump test must be made to check if the concrete is still in good condition to be applied.

Once again, in order to guarantee a methodic organization, a paper with the guide number, name of the driver, plate number and time and date of the exit from the batching plant is delivered to the driver of the truck so he can deliver it to the responsible Engineer on site. An attachment of a casting report can be found on attachment B.

7
Conclusion

In such an important construction work that can define a city and with such a strategic dimension to the country, the quality management plan is well organized and solid, ensuring that all the requirements and specifications are respected.

The organization, when it comes to the contractor and consultant, is well defined and the responsibilities between all involved are known and respected. Even though sometimes it is hard to manage all people involved in some specific works, in the end all workers know what job is theirs to perform.

When it comes to the concrete production and its quality control, it is clear that the work is going well. CRBC and GAUFF work together in order to guarantee that the concrete has all the required characteristics, and the compressive test results for the hardened concrete show that the concrete production is a well-defined process. Even though the only control for the fresh concrete leaving the batching plant for site is the slump test, it also reflects the good quality of the concrete, being the results often more than satisfactory. The compressive test results are done to comply with the requirements from the design team. The concrete production is a difficult job to perform, especially when different elements are being casted, with different concrete classes and mix designs.

Considering all the results for the concrete production and for all the concrete constituents, it can be said that the process is good, since the quality of the mix design, the inspection plan, the quality management plan that is implemented and includes the laboratory performance, is good.

Regarding the control on the application, the process is strict and every time there is some concrete casting, Engineers from CRBC and GAUFF are present in the batching plant and in situ, guaranteeing that the concrete arrives in good conditions and that it is poured according to the method statement and the requirements, as well as to inspect if the concrete samples are taken according to the technical specifications.

When it comes to timing for the construction works, normally they are well planned and go according to that, benefiting also from the good weather conditions that normally exist in Maputo. Regarding the Piers, S1 to S7 are the next and last to be constructed, since the others are finalized, with some of them already with the bent caps casted. Both Pylons are growing in a good rhythm and the North Approach Bridge is also developing according to the planning. The construction is going to be finalized later than expected since the works started later then what was planned, having nothing to do with the construction works performed until now, which are according to the planned schedule.

To conclude, the construction works so far have been really positive, and the test results for all elements and the overall appearance is very good. Mozambique and specially Maputo and Katembe will have the long awaited connection that will change the skyline of both cities and the lives of thousands of Mozambicans, providing good access for the travels between these two cities and also the following connections to South Africa and Swaziland.

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[7]http://footage.framepool.com/en/shot/524253829-great-belt-bridge-bridge-pier-steel-cable-strait (February 2016)

[8]http://www.newcivilengineer.com/highways-special-extending-the-life-of-the-humber-bridge/8624789.article (February 2016)

[9] CRBC – Generic Documents – *Preliminary Design of Bridge and North Link roads – Part 1 – Route*

[10] CRBC – Generic Documents – *Preliminary Design of Bridge and North Link roads – Maputo Bridge – Overall Arrangement*

[11] CRBC – Generic Documents – *S4-S6 South Approach Bridge – Construction Design Instructions for the South Approach Bridge – Critical Design Parameters*

[12] CRBC – Generic Documents – *Preliminary Design of Bridge and North Link roads – Maputo Bridge – Solution Design for approach – Typical Cross Section for South Approach Span*

STANDARDS AND SPECIFICATIONS

[13] SATCC, *Standard Specification for road and bridge works. Table 6306/1 – Minimum concrete cover reinforcement*, September 1998.

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[18] SABS EN 196-6, *Methods for testing cement. Part 6: Determination of fineness*, 2014.

[19] SANS 50196-2, *Methods for testing cement. Part 2: Chemical analysis of cement*, 2014.

[20] SANS 50450-1, *Fly ash for concrete. Part 1: Definition, specifications and conformity criteria*, 2014.

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[22] SANS 3001-AG10*, Civil engineering test methods. Part AG10: ACV (aggregate crushing value) and 10% FACT (fines aggregate crushing test) values of coarse aggregates*, 2012.

[23] SANS 3001-AG4*, Civil engineering test methods. Part AG4: Determination of flakiness index of coarse aggregates*, 2015.

[24] SABS 843/844.

[25] SANS 5863, *Concrete tests. Compressive strength of hardened concrete, 2006.*

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[27] SATCC, *Standard Specification for road and bridge works. Table 7205/5 –Acceptance factor for strength concrete*, September 1998.

[28] NP EN 206-1, *Betão. Parte 1: Especificação, desempenho*, produção e conformidade, 2007.

[29] NP EN 206-1, *Betão. Parte 1: Especificação, desempenho*, produção e conformidade – Critérios de conformidade de resistência à compressão, 2007.

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[31] SANS5862-1, *Concrete tests. Consistence of freshly mixed concrete – Slump test*, 2006.

OTHER CONSULTED DOCUMENTS

GAUFF – Generic documents – *Maputo Concrete manual C40 M2015003 to M2015007*

GAUFF – Generic documents – *162 C20, C30, C50 Concrete mix design for the South Bank*

GAUFF – Generic documents – *Katembe Lab – Aggregate testing*

GAUFF – Generic documents – *Katembe Lab – Cement testing*

GAUFF – Generic documents – *Katembe Lab – Fly ash testing*

GAUFF – Generic documents – *Katembe Lab – Concrete cube results*

GAUFF – Generic documents – *Concrete job mix design overview*

GAUFF – Generic documents – *Inspection testing plan*

CRBC – Generic documents – *20150623 Method Statement of Pier Column in South Bank*

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ATTACHMENTS

A – SUPERVISION REPORTS FOR PIER CONSTRUCTION

CHINA ROAD AND BRIDGE CORPORATION (CRBC)	GAUFF	MAPUTO BRIDGE AND LINK ROADS PROJECT QUALITY MANAGEMENT PLAN (QMP)	
EMPLOYER: MAPUTO SUL, E.P.	REV.00	SITE VISIT INVITATION	Form: CP

