DEVELOPMENT OF EL VERIL (BATCH 1)

STUDY AND COMPARISON OF DEMOLITION METHODOLOGIES AND PRACTICAL APPLICATION FOR PEDESTRIAN BRIDGES

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Abstract
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Once a structure has reached its service life or does not satisfy the requirements or capacity it was designed to withstand, it may be possible to resort on rehabilitation. If that were not to be the case, the replacement or removal of the structure becomes a necessity. Demolition is a common technique in construction used to liberate a space or alternate the use of it, commonly associated with cities due to the limited space in them.

The aim of this thesis is to propose an analysis method for the demolition of structures related to bridges. This paper contains a study and comparison for a variety of available techniques and their application in a case study for an optimal methodology procedure in the demolition of a pedestrian bridge project in Maspalomas, Gran Canaria. Finally, a conclusion of the guidelines to follow with the criteria applied is presented.

This paper will discuss the most relevant factors for a correct criteria in the selection of demolition methods for bridge structures. Different operative procedures will be presented and compared, and therefore a comprehensive study of these factors which affect the final decisions; budget, time consumption, safety, environmental impact and the effect of the traffic disruption. The main methodologies presented will be variables of mechanical demolitions. Other methodologies, as the use of explosives, chemical demolition methods or manual demolition activities will be contemplated and compared.

By the end of this paper, the applications of different methodologies will offer a visual example of different possibilities to approach a demolition project. The case study presented in section 3, which will result in a preliminary design project for the Spanish local authorities, as in Ayuntamiento de San Bartolomé de Tirajana, is intended to be executed. This case study may serve as a guideline for any similar demolition at the same project phase. A conclusion will be presented from the theoretical study of different methodologies and from the results in the comparison of their practical application.

Keywords Bridge, demolition, methodology, safety, structure
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1 INTRODUCTION

Demolition is a process which consists of tearing down a building or other structure. Other similar methods are dismantling or deconstructing, which aim to the same purpose but carefully removing the elements, minimizing the damage to the materials. This does not happen in the case of a demolition.

Throughout history, there have been many reasons for what is now known as demolition, from the need to reuse the materials to the demolition because of acts of war. Manual means were the initial method used due to the simplicity of it, but over the years the buildings were larger and done with new construction methods, and for that, demolition techniques were improved and adapted so that it took less time to demolish these structures.

Demolition methods are based on the type of building, so it can be considered individually per case. Variables, such as the structural system, the type of material, location, nearby structures, and other factors, influence, but there is no strict methodology where parameters are proposed to facilitate the decision of the most appropriate method for each typology. A criteria proposal is made that seeks to optimize the process to select the demolition method for the decision making during the preliminary stages of the project, considering the most significant variables; safety, cost, time and environmental impact.

In this thesis, general demolition techniques will be analysed and compared, and the advantages and disadvantages will be presented.

This thesis has been done under the supervision of Spanish local authorities, as in the city hall of San Bartolomé de Tirajana, the commissioner and client of the project. The goal of the work is to present possible solutions and feasibility of different methodologies applicable to the total demolition of bridge structures, in a case study which will be explained later on in this paper. Different execution procedures will be detailed, as well as the feasibility of these.

2 DEMOLITION TECHNIQUES

The selection of the appropiate demolition method depends on the situation of each project; the construction site conditions and limitations, availability of machinery or equipment or the necessity of a certain required sensitivity on the methods applied. It is the responsibility of the technician or engineer to select the optimal method for each demolition project according to the necessities mentioned above as well as in compliance with the wishes of the client.

For these reasons, the acknowledgement of the safety conditions, advantages, disadvantages and requirements is of utter importance. In the following chapters, the main demolition techniques described are:

a) Manual demolition
b) Mechanical demolition
c) Explosives demolition

Other less known or common methodologies exist, but their use is limited to the current development of the techniques, to the special conditions they require, or the capability of contractors to acquire the knowledge, equipment and/or formed specialists. Further on, in chapter 2.4 of this paper, a brief description of lesser known methodologies will also be described.

There are several factors that must be taken into account to reach a functional and safe decision to demolish a building. Firstly, there is the need to carry out a structural and soil mechanics´ evaluation that determines the need and possibility proceed with the demolition. Another analysis that must be done is an economic one, which determines whether it is technically possible to repair a structure and whether it is less expensive than replacing the whole structure. The tools and equipment that can be used for any demolition must be the ones indicated in the project’s respective safety study, as ensuring a safe practice of activities plays an important role in a good process of work.

In any demolition project, there are several preliminary conditions to be studied which later will affect on the decisions for the methodology selected and the safety purposes. Examples of these actions are:

a) Site visit for recognition and verification of plans and images, where differences to the real condition of the site are perceived.
b) Locate any service installations (water pipes, electricity, gas, etc.)
c) On site study of the condition of the structure and nearby structures. During this visit, it is recommended to state constancy of the condition via photographs.
d) Reach out to any authorities or institutions for information or documents regarding the projected demolition.

2.1 MANUAL DEMOLITION

Manual demolition is the oldest and simplest method to partially or completely demolish a building. This method requires a small amount of equipment and tools but also an experienced workforce.

Often, manual demolition techniques are combined with the use of mechanical methods. The use of machinery depends on the size of the structure to demolish, the characteristics of the foundations, as well as the budget and time limitations for the project.

2.1.1 EQUIPMENT

The tools and equipment to be used in each project are a key factor for a good progress. Along with this, a rutinary maintaineance required for the equipment should be considered within the timetables.

Following are listed some common tools used in this methodology, as well as more technical equipment for specific purposes:

a) Mallet (Different weights)

b) Hand shovel

c) Pickaxe

d) Oxy-fuel cutting equipment. This method relies on chemical agents (fusion of oxygen and metal) in order to cut reinforced concrete at very high temperatures. The operator requires expertise in order to use special equipment like thermal lances (Figure 1).

Figure 1. Operator using a thermal lance. Thermal Lancing Training video from XLT Australia.

e) Wheelbarrow

f) Demolition hammer. Percussion hand breakers serve the purpose of crushing and drilling concrete surfaces (Figure 2). The weight of these machines can become too heavy to use on vertical surfaces, however, smaller tools for the same purpose are widely available, as well as capacity and shapes. The machines are generally powered by standard portable air compressors as in pneumatic breakers, other power sources possible for these machines are hydraulics and/or electric portable motors attached to the tool itself. There is also a wide variety of tool tips available for demolition hammers, each serving a different purpose (Figure 3).

Breakers are capable of drilling holes to considerable depths with an appropriate tool tip without jamming. In demolition works, apart from breaking concrete apart, other uses of breakers may be to create holes to house explosives, blasting devices, break apart lower resistance materials (tiling), or to provide access for rebars, as some examples.

Figure 2. Example of a demolition hammer under work

Figure 3. Different attachments for demolition hammers (Various purposes). (Champion Chisel Works, Inc, n.d.).

g) Hacksaw (Metal cutting) and Bow saw (Wood cutting)

h) Circular saws. Very versatile cutters for a broad selection of works. Harder materials would require strong tools to accomplish a cut.

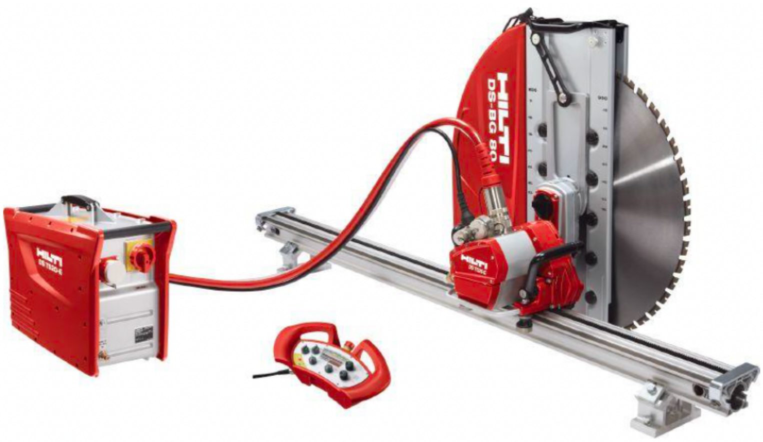
i) Generators

j) Compressors

Among tools for cutting and drilling, due to their characteristics, diamond equipment is very convenient for concrete demolition works, as diamond is the strongest material in the world. Examples of diamond equipment are:

a) Diamond saw blade (Figure 4). These are similar to circular saws but the blade is composed of diamond. The cutting process produces greater amounts of noise compared to their counterparts, but with a low level of dust and vibrations emitted. The operation of these tools is generally remote, and allows for vertical, horizontal, or inclined cuts.

Figure 4. Diamond saw blade equipment.



b) Diamond wire saw. This cutting system (Figure 5) consists of a stainless steel wire with diamond pearls, which are installed with pulleys and a refrigerant to cool down the wire. The usage of this equipment is common for elements with large dimensions with precision where other tools could not be able to cut through, or which are limited by the height. This equipment is autonomous during the work, requiring only supervision but no operator working directly on it. The process of cutting is relatively silent and produces minimal vibrations and dust.

Figure 5. Diamond wire saw equipment under work. (Aracorte, n.d.)

c) Hydraulic chainsaw. It acts as a regular chainsaw, with the advantage of the material, which is able to cut across concrete with ease. The range of the cut is limited to the size of the same tool. The advantage of such a versatile tool is the precision, which allows for small section cuts and the ability to work in reduced work spaces.

In order to optimize the use of these tools, machinery can be used to act as auxiliary or complementary equipment, not only demolishing, but focusing on the clearing and transporting of the waste generated. Nevertheless, waste can be transported and loaded onto dump trucks manually.

The machinery that better fulfills this labour are the following:

a) Bulldozer

b) Excavator

c) Dump trucks

2.1.2 SAFETY

A very important aspect in any construction or demolition project is safety, which must prevail throughout the whole work process. Therefore, any accident, no matter how small, ought to be prevented. There are various hazards present during a demolition project, which depending on the methodology adopted can be: physical, heat, electrical, from airborne particles and/or chemical.

With the purpose of minimizing exposure to these different hazards, the use of personal protective equipment, commonly referred to as “PPE”, is mandatory for all workforce present at the site. According to the new Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on personal protective equipment, PPE is “Any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards”. (Regulation (EU) on personal protective equipment and repealing Council Directive 2016/425).