SITE VISIT INVITATION

Section I — No-S1-(C2233)

SITE VISIT DETAILS	SCOPE OF SITE VISIT		LOCATION
	COMMON SITE INSPECTION	☐	
	TESTS ON SITE	☐	
	SAMPLING *)	☐	
	STOPPING / CHECK POINT*)	☒	S9L4
	TOPO SURVEY CHECK *)	☐	
	OTHER *)	☐	

Proposed date for the site visit:	Time for the appointment :	Appointment location
13 MAY 2016	15:00 PM	KaTembe Site Office

Give details : *)
Reinforcement inspection of S9L4

Contractor's invitation prepared by:			Invitation confirmed by Consultant		
Name	Date	Signature	Name	Date	Signature
郝荣飞	12 MAY 2016	郝荣飞	Emerson Galler	12/05/2016	E. Gallo

SITE VISIT CONCLUSIONS

TEST RESULTS ACCEPTANCE		Consultant		Contractor	
ACCEPTED	OK ✓	Name	Tiago Carvalho	Name	郝荣飞
REJECTED		Signature	Carvalho	Signature	
RE-TESTING		Date	13/5/2016	Date	

Reference documents (Test results in annex):	Comments and/or recommendations:
	S9L4 Reinforcement inspection was made on 13/5/2016. Position and quantity of rebars was according with the drawings. Quality of the welding was good.

NOTE: The Site visit invitation shall be submitted to the Consultant at least 1 day before the proposed site visit date

Verified by:	Revised by:	Approved by:

REINFORCEMENT CHECK

CONSTRUCTION MONITORING CHECKLIST

PROJECT NO. / NAME: Maputo Bridge and Link Roads Project

INSPECTOR'S NAME(S): Tiago Carvalho

STRUCTURE: South Approach Bridge Piers **ELEMENT:** Pier S914

ACTIVITY AND DETAILS	APPROVAL			
	ACC	NOT ACC	Check again	Acceptance criteria
General				
Drawings	☒	☐	☐	Latest approved version
Previous Work				
Cleanliness	☒	☐	☐	Free from bar and wire pieces, clean
Roughness	☒	☐	☐	Surface roughened
Starter Bars	☒	☐	☐	Acc. to drawing bar sizes, dimension, numbers, position
Steel cage				
Condition of steel cage	☒	☐	☐	Free from oil, grease, dirt, paint and loose rust
Amount of rebars	☒	☐	☐	Acc. to drawing
Diameter of rebars	☒	☐	☐	Acc. to drawing
Size/ shape of bent rebars	☒	☐	☐	Acc. to drawing
Space between bars	☒	☐	☐	Acc. to drawing minimum 2,5cm, maximum 35.0cm
Rectilinearity	☒	☐	☐	Acc. to drawing, all bars should be straight, not shifted or rotated
Stirrups	☒	☐	☐	Hooks lengths minimum 10d
Stagger of splices	☒	☐	☐	Distance between splices 35d, minimum 50cm maximum 50% on the same height
Coupler (mechanical)	☒	☐	☐	Fixed and well fastened
Welding (seam)	☒	☐	☐	single side length 10d double side length 5d
Welding (process)	☒	☐	☐	Right electrodes IGS-J502, Welding Machine maximum 150A - 200A
Spacer	☒	☐	☐	Concrete spacers every 1,5m (vertical and horizontal)
Concrete cover	☒	☐	☐	No bars or wire outstanding – visual check
Cooling system	~~☐~~	~~☐~~	~~☐~~	Installed, fixed and tight
Starter bars for next layer				
Fixation on top	☒	☐	☐	Will not bend during concrete casting
Opening for concreting / vibrating	☒	☐	☐	Available

DATE: 13/5/2016 **SIGNED:** [signature]

SITE VISIT INVITATION – PICTURES SELECTION






Verified by:	Revised by:	Approved by:

CHINA ROAD AND BRIDGE CORPORATION (CRBC) / GAUFF	MAPUTO BRIDGE AND LINK ROADS PROJECT QUALITY MANAGEMENT PLAN (QMP)	
EMPLOYER: MAPUTO SUL, E.P. — REV.00	SITE VISIT INVITATION	Form: CP

SITE VISIT INVITATION		Section I	No-S1-(C2236)
SITE VISIT DETAILS	SCOPE OF SITE VISIT		LOCATION
	COMMON SITE INSPECTION	☐	
	TESTS ON SITE	☐	
	SAMPLING *)	☐	
	STOPPING / CHECK POINT*)	☒	S8L3
	TOPO SURVEY CHECK *)	☐	
	OTHER *)	☐	

Proposed date for the site visit:	Time for the appointment :	Appointment location
14 MAY 2016	10:00 AM	KaTembe Site Office

Give details : *)
Formwork inspection of S8L3

Contractor's invitation prepared by:			Invitation confirmed by Consultant		
Name	Date	Signature	Name	Date	Signature
郝荣飞	13 MAY 2016	郝荣飞	Emmanou Gabler	13/05/2016	[signature]

SITE VISIT CONCLUSIONS

TEST RESULTS ACCEPTANCE		Consultant		Contractor	
ACCEPTED	OK ✓	Name	Tiago Carvalho	Name	郝荣飞
REJECTED		Signature	[signature]	Signature	
RE-TESTING		Date	15/5/2016	Date	

Reference documents (Test results in annex):	Comments and/or recommendations:
	S8L3 Formwork inspection was made on 15/5/2016 at 10:30 am. Concrete cover was good and overall cleanliness and position was good. Ready for concreting.