Mentioned below are some of the different types of PPE:

a) Head Protection (E.g. Hard hat)

b) Hand and arm protection (E.g. Gloves)

c) Foot protection (E.g. Safety shoes)

d) Respiratory Protective equipment (E.g. Respirators)

e) Eye protection (E.g. Safety glasses)

f) Ear protection (E.g. Earmuffs)

g) Fall protection (E.g. Safety harnesses)

h) Body protection (E.g. Protective high-visibilty clothing)

PPE is the most basic safety requirement for anyone entrying a demolition site, regardless of the activity.

Apart from equipment, there are general safety conditions to consider, not only concerning this methodology, but generally. All of the following are to be met:

a) Interrupt the work if the weather conditions are adverse, namely heavy rains, strong winds, electrical storms, or extreme temperatures.

b) Elements that ensure the stability of others parts of the building shall not be demolished. At the same time, at the end and beginning of each work day, the areas susceptible to collapse are to be inspected.

c) Bracing or other types of auxiliary measures must be used on the structure in case an accidental collapse may occur.

d) Remove the demolition waste only once the demolition works have halted (specially with machinery and manual operators involved simultaneously).

e) Remove any hanging element or loose items from the site, hence, preventing the accumulation of waste which could produce an overload or fall of object from heights.

f) Watering over the demolished elements to prevent dust from raising. In case of closed sites, extraction of dust should be ensured.

g) If there are adjacent buildings, the contractor is responsible for controlling the state of them along the process of demolition, especially if vibration may affect these.

h) Whilst demolishing retaining walls and/or foundations, colliding structural elements from nearby structures must be strenghtened if necessary.

Auxiliary equipment plays an important role to prevent health hazards towards workers as well as reduce environmental impacts derived from the use of manual equipment and tools. Some examples are the following:

Dust extractors: In activities indoor, the use of a dust extractor becomes necessary to paliate the producement of dust. Some tools have dust extractors available as attachments of the equipment itself, but if not, independent machines can be relied on.

Noise suppressors: There are various ways of reducing the amount of noise produced from a working site. A noise suppressor can be installed to minimize the exhaust noise of different machinery or a muffler can be attached onto manual equipment for the same purpose.

Proper coordination of works not only benefits the pace of the project, but also helps maintain the safety aspects, as all activities that are foreseen under the specific circumstances of each structure. The combination of manual and mechanical methods should be well planned, following the safety guidelines of each machine. During the preliminary phase of the project, the hazards and risks that may occur during the works ought to be foreseen and a custom safety program must be followed.

A demolition activities´ work program shall be carried out, where a good planning of activities and an efficient coordination of the expected demolition works facilitates a correct and safe execution process at the time of the demolishing.

2.1.3 ADVANTAGES AND DISADVANTAGES

Advantages of the procedure

Many demolition works can be carried out manually either due to their location or because a complete demolition is not intended. Small tools, such as claw bars, hammers, pneumatic hammers and many listed before in this paper, are used exclusively, which offers a better logistical option and availability to work in smaller or enclosed areas without much accessibility.

This method is recommendable, appropriate for buildings of any height, depending on the time available for said demolition. In frequent cases, it is best to resort to this procedure when there are adjacent buildings due to the precision it allows. This method is recommended especially for non-collapsed buildings or structures.

Manual demolition works best when partially demolishing a structure at great heights and allowing the high-performance backhoes to work on lower heights, minimizing risks and taking advantage of their full potential.

There are many materials that could be salvaged and recovered in connection with, or during the process of manual demolition of a building, as workers are able to dismantle a series of objects and materials before demolishing. This presents an advantage from an economic point of view. Below are mentioned some materials which could be reclaimed:

a) Non-structural components: Roof materials, wall coverings, etc.

b) Reinforcing steel: rod of all diameters, stirrups, etc.

c) Hydraulic Installations: pipes (specially pipe coverings), tanks, water tanks, bathroom accessories: faucets, showers, sinks, tubs, etc.

d) Electrical installations: cables, contacts, switches, lamps, etc.

e) Carpentry materials: Wardrobe, closet, desk, etc.

f) Framing materials: Door, window, handrails, railing, etc.

Disadvantages of the procedure

Due to its characteristics, the procedure is:

a) Slow, taking notably longer than other methods. This applies from the demolition itself to other works like the waste management.

b) It is highly pollutive in terms of dust, noise, and vibrations. These not only affect the health of the workers but the environment of the project.

c) Many safety concerns need to be taken into account. There is a greater probability of vehicle or bypasser damage, due to the possibility of tools falling from heights as well as materials or waste. If workers are inside the building, unexepected collapses are a major hazard.

2.2 MECHANICAL DEMOLITION

Mechanical demolition, in general, involves the use of any type of machinery for the purpose of disassembling or demolishing an existing structure. Common mechanical methods include the use of a pusher arm (Figure 6), hydraulic machinery, and clam shell (Figure 7). These methods are commonly applied to structures, such as isolated buildings on relatively flat ground. The good practice of mechanical demolition must have a specific order, which complies with all and the best of civil works. There is the possibility of combining different manual and mechanical methods when correctly coordinated, and even the application of a variety of machinery and controlled explosive methods. Currently in Spain, heavy machinery is used as the main instrument of work for most demolition works, this practice is carried out specially with tools on vehicles or combined with manual methods.

The most common operations of these applications are illustrated in the following images:

Figure 6. Pusher arm techniques. In order of appearance, from left to right: Inwards pusher arm technique and outwards pusher arm technique.