NOTE: The Site visit invitation shall be submitted to the Consultant at least 1 day before the proposed site visit date

Verified by:	Revised by:	Approved by:

FORMWORK CHECK

CONSTRUCTION MONITORING CHECKLIST

PROJECT NO. / NAME: Maputo Bridge and Link Roads Project

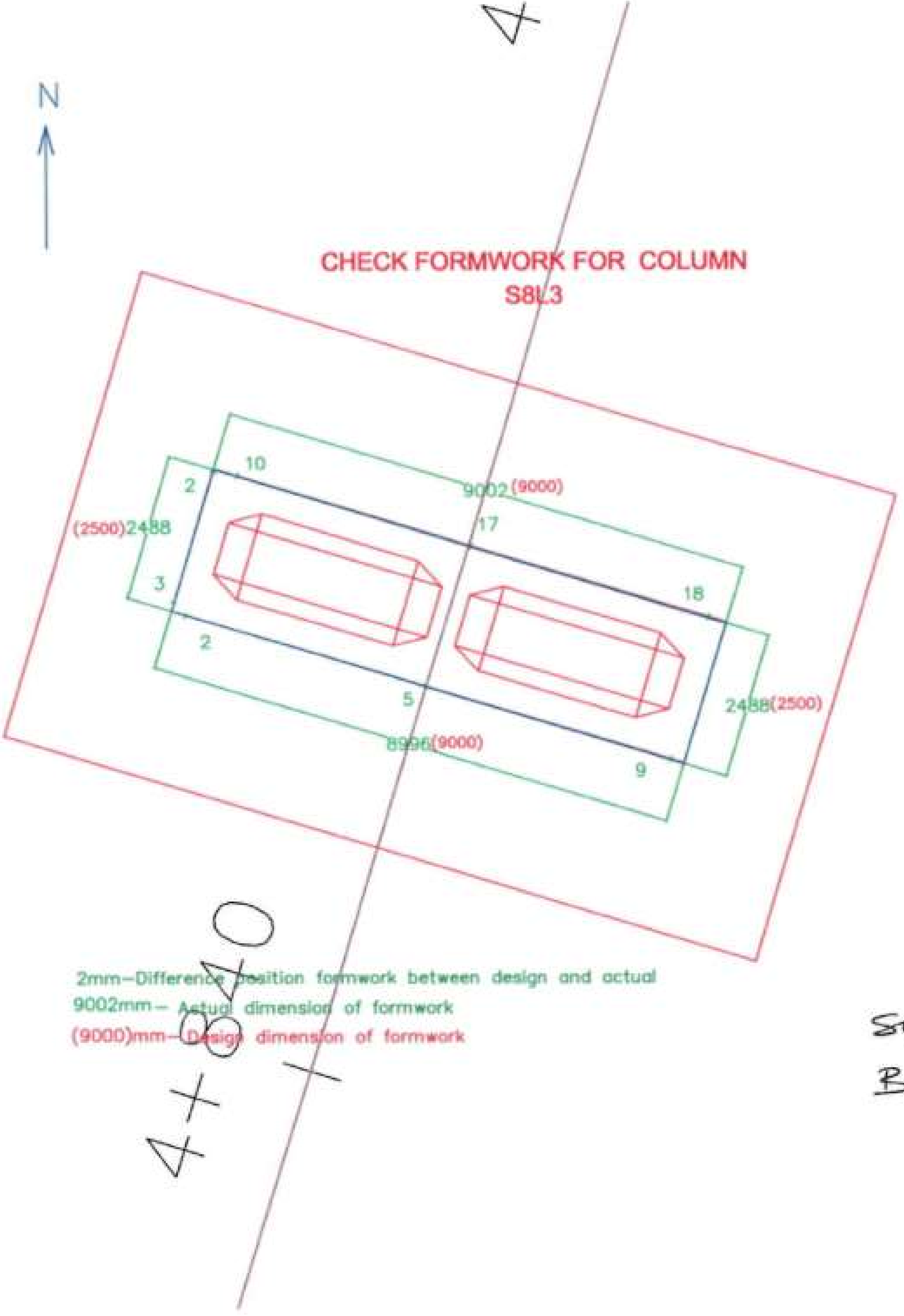
INSPECTOR'S NAME(S): Tiago Carvalho

STRUCTURE: South Approach Bridge Piers **ELEMENT:** Piers SB13

ACTIVITY AND DETAILS	APPROVAL			
	ACC	NOT ACC	Check again	Acceptance criteria
General				
As built survey	☒	☐	☐	Acc. to drawings (provided by surveyor)
Re-check				
Cleanliness lower concrete surface and steel cage	☒	☐	☐	No bar and wire pieces No loose wire on the cage
Reinforcement cage, starter bars	☒	☐	☐	Acc. to drawings, fixed and fastened Bar sizes, dimension, numbers, position
Cover				
Concrete cover	☒	☐	☐	Acc. to drawing, minimum 6.0cm free of bars, wire or foam
Formwork				
Overall dimensions of concrete body	☒	☐	☐	Acc. to drawings, width, length, height
Surface	☒	☐	☐	Clean and oiled
Formwork well fastened	☒	☐	☐	Anchors not loose, Acc. to method statement
Shape of formwork	☒	☐	☐	Straight, no belly
Tightness	☒	☐	☐	All joints and holes closed, no gaps
Embedded items	☒	☐	☐	Well fastened
Tendon ducts (prestressing)				
Position and amount	~~☐~~	~~☐~~	~~☐~~	Acc. drawing
Closed and fastened	~~☐~~	~~☐~~	~~☐~~	Can not move during casting, tight
Anchor	~~☐~~	~~☐~~	~~☐~~	Right position, well fastened

DATE: 14/5/2016 **SIGNED:** [signature]

CHECK FORMWORK FOR COLUMN
S8L3



2mm–Difference position formwork between design and actual
9002mm– Actual dimension of formwork
(9000)mm–Design dimension of formwork

SURVEYOR, GAUFF!
B. Chaucate, 13.05.2016

SITE VISIT INVITATION – PICTURES SELECTION

Verified by:	Revised by:	Approved by:

CHINA ROAD AND BRIDGE CORPORATION (CRBC) / GAUFF	MAPUTO BRIDGE AND LINK ROADS PROJECT QUALITY MANAGEMENT PLAN (QMP)	
EMPLOYER: MAPUTO SUL, E.P. — REV.00	SITE VISIT INVITATION	Form: CP

SITE VISIT INVITATION			Section I	No-S1-(C2237)
SITE VISIT DETAILS	SCOPE OF SITE VISIT		LOCATION	
	COMMON SITE INSPECTION	☐		
	TESTS ON SITE	☐		
	SAMPLING *)	☐		
	STOPPING / CHECK POINT*)	☒	S8L3	
	TOPO SURVEY CHECK *)	☐		
	OTHER *)	☐		

Proposed date for the site visit:	Time for the appointment :	Appointment location
14 MAY 2016	10:00 AM	KaTembe Site Office

Give details : *)
Concrete inspection of S8L3

Contractor's invitation prepared by:			Invitation confirmed by Consultant		
Name	Date	Signature	Name	Date	Signature
郝荣飞	13 MAY 2016	郝荣飞	Emmerson Galler	13/05/2016	E. Galler

SITE VISIT CONCLUSIONS

TEST RESULTS ACCEPTANCE		Consultant		Contractor	
ACCEPTED	ok ✓	Name	Tiago Carvalho	Name	郝荣飞
REJECTED		Signature	Carvalho	Signature	
RE-TESTING		Date	14/5/2016	Date	

Reference documents (Test results in annex):	Comments and/or recommendations:
	S8L3 Concrete inspection was made on 14/5/2016. Several discharging points were used and everything went well. A change of crawler crane and steel hopper occured in the middle of concreting.

NOTE: The Site visit invitation shall be submitted to the Consultant at least 1 day before the proposed site visit date

Verified by:	Revised by:	Approved by:

CONCRETE CHECK

CONSTRUCTION MONITORING CHECKLIST

PROJECT NO. / NAME: Maputo Bridge and Link Roads Project

INSPECTOR'S NAME(S): Tiago Carvalho

STRUCTURE: South Approach Bridge Piers **ELEMENT:** Pier SB13

ACTIVITY AND DETAILS	APPROVAL			
	ACC	NOT ACC	Check again	Acceptance criteria
Equipment				
Equipment for concreting	☒	☐	☐	Quantity, fitness, compensating measures
Cleanliness (tremie, hopper)	☒	☐	☐	Pipes, openings are free
Tests				
Temperature air	☒	☐	☐	Take measurement, check report
Temperature concrete	☒	☐	☐	Take measurement, check report
Slump test	☒	☐	☐	200mm +/- 20mm
Cubes (quantity, designation)	☒	☐	☐	Amount of cubes: 0-20m³ = 3 for tests after 28d 21-40m³ = 6 41-70m³ = 9 71-100m³ = 12 101-150m³ = 15 > 151m³ = 18 Plus 3 for strength test after 7d and plus 3 for additional early strength tests
Casting report	☒	☐	☐	Check during the casting
Mix design	☒	☐	☐	Concrete class acc. to drawing
Workmanship				
Surface of hard concrete	☒	☐	☐	Moistened with water
Height of free drop	☒	☐	☐	Concrete in concrete maximum 2.0m, concrete in reinforcement mesh max. 0.5m
Vibration	☒	☐	☐	Acc. to method statement / standard
Breaks during concreting (hardness)	☒	☐	☐	Concrete not hardened

DATE: 14/5/2016 **SIGNED:** Carvalho

SITE VISIT INVITATION – PICTURES SELECTION

Verified by:	Revised by:	Approved by:

CHINA ROAD AND BRIDGE CORPORATION (CRBC) / GAUFF	MAPUTO BRIDGE AND LINK ROADS PROJECT QUALITY MANAGEMENT PLAN (QMP)	
EMPLOYER: MAPUTO SUL, E.P. — REV.00	SITE VISIT INVITATION	Form: CP

SITE VISIT INVITATION			Section I	No-S1-(C2221)
SITE VISIT DETAILS	SCOPE OF SITE VISIT		LOCATION	
	COMMON SITE INSPECTION	☐		
	TESTS ON SITE	☐		
	SAMPLING *)	☐		
	STOPPING / CHECK POINT*)	☒	S9L3	
	TOPO SURVEY CHECK *)	☐		
	OTHER *)	☐		

Proposed date for the site visit: 11 MAY 2016	Time for the appointment : 08:00 AM	Appointment location KaTembe Site Office

Give details : *)
S9L3's acceptance

Contractor's invitation prepared by:			Invitation confirmed by Consultant		
Name	Date	Signature	Name	Date	Signature
郝荣飞	10 MAY 2016	郝荣飞	Emmeran Gabler	11/05/2016	E. Gabler

SITE VISIT CONCLUSIONS

TEST RESULTS ACCEPTANCE		Consultant		Contractor	
ACCEPTED	ok ✓	Name	Tiago Carvalho	Name	郝荣飞
REJECTED		Signature	[signature]	Signature	
RE-TESTING		Date	11/5/2016	Date	

Reference documents (Test results in annex):	Comments and/or recommendations:
	S9L3 Acceptance was made on 11/5/2016 at 10:30 am. Visual inspection and cosmetic touches were made. The surface is becoming more irregular so maybe should be considered forward replacement.