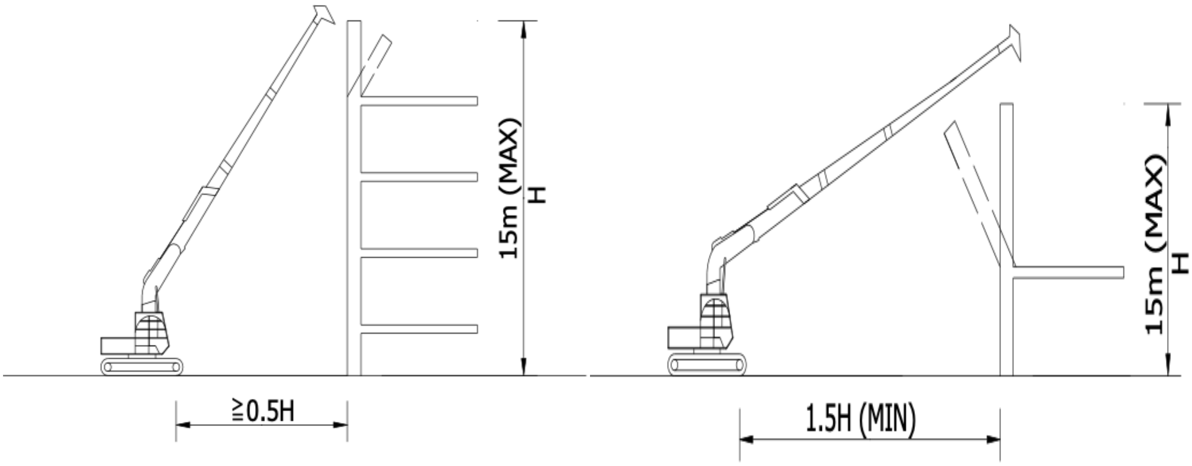
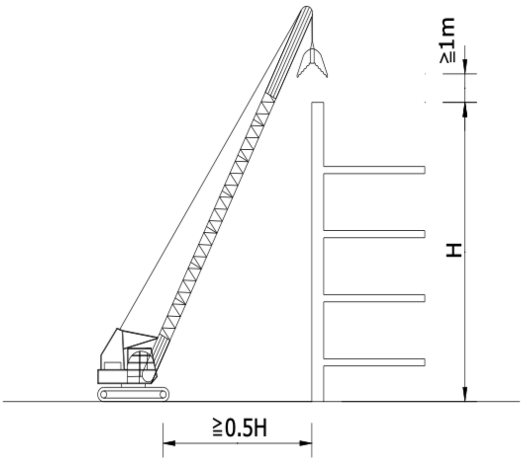


Figure 7. Clam shell machinery example.



Larger buildings may require the use of a wrecking ball, a heavy weight on a cable that is swung by a crane onto the buildings façade. Wrecking balls are especially effective against masonry, but are more difficult to control and often less efficient than other methods in terms of time and the impact to the environment.

2.2.1 EQUIPMENT

Aforementioned are some machines aiding the manual methodology of demolition and others used in specific techniques like pusher arms. Following will be listed the overall machinery used in this methodology, taking into account that each may have available accessories for easier or different purpose:

a) Excavators

b) Bulldozers

c) Cranes. Stationary machinery with different counterweights commonly used for heavy lifting or for great heights.

d) Wrecking ball

e) Telescopic boom crane. Mobile cranes (Figure 8); these are commonly attached onto trucks or crawlers. In industrial works, these can be installed as stationary for long periods of work.

Figure 8. Example of a telescopic boom crane for demolition.

Regarding the accessories available, advances in technology have proved valuable for the development of this methodology, some of the most practical and wide-spreaded equipment for demolition are the following:

Pneumatic breakers are a clear example of an improvement from the equivalent manual techniques. This percussion breaker attachment (Figure 9) allows for greater power compared to a manual percussion hammer and the possibility of demolishing above the level of the machine.

Figure 9. Excavator with pneumatic breaker attachment under work.

Hydraulic breakers serve the same purpose as their pneumatic counterparts as attachments for excavators, with the advantage of the reduced noise, vibrations and dust produced from its use in comparison.

Other attachments are the rotary hydraulic shears (Figure 10) to cut or break through wood, steel, and concrete. The use of shears is common where cutting metal with any manual method would be dangerous.

Figure 10. Example of a long-range scrap shear machine.

Similarly to scrap shears, the demolition multi-processor is equipped with a demolition jaw capable of breaking through concrete, with or without rebars.

Excavators have a wide variety of attachments available for different fields and needs. Smaller versions of these also exist; compact excavators are versatile solutions when space is a limiting factor.

Rock crushers are very commonly used within the mining industry, as the main purpose of this machine is to crush down rocks or concrete into smaller and more manageable pieces. In the case of demolition works, these machines are not used often as the requirements and costs to use these machines are high. The outcome produced from these machines may be used for an easier transport of waste or for landfill material producement in-situ for the civil engineering field. These methods apply best on more isolated buildings on a relatively flat ground.

The telescopic boom crane applications are versatile for demolition works. The main characteristic would be the long range it possesses. Pusher arm techniques are benefited from the span of the crane combined with the force it is able to produce, which could be advantageous for demolition of masonry walls at heights, for example. Other use of this crane is the lifting of elements, as the installment is faster and easier compared to stationary cranes, but with a reduced capacity due to the difference in power.