NOTE: The Site visit invitation shall be submitted to the Consultant at least 1 day before the proposed site visit date

Verified by:	Revised by:	Approved by:

ACCEPTANCE CHECK

CONSTRUCTION MONITORING CHECKLIST

PROJECT NO. / NAME: Maputo Bridge and Link Roads Project

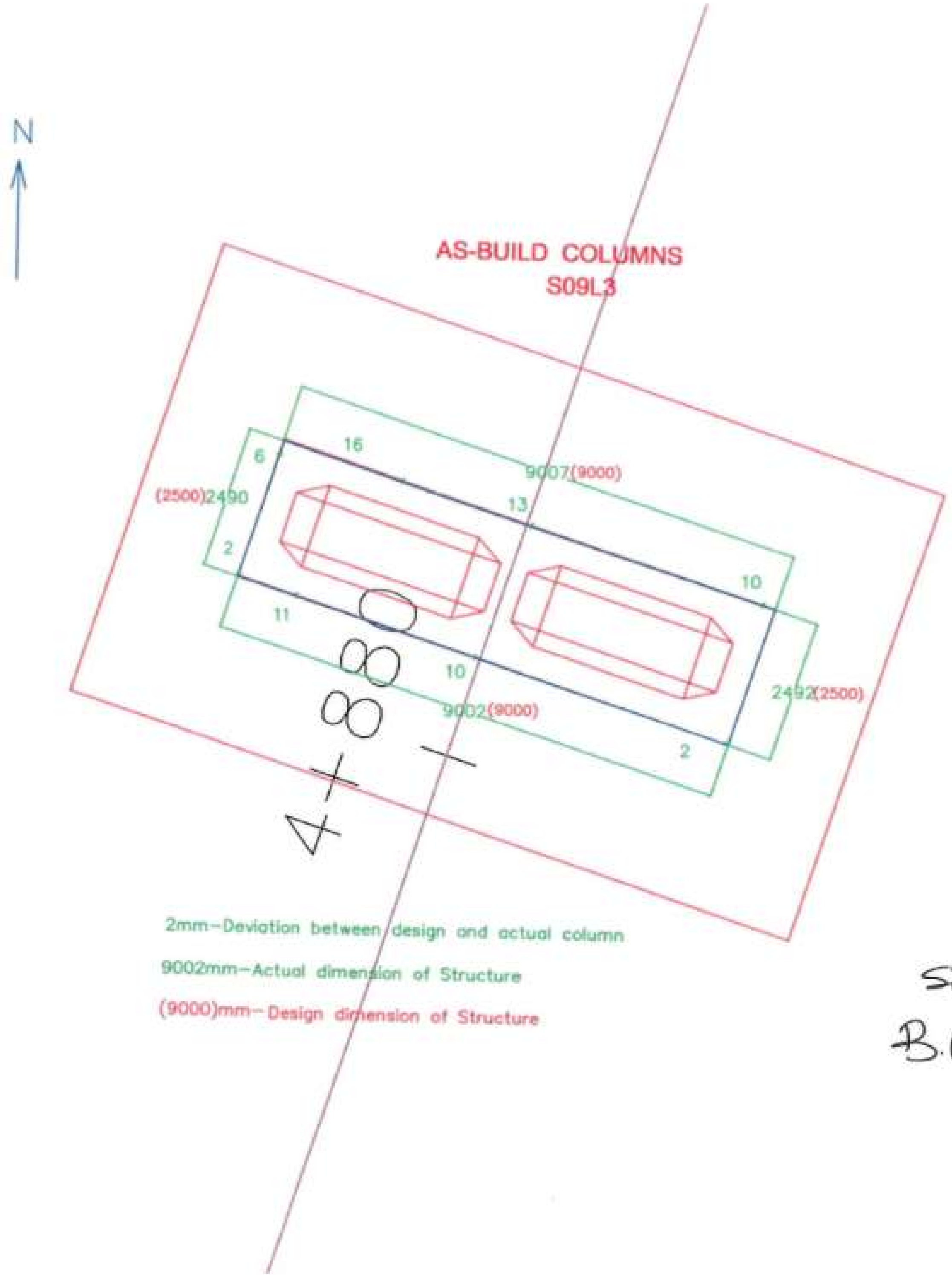
INSPECTOR'S NAME(S): Tiago Carvalho

STRUCTURE: South Approach Bridge Piers **ELEMENT:** Pier S9L3

ACTIVITY AND DETAILS	APPROVAL			
	ACC.	NOT ACC.	Check again	Acceptance criteria
General				
As built survey	☒	☐	☐	Acc. to drawings (provided by surveyor)
Concrete curing	☒	☐	☐	Has been applied acc. to method statement
Surface				
Cleanliness	☒	☐	☐	Gravel accumulations, visible bars / wire
Cracks	☒	☐	☐	No cracks
Holes/ openings				
Holes filled	☒	☐	☐	Material acc. to Method Statement
Cracks	☒	☐	☐	No cracks

DATE: 11/5/2016 **SIGNED:** [signature]

AS-BUILD COLUMNS
S09L3



2mm–Deviation between design and actual column

9002mm–Actual dimension of Structure

(9000)mm–Design dimension of Structure

SURVEYOR, GARIFF!
B. Chaucato, 16.05.2016

SITE VISIT INVITATION – PICTURES SELECTION






Verified by:	Revised by:	Approved by:

B – CONTROL ON THE APPLICATION – CASTING REPORT

CHINA ROAD AND BRIDGE CORPORATION (CRBC) / GAUFF		MAPUTO BRIDGE AND LINK ROADS PROJECT QUALITY MANAGEMENT PLAN (QMP)	
EMPLOYER: MAPUTO SUL, E.P.	REV.00	SITE VISIT INVITATION	Form: CP

SITE VISIT INVITATION	Section I	No-S1-(L2008)

	SCOPE OF SITE VISIT		LOCATION
SITE VISIT DETAILS	COMMON SITE INSPECTION	☐	
	TESTS ON SITE	■	Laboratory
	SAMPLING *)	☐	
	STOPPING / CHECK POINT*)	☐	
	TOPO SURVEY CHECK *)	☐	
	OTHER *)	☐	

Proposed date for the site visit: 20 May 2016	Time for the appointment : 5:00 PM	Appointment location KaTembe Site Office

Give details : *)
Manufacture of 9 Concrete Cubes for pier S9L4.