Bulldozers serve best in piling and loading waste or for groundworks. This powerful machinery can replace the front blade to fullfill different works. A great variety of blades is available, as well as attachable winches or rakes, but it is uncapable of operating on uneven terrains.

2.2.2 SAFETY

Machinery in general can be considered safer for workers on site, as the number of personnel is reduced, which can reduce the risks. The key factor to ensure safety whilst machinery is under use is the stability of both the structure and the machine, preventing unexpected overturnings or overloads, and, it is implied that a correct maintaineance and supervision of the machinery is strictly necessary during the activities and the movement of machines. No machine shall work if workers are underneath the machine´s span, and even the movement of them around the site ought to be supervised and known to other workers. The same principle applies to other machines if these were to coincide during the works. Each machine requires certain specific conditions to work under, which not only affects the efficiency they might provide, but a correct coordination also establishes a secure procurement for the work. The experience of the operators plays a key role, not only for safety, but greatly affecting the efficiency.

The most general concerns and guidance needed for the use of such machines are:

a) The machine´s engine must start on flat and firm ground. At the same time, there must be enough counterweights to prevent overturning of the machine during the process.
b) All the equipment and accessories should have correct and frequent maintaineance and be repaired or replaced when needed.
c) There must be control over the section of the building being demolished at all times, to prevent the fall of unexpected loads, the damaging or vibrations on nearby structures, and possible interferences on services.
d) If machinery is at work, no personnel must be in the range of work of the machine nor inside the building. No unauthorized person must enter the site during the process, and the site should be kept under surveillance to ensure this.

2.2.3 BENEFITS AND DRAWBACKS

The benefitial aspects of the use of mechanical means are the following:

The operator and machine work from outside the building or structure during the demolition process, preventing damages that could be caused from sudden collapses, and hence, lowering hazards and risks during the project.

The unitary cost for machines is relatively low once installed on site due to the time efficiency they provide.

The use of machinery can be applied along all the project phases, from the initial demolishing to dismantling, crushing of the elements, transport, and/or loading of waste or materials. The crushing of concrete is particularly efficient to do with mechanical means.

Drawbacks produced or derived from the use of machinery are the following:

The use of machinery may seem limited because of the amount of noise, dust and vibrations these might produce, even with the use of auxiliary equipment to prevent them, for example the use of noise supressors for certain machines or watering during the demolition to prevent the raise of dust.

In the case of requiring cranes for a demolition process, the efficiency will be limited by the size and capacity of such crane.

The size of the structure to be demolished is a major condition for the use of machinery. The span of demolition machinery in general cannot reach great heights, unabling their use due to the hazards of collapse affecting the machine. On the other hand, the movement and installment of machines may seem excessive for little buildings.

The working area ought to be accessible for the machinery, and at the same time, the ground withholding the machine´s weight must be stable and as plain as possible.

Lastly, one aspect which should be considered per each situation is the need of manual means in order to cut reinforcement rebars due to the incapacity of machinery. This allows for a better recovery of materials but may present problems in the case of pre-stressed reinforcements. This case does not apply to crushers, which are able to cut reinforcements.

2.3 EXPLOSIVES DEMOLITION

The use of explosives, being developed during times of war and other investigations applied to industrial or working fields. Due to the destructive effectiveness this method has proved, explosives have been used widely and frequently, but regulated and controled in equal terms due to it.

Currently, this technique has been developed and frequently used to comply with tasks that benefit from speed such as tunnel construction, quarrying, mining, highways, and railways. The use of explosives is generally applied for large working sites or to replace the need of a fleet of machinery for excavations. This benefit is reflected also in the demolition of buildings.

The use of explosives in the demolition of structures requires proper quality control, experience and application of techniques. It is important that the demolition operation is known to guarantee the safety of those who work in this discipline and anyone in the vicinity that may be affected. Due to this, different authorities require several previous approvals, an example of this procedure will be explained in the study case in chapter 3.5.

2.3.1 TYPES OF EXPLOSIVES AND DETONATORS

There are many types of explosives that are used in a variety of fields, but the ones regarding civil engineering are mainly composed of ammonium nitrate. The combination of ammonium nitrate with other elements results in explosive products widely used in blasting, quarrying, and demolishing processes. The types of explosives are the following:

Dynamite: The addition of nitroglycerin as the main active component and other additives to ammonium nitrate creates a sensitive and powerful explosive, dynamite. The structure can be in pipe charges containing powder or dynamite cartridges which are more malleable, in addition to being waterproof. Dynamite was first created in order to allow a safer method for blasting boulders or tunneling, but it is also widely used for any type of open pit blasting, for high precision blasting, and especially for smaller projects of demolition.

Emulsion: With the addition of water, oil, wax, and additives, it is possible to create an emulsion explosive. The features of the assembly are similar to those of the dynamite, consisting of pipe charges or cartridges. The usage is very wide, as it is used on all types of open pit or underground blastings. As opposed to dynamite, emulsion is not sensitive, but special care is needed when handling or installing them with connectors or detonators.

ANFO: The acronym stands for ammonium nitrate fuel oil, which is the sum of all componets required to elaborate this explosive. It is considered to be a bulk product (Figure 11), as the explosives are in the form of small prills, needing large quantities in order to reach an adequate reaction. The structure of the explosive needs boosters or primers to initiate the reaction, which provide enough activation energy in the form of cartridges, as they are sensitive to detonators. ANFO is commonly used for large scale open projects and for tunnelling and mining.

Figure 11: Example of ANFO product. Dyno nobel (March 2012)

Bulk emulsion: As the name implies, this type of bulk product requires of large amounts to fulfill the required reactive energy. The explosive can be prepared or made on site, expanding in the drill holes. Similarly to ANFO, bulk products require booster or primers and are used for the same purposes, but in this case, bulk emulsion is waterproof.

Explosives need an external factor to achieve activation energy, this is supplied by the detonators, which also serve to regulate the order of ignitions. Different detonator types possess qualities which make them more suitable for certain works. The types of detonators are the following:

Electric detonators: These detonators rely on an electric current and a capacitor firing device, which allows the use of an ohmmeter to test the connections before using. A common usage for these detonators is in open pit blasting projects, but they also serve to ignite shock tube systems. The environment of the project is key for safety considerations, as these detonators are sensitive to electromagnetic hazards. Possible hazards which can present a risk are thunder, mobile and radio phones, transmitters, or power lines.

Shock tube detonators: This type of detonator is dependent of the previously mentioned electric detonators or special firing devices. The detonators are connected to delay elements, connectors and with a detonating cord, this offers versatile possibilities to plan and execute the order. The same elements could be affected and be a risk for the detonation process and site area thereon, the connectors cannot be tested so they require a correct and careful execution. The usage of these detonators are generally within the tunnelling and mining industry, on large open field projects, or when electromagnetic hazards could affect other types of detonators.

Electronic detonators: These detonators are the most advanced within the types available on the market. The usage of it requires of a special firing device and special training, but the advantages it possesses are various; the device is completely programmable and offers a great range of intervals and delays for the ignitions. The fact that the device is programmable also allows for safe testing and comprobations, this device is optimal for any demolition project, specially if electromagnetic hazards are present.

The use of explosives is usually combined with auxiliary equipment in order to secure a safe and programmed process for preliminary works. Some common examples of the recommended equipment to be used along explosives are the following:

a) Rotary drilling equipment: This equipment serves the purpose of drilling the boreholes where the explosives ought to be installed. These machines work with air pressure and are differentiated by weight. The amount of air pressure required is related to the weight of the tool; the more pressure, the more weight.

b) Jackhammer: Also known as demolition hammer, this is a percussion based manual tool. The structure of the equipment is composed of a hammer and a chisel powered by a pneumatic, electro-mechanical, or hydraulic system, used to perforate hard surfaces, namely rock or concrete. This tool is usually used to replace the need for explosives in small sections rather than auxiliate it. Because of the slowness of the manual equipment, oftentimes there are many of these tools working simultaneously. In order to secure a good performance of the tool, it is necessary to conduct a correct selection of the steel head and rutinary maintenance.

c) Air leg rock drill: It is considered an important equipment when boreholes are needed to be drilled on horizontal or vertical surfaces. The structure of the tool seems pistol-like, with an enlarged tube attached to it. This tube contains a valve that applies compressed air onto a central bar, and the bar acts as a stabilizer for the tool and a drill on the other end of the tool.

d) Compressor: A widely used equipment for construction works, this machine compresses and stores air with the help of an internal combustion engine and transfers the air towards the tools that are connected to it. Compressors vary in size and power. It is possible to attach more than one tool at a time to this equipment, which may also supply machinery.

2.3.2 ENVIRONMENTAL IMPACT OF BLASTING

The power of this type of explosives carry risks with them, if to be used innaproppiately, badly planned or executed. A poor operation of explosives can provoke consequential hazards in different forms, affecting directly the integrity of people and/or nearby structures along with the environment. The environmental impacts derived from inadequate explosions are the following:

Flyrocks: A lack of proper planning or safety measures might cause a risk for fly rocks. If the blast power surpasses the expectations or due to failures in the execution, fragments of rocks might surpass the blast area, which can cause a hazard for nearby structures and people, which might be fatal. There could be many reasons for this happening depending on the field of operation. It is of importance to prevent this hazard from happening with a proper and careful planning, drilling and possible covering.

Noise and dust: Noise which proceeds from the blasting is unavoidable, unless covered in the case of section blasting in small areas. The main noise pollutant is due to the machinery applied for the preliminary works, as happens with mechanical methods for long term operations. In order to prevent noise, or diminish the noise impact, a proper selection of working times is necessary to prevent inconvenience, as well as measurements and noise protection for the machines applied.

Dust occurs both during the machinery works and blasting and it depends entirely on the environment of work, relying on different methods to palliate the pollution. If working in closed areas, dust extractors are needed to ventilate. In the case of open works or blastings, watering the area at the time of the explosion prevents the dust from lifting.

Vibrations and air shock waves: One of the resulting products from an explosives blast are the vibrational waves, depending on the media they travel on. These can be divided into two categories: seismic waves travelling through the ground, or air shock waves. These effects are specially negative for structures or sensitive equipment (e.g. hospital equipment), and strictly regulated under maximum limitation values. Nevertheless, explosives ought to be subjected to a regular and strict control if third parties could be affected by these long range waves.