Contractor's invitation prepared by:			Invitation confirmed by Consultant		
Name	Date	Signature	Name	Date	Signature
汤号伟	20 May 2016	[signature]	Stefan Kagerer	20/05/16	[signature]

SITE VISIT CONCLUSIONS

TEST RESULTS ACCEPTANCE		Consultant		Contractor	
ACCEPTED	✓	Name	Stefan Kagerer	Name	汤号伟
REJECTED		Signature	[signature]	Signature	[signature]
RE-TESTING		Date	23/05/16	Date	2016.5.20

Reference documents (Test results in annex):	Comments and/or recommendations:

NOTE: The Site visit invitation shall be submitted to the Consultant at least 1 day before the proposed site visit date

Verified by:	Revised by:	Approved by:

CHINA ROAD AND BRIDGE CORPORATION | *Maputo Bridge and Link Road Project*

Concrete Casting Record

Casting Date: 20160520 | Concrete Class: C40 | Mix Design ID: C40-6 | Casting Place: PIER 59L4

Truck Plates No.	Delivery Ticket No.	Plant	Time: Time at Baching Plant	Time: Truck Arrival Time	Temperature: Ambient (°C)	Temperature: Concrete (°C)	Cement Content (kg/m³)	Measured Slump: At Check Point (mm)	Measured Slump: At site (mm)	Cubic Samples: Number of Samples (pcs)	Cubic Samples: Cube ID	Discharge time: Starting	Discharge time: Completed	Concrete Volume: Of the Truck (m³)	Concrete Volume: Cumulative (m³)	Remarks
7#	2016052008	1#	16:55	16:56	19.5	21.5		195		3	9343, 9344, 9345	17:00	17:43	8	8	
7#	2016052009	1#	17:56	17:57	19.0	21.3		200		3	9346, 9347, 9348	17:58	18:54	8	16	
7#	2016052010	1#	19:05	19:06	19.0	21.7		190				19:07	19:42	8	24	
8#	2016052011	1#	19:51	19:52	19.0	21.9		200		3	9349, 9350, 9351	19:53	20:31	6	30	
8	2016052012	1#	20:42	20:43	18.5	21.7		195				20:44	20:58	2.5	325	

20.05.2016 (20:30PM)

C – INSPECTION PLAN AND SOUTH BANK C40 MIX DESIGNS

QC Test						
Aspect to be Controlled / Testing Required	Required by Tech. Specifications / Standard (Ref. No)	Testing Method	Sample Size	Testing Frequency	Specification Requirements	Tolerances
TESTING OF CONCRETE COMPONENTS						
COARSE AGGREGATES						
Grading of large aggregate size (10-25) 26.5mm nominal	SANS 3001 - AG 1	TMH Method B4	50 KG	3 / 250 m^3 ④	passing 13.2 mm 100% 9.5 mm 85-100 % 6.7 mm 0-55 % 4.75 mm 0-25 % 2.36 mm 0-5 %	N/A
Grading of small aggregate (5-10) 9.5 nominal size	SANS 3001 - AG 1	TMH Method B4	50 KG	3 / 250 m^3 ④	passing 37.5 mm 100% 26.5 mm 85-100 % 19.0 mm 0-50 % 13.2 mm 0-25 % 9.5 mm 0-5 %	N/A
Soundness Na_2SO_4	SANS 3001 - AG 1	ASTM C-88-(1976)	50 KG	New source	≤ 12	N/A
Potential Alkali Reactivity	SANS 3001 - AG 1/ 6245	ASTM C 289-1971		New source	non reactive	N/A
Sulfate determination	SANS 3001 - AG 1	ASTM C 25-88		New source	2000 mg/l	N/A
Aggregate Crushing Value	SANS 3001 - AG 10	TMH Method B1		3 m^3 / 250 m^3 ④	≤ 20	N/A
Fineness Modulus	SANS 3001 - AG 1	TMH Method B 13		3 / 250 m^3 ④	1.2 to 3.5	0.2
Dust Content	SANS 3001 - AG 1	TMH Method B4		3 / 250 m^3 ④	5% to 10%	N/A
Clay content	SANS 3001 - AG 1	THM Method A6		3 / 250 m^3 ④	max 2%	N/A
Flakiness Index	SANS 3001 - AG 4	TMH Method B3		3 / 250 m^3 ④	max 35%	N/A
Water Absorption	SABS 843 / 844	TMH Method B14		3 / 250 m^3 ④	max 1%	
FINE AGGREGATES						
Grading of sand	SANS 3001 - AG 1	TMH Method B4	50kg	3 / 250 m^3 ④	passing 4.75 mm 90-100% 2.36 mm 75-100 % 1.18 mm 60-90 % 0.60 mm 40-60 % 0.3 mm 20-40 % 0.15mm 10-20% 0.075mm 5-10%	N/A
Clay content	SANS 3001 - AG 1	THM Method A6	50 kg	3 / 250 m^3 ④	max 2%	N/A