Effect on the ground water levels: Water levels may seem affected, the flow of superficial water and underground currents could become altered and further risks could come along with this. To acknowledge the paths of water and planning or preparing solutions beforehand reduce the hazards.

The secondary effects of malfunctioning explosives during the blasting should also be taken into account, as undetonated explosives emit harmful nitrogen oxide to the ground or environment.

2.3.3 ADVANTAGES AND DISADVANTAGES OF EXPLOSIVES

The clearest advantage that the explosive method possesses is the versatility due to the variety of explosives and detonators available and the rapidness of the process. The economic factor is also advantageous, in terms of both material and personnel required. The waste created, if the blast is controlled and the operators are experienced, accumulates and allows for an easy extraction.

On the other hand, the list of hazards and risks is extensive. The blasting area should be secured to prevent fatalities, and precaution should be taken from the preliminary stages of the project till the end of the process, as the environmental impact could be very harmful. Due to this, the process needed to buy and use explosives is specific and strict, requiring special permits and professionals according to each national regulations, which could present delays in order to start a project. The use of explosives is very limited generally in terms of building demolitions, as it totally depends on the circumstances of each project environment. A lack of expertise in this method entails unexpected reactions, as well as the possible necessity to make further demolitions if the efficiency or placement of the explosives were not appropiate.

2.4 OTHER TECHNIQUES

Along with the advances in science and technology present in the 21st century, the field of civil engineering is also included, presenting unorthodox or innovative measures to tackle different problems within the field, or in order to optimize schedules, budget and/or efficiency. The British Standard Code of Practice for Demolition defines four main types of demolition techniques: Demolition with machines, demolition by hand, demolition with the use of chemical agents, and demolition with high-pressure water jetting (Arham, 2003).

Some noticeable techniques are the following:

Bursting: Bursting of concrete can be reached with the use of either mortar or gasses. The process consists of the filling of a borehole with either of these products. The mortar used is highly expansible, and once hydrated, it begings expanding over time. The gas in question (Carbonic oxide) expands due to alloyed steel cells (Cardox). The use of Calcium oxide also serves the same purpose. The use of expansive mortar is a clean methodology, as the process does not liberate any gasses nor waste from the material itself, nor does it produce any vibration or noise.

The use of high-pressure water jetting, also known as hydrodemolition, is a viable option to erase dust and vibration problems. The high pressure water penetrates the cracks and openings on the concrete surface, creating internal pressure which breaks the concrete apart. This process requires of a system to extract the water.

Hydrodemolition is the technique where high-velocity jets of water are applied to remove damaged or deteriorated concrete. The depth of the removal depends on the strength of the concrete and other factors regarding the equipment and structure itself. Deteriorated concrete is easily removed by hydro-demolition, whereas dense, homogeneous concrete is not (Transp. Res. Board, Nat. Res. Council, Washington, D.C, 1991). This methodology can be divided into two sub-categories: abrasive or nonabrasive. According to Dr. Andreas W. Momber (2005), the tool of any hydro-demolition process is a high-pressure water jet (Figure 12). Although the speed of the jet is its fundamental physical property, the pressure generated by the pump unit that produces the jet is the most important evaluation parameter in practice. Hydro-demolition of concrete surfaces and reinforced concrete. Nonabrasive water jet cutting serves best to clean and cut surface areas, whilst ultra-high pressure as in abrasive water jet cutting is more powerful but less controlled.

Figure 12. Operator with water jet removing concrete.

Hydraulic splitters are installed into previously drilled holes, where the wedge is inserted (Figure 13) and with hydraulic pressure, the elements are torn apart. This process does not produce vibrations nor dust, and a minimal amount of noise. This portable tool is advantageous for small spaces or where the access is difficult. It offers a high degree of precision but the splitting distance towards the elements is limited.

Figure 13. Example of hydraulic splitter´s counter wedge working.

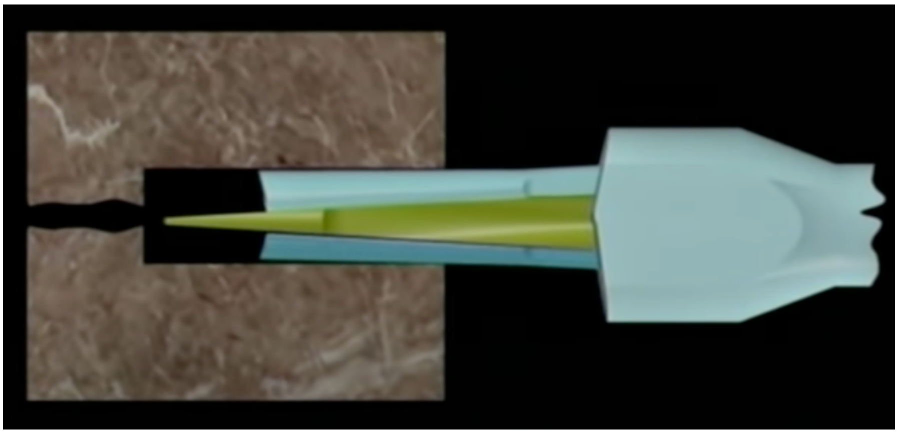


Table 1 below recapitulates most previously mentioned methodologies (excluding complementary activities or combinations of methodologies), their application to bridge demolitions, and main advantages and disadvantages.