MIXING WATER						
Sugars	SANS 51008/EN 1008	SABS 837	5 liters	New Source	max 100 mg/l	N/A
Phosphates	SANS 51008/EN 1009				max 100 mg/l	N/A
Nitrates	SANS 51008/EN 1010				max 500 mg/l	N/A
Lead	SANS 51008/EN 1011	SABS 212			max 100 mg/l	N/A
Zinc	SANS 51008/EN 1012				max 100 mg/l	N/A
Sulphates	SANS 51008/EN 1013				max 2000 mg/l	N/A
CEMENT						
Compressive Tests 2 d 42.5 N	SABS EN 197-1	SABS 196-1	50 kg	Per New Batch	≥ 10	N/A
Compressive Tests 28 d 42.5 N	SABS EN 197-1	SABS 196-1		Per New Batch	≥ 42.5 ≤ 62.5	N/A
Rupture Strength 2d 42.5 N	SABS EN 197-1	SABS 196-1		Per New Batch	≥ 3.5	N/A
Rupture Strength 28 d 42.5 N	SABS EN 197-1	SABS 196-1		Per New Batch	≥ 6.5	N/A
Setting time - Jelling	SABS EN 197-1	SABS 196-1		Per New Batch	≥ 45	N/A
Setting time - Final	SABS EN 197-1	SABS 196-1		Per New Batch	≤ 600 min	N/A
Fineness	SABS EN 197-1	SABS 196-1		Per New Batch	≤ 10 %	N/A
Chemical analysis	SANS 50196-2	Chemical analysis certificate supplied with delivery note				
FLY ASH						
Loss of ignition	SANS 50450-1	Chemical analysis certificate supplied with delivery note			max 5.0%	N/A
Chloride content	SANS 50450-1				max 0.1%	N/A
Sulphuric anhydride	SANS 50450-1				max 3.0%	N/A
Free calcium oxide	SANS 50450-1				max 2.5%	N/A
Calcium oxide	SANS 50450-1				max 10.%	N/A
Fineness	SANS 50450-1				max 12%	N/A
Activity index	SANS 50450-1				min 75%	N/A
Soundness	SANS 50450-1				max 10mm	N/A
Water requirement	SANS 50450-1				max 95%	N/A

TESTING OF HARDENED CONCRETE						
MANUFACTURED CUBES OF CONCRETE POUR						
Concrete cube strength determination	SANS 5863	TMH Method D1	6 x (150x150x150) for 7 days 15 x(150x150x150) for 28 days	0-20m² = 3 21-40m² = 6 41-70m² = 9 71-100m² = 12 100-150m² = 14	CS = C50	58.0 for TAS Average of 3 = 2 MPa above CS
Concrete cube strength determination	SANS 5863	TMH Method D1	6 x (150x150x150) for 7 days 15 x(150x150x150) for 28 days	0-20m² = 3 21-40m² = 6 41-70m² = 9 71-100m² = 12 100-150m² = 14	CS = C40	48.0 for TAS Average of 3 = 2 MPa above CS
Concrete cube strength determination	SANS 5864	TMH Method D1	6 x (150x150x150) for 7 days 15 x(150x150x150) for 28 days	0-20m² = 3 21-40m² = 6 41-70m² = 9 71-100m² = 12 100-150m² = 15	CS = C30	38.0 for TAS Average of 3 = 2 MPa above CS
Concrete cube strength determination	SANS 5865	TMH Method D1	6 x (150x150x150) for 7 days 15 x(150x150x150) for 28 days	0-20m² = 3 21-40m² = 6 41-70m² = 9 71-100m² = 12 100-150m² = 16	CS = C25	33.0 for TAS Average of 3 = 2MPA above CS
Concrete cube strength determination	SANS 5866	TMH Method D1	6 x (150x150x150) for 7 days 15 x(150x150x150) for 28 days	0-20m² = 3 21-40m² = 6 41-70m² = 9 71-100m² = 12 100-150m² = 17	CS = C20	28.0 for TAS Average of 3 = 2MPA above CS

TESTING OF FRESH CONCRETE						
Air entrainment if required	SANS 5863	SABS 1252:1994	40 kg	Eng instruction	Eng Request	+/-1.5%
Fresh Concrete Slump Test used for piling works(tremme pipe)	SANS 5863	TMH Method D3	40kg	per truck	as per design	N/A
Fresh Concrete Slump Test (Piston pumping)	SANS 5864	TMH Method D4	40kg	per truck	as per design	N/A
Fresh Concrete Slump Test (pneumatic pumping)	SANS 5863	TMH Method D3	40kg	per truck	as per design	N/A
SLUMP LESS THAN 100mm =(25mm either side) SLUMP MORE THAN 100mm=(40mm either side) of the target						

CRBC — CHINA ROAD AND BRIDGE CORPORATION — GAUFF		Maputo Bridge and Link Roads Project CONSTRUCTION QUALITY PLAN (CQP)
Employer: Maputo Sul, E.P	Rev 00	MBLRP-S1

SOUTH BANK MIX DESIGNS

Mix Design for Concrete C 40....SOUTH BANK MIX 4 Pier and Pier Cap

Identification		Cement			Aggregates			Water	Additive	Water - cement ratio	Fly ash		Slump	Compressive strength at .... Days				Density (28 day results)
														7		28		
No.	Date	Type	Supplie	Quantity	Type	Proportion	Quantity	Quantity	Quantity		Source	Quantity		Required	Obtained	Required	Obtaine	
				[kg]		[%]	[kg/m3]	[l]	[kg]			[kg]	(mm)	[Mpa]	[Mpa]	[Mpa]	[Mpa]	[kg/m3]
PHB C40-4	16/04/2015	CEMII 42.5 A-L N	CM	273	SAND	43	738	164	5,04	0,39	LULA (35 %	147	195	36,0	37,5	48,0	48,0	2264
Report	02/03/2015				9.5mm	11	195											
Test	01/05/2015				26.5mm	46	782											

Mix Design for Concrete C 40....SOUTH BANK MIX 10 PIER, CAP BEAM, ANCHORAGE, PILE CAP

Identification		Cement			Aggregates			Water	Additive	Water - cement ratio	Fly ash		Slump	Compressive strength at .... Days				Density (28 day results)
														7		28		
No.	Date	Type	Supplie	Quantity	Type	Proportion	Quantity	Quantity	Quantity		Source	Quantity		Required	Obtained	Required	Obtaine	
				[kg]		[%]	[kg/m3]	[l]	[kg]			[kg]	(mm)	[Mpa]	[Mpa]	[Mpa]	[Mpa]	[kg/m3]
PHB C40-6	01/03/2016	CEMII 42.5 A-L N	CM	273	SAND	43	738	164	5,04	0,39	DuraPozz (20	147	140-220	36,0	43,5	48,0	56,0	2322
Report	05/04/2016				9.5mm	11	196											
Test	29/03/2016				26.5mm	46	782											

D – COMPRESSIVE TEST CALCULATIONS

Average of 7 days compressive strength sample tests (3 cubes) (Mpa)	Number of samples	Average 7 days compressive strength (Mpa)	σ [Mpa]	μ+2 σ [Mpa]	μ-2 σ [Mpa]
43, 3	3	42, 50	2, 13043	46, 76	38, 23
43, 3	6	42, 50	2, 13043	46, 76	38, 23
43, 7	9	42, 50	2, 13043	46, 76	38, 23
43, 8	12	42, 50	2, 13043	46, 76	38, 23
40, 5	15	42, 50	2, 13043	46, 76	38, 23
37, 8	18	42, 50	2, 13043	46, 76	38, 23
37, 7	21	42, 50	2, 13043	46, 76	38, 23
39	24	42, 50	2, 13043	46, 76	38, 23
43, 3	27	42, 50	2, 13043	46, 76	38, 23
43, 2	30	42, 50	2, 13043	46, 76	38, 23
43, 3	33	42, 50	2, 13043	46, 76	38, 23
43, 2	36	42, 50	2, 13043	46, 76	38, 23
44, 5	39	42, 50	2, 13043	46, 76	38, 23
41, 8	42	42, 50	2, 13043	46, 76	38, 23
43, 5	45	42, 50	2, 13043	46, 76	38, 23
44, 3	48	42, 50	2, 13043	46, 76	38, 23
44, 5	51	42, 50	2, 13043	46, 76	38, 23
43, 2	54	42, 50	2, 13043	46, 76	38, 23
44	57	42, 50	2, 13043	46, 76	38, 23
44, 7	60	42, 50	2, 13043	46, 76	38, 23
43, 5	63	42, 50	2, 13043	46, 76	38, 23
41, 8	66	42, 50	2, 13043	46, 76	38, 23
43, 7	69	42, 50	2, 13043	46, 76	38, 23
38, 3	72	42, 50	2, 13043	46, 76	38, 23

Average of 28 days compressive strength sample tests (3 cubes) (Mpa)	Number of samples	Average 28 days compressive strength (Mpa)	σ [Mpa]	μ+2 σ [Mpa]	μ-2 σ [Mpa]
56, 8	3	54, 73	1, 16	57, 06	52, 41
56	6	54, 73	1, 16	57, 06	52, 41
56, 2	9	54, 73	1, 16	57, 06	52, 41
53, 5	12	54, 73	1, 16	57, 06	52, 41
55, 5	15	54, 73	1, 16	57, 06	52, 41
55, 2	18	54, 73	1, 16	57, 06	52, 41
54	21	54, 73	1, 16	57, 06	52, 41
53, 7	24	54, 73	1, 16	57, 06	52, 41
54, 2	27	54, 73	1, 16	57, 06	52, 41
55, 7	30	54, 73	1, 16	57, 06	52, 41
55, 5	33	54, 73	1, 16	57, 06	52, 41
56, 7	36	54, 73	1, 16	57, 06	52, 41
54, 3	39	54, 73	1, 16	57, 06	52, 41
55	42	54, 73	1, 16	57, 06	52, 41
55, 3	45	54, 73	1, 16	57, 06	52, 41
51, 7	48	54, 73	1, 16	57, 06	52, 41

52, 2	51	54, 73	1, 16	57, 06	52, 41
55, 7	54	54, 73	1, 16	57, 06	52, 41
55, 2	57	54, 73	1, 16	57, 06	52, 41
55, 8	60	54, 73	1, 16	57, 06	52, 41
54, 2	63	54, 73	1, 16	57, 06	52, 41
52, 7	66	54, 73	1, 16	57, 06	52, 41
55, 5	69	54, 73	1, 16	57, 06	52, 41
55, 3	72	54, 73	1, 16	57, 06	52, 41
52, 5	75	54, 73	1, 16	57, 06	52, 41
53, 8	78	54, 73	1, 16	57, 06	52, 41
54, 8	81	54, 73	1, 16	57, 06	52, 41
54, 7	84	54, 73	1, 16	57, 06	52, 41
56, 8	87	54, 73	1, 16	57, 06	52, 41
56, 2	90	54, 73	1, 16	57, 06	52, 41
55, 3	93	54, 73	1, 16	57, 06	52, 41
56, 3	96	54, 73	1, 16	57, 06	52, 41
53, 7	99	54, 73	1, 16	57, 06	52, 41
55, 5	102	54, 73	1, 16	57, 06	52, 41
55, 2	105	54, 73	1, 16	57, 06	52, 41
52, 7	108	54, 73	1, 16	57, 06	52, 41
56, 7	111	54, 73	1, 16	57, 06	52, 41
55, 5	114	54, 73	1, 16	57, 06	52, 41
55, 3	117	54, 73	1, 16	57, 06	52, 41
55, 3	120	54, 73	1, 16	57, 06	52, 41
54, 7	123	54, 73	1, 16	57, 06	52, 41
53, 8	126	54, 73	1, 16	57, 06	52, 41
54	129	54, 73	1, 16	57, 06	52, 41
55, 2	132	54, 73	1, 16	57, 06	52, 41
53, 8	135	54, 73	1, 16	57, 06	52, 41
54, 8	138	54, 73	1, 16	57, 06	52, 41
53, 8	141	54, 73	1, 16	57, 06	52, 41
55	144	54, 73	1, 16	57, 06	52, 41
54, 3	147	54, 73	1, 16	57, 06	52, 41
54, 2	150	54, 73	1, 16	57, 06	52, 41
55, 3	153	54, 73	1, 16	57, 06	52, 41
53, 5	156	54, 73	1, 16	57, 06	52, 41
53, 7	159	54, 73	1, 16	57, 06	52, 41
54, 2	162	54, 73	1, 16	57, 06	52, 41
53, 8	165	54, 73	1, 16	57, 06	52, 41
54, 7	168	54, 73	1, 16	57, 06	52, 41