Table 1. Bridge demolition methodologies summary.

Method	Application	Advantages	Disadvantages
Machinery with variable attachments.			
Hydraulic hammers and shears	Demolition of elements, partial or total structure removal	Highly efficient, good mobility and not dependant of weather conditions	Noise, dust, vibrations. Limited to size of structure and environment.
Ball and crane / Crane	Complete structure removal	Simple methodology. Safe for workers on site.	Noise, dust, vibrations. Expertise for operator.
Manual means	Element demolition or partial demolitions	Reduced costs, versatility, precision and material recovery	Time-consuming, pollutive and greater amount of risks
Thermal cutting	Partial removal of concrete	No vibration, low noise, highly maneuverable.	Costly, fire hazards and produces fumes.
Diamond tools	Great variety of applications	Precision, rapidness, low environmental impacts	Expensive
Blasting	Full and partial demolitions.	Rapidness, short span of noise.	Noise, dust, vibrations, flyrocks, air-shock waves.
Hydrodemolition			
Nonabrasive water jet cut	Deck partial removal	No dust, low noise, no vibrations. High efficiency	High water input and output. Cost. Problem around rebars
Abrasive water jet cut	Deck partial removal	No dust, low noise, low vibrations, clean cuts	High water input and output. Cost. Dangerous
Bursting	Full and partial demolitions.	No vibration, no noise, ensured safety	Time-consuming. More expensive than explosives.

3 PRACTICAL CASE STUDY

3.1 BACKGROUND AND PURPOSE

The following section will present a case study with different hypotheses to give insight of the practical knowledge in a real case scenario. Even tough the combination of several procedures can be expected within the same project, the aim of this section would be to describe and detail the execution of “CONDITIONING OF EL VERIL (BATCH 1)”, with predominantly distinguished methodologies, as well as the machinery and tools to be used in the main work activities and the safety measures requirements for each method.

The modus operandi selected by the contractor may also differ from the one described below, which might be due to limitations or distintions in machinery, personnel, or equipment. This does not exempt the contractor from the responsibility of ensuring safety during the whole process, and the contrator must state and detail all the processes on the offer to the tender notice in order to be previously approved, being as similar as possible to the procedures expected.

The present object of study is located in San Bartolomé de Tirajana, a Spanish municipality in the south of the island of Gran Canaria, in the province of Las Palmas, Canary Islands, Spain (Appendix 1). This municipality is 54 km away from the capital of Las Palmas de Gran Canaria to the south, and its neighbouring municipalities are Mogán, Santa Lucía de Tirajana, Tejeda, and Vega de San Mateo.

San Bartolomé de Tirajana is the most extensive municipality of the island by surface, with 333,1 km^2 and a population of over 53 000 inhabitants. It is characterized by Maspalomas, the touristic nucleus of the island established in the decade of 1960.

The avenue “Avenida de la Unión Europea”, formerly known as GC-500 has been subject to a transformation into an urban road since the expansion of the motorway southwards in 1990. For this reason, the responsibility of the infrastructure was ceded from the island council onto the local authorities of the municipality. It allows the connection from urban centers located along the coastline with the central area of Maspalomas (Playa del Inglés and San Fernando). In the area of work, there are two roadways with one lane each, as well as an area which used to serve as a bus stop but is currently out of commission.

The pedestrian bridge allows a safe crossing over these two roadways. Given the absence of any urban or industrial centers on the north side of the bridge, plus the existence of a reserve of native palm trees, the sole purpose of the infrastructure is to connect with a bus stop to the north side of the bridge. Due to recent modifications in the transformation of the avenue, the previously mentioned bus stop has been relocated less than 200 meters away from the original location, with a faster and safer connection for the pedestrians. A stop sign has been placed next to the main column as it was expected to be demolished, but it now presents a danger for traffic as the visibility is null, requiring cars to invade part of the avenue for drivers to be able to see. For this reason, the bridge has been considered obsolete.

The second part of the whole project consists on the road´s repavement and the construction of a parking lot with a new retaining wall on the south end of where the bridge is located, being able to use more than 1.500 squared meters of area which is currently not in use. Considering this, the condition of the road is not a priority by the end of the first half studied in this paper, requiring only the extraction of all structural components and readiness of the ground for latter works.

3.2 PRE-PROJECT STUDIES

In this section, the preliminary studies are presented next, considering important factors that may intervene in the process of demolition.

Criteria must be applied to rate the importance of relevant factors of the decision-making. The reasoning behind the criteria selection of this case is the following:

1. The safety of workers and bypassers is primordial to any other factor.

2. The effect on traffic is considerable, as well as the negative impact produced to nearby hotels and touristic complexes, requiring the fastest option available to palliate this.
3. The proximity of critical services (petrol station and electrical sub-station) and near touristic complexes are considered influential and limiting on the methodologies feasibility, as long as there is no direct safety concerns. Hence, a correct waste management and reducement of negative impact on comfort is sufficient.
4. Being a public entity, the commissioner, with no interest in benefits whatsoever, lowers the importance of budget, limited to a correct estimation and supervision of funds.

3.2.1 STUDY OF THE STRUCTURE

The bridge structure (Figure 14) consists of a superstructure and substructure, being divided by the groundlevel. The structure as a whole is symmetrical, the starting level of the mirrored elements is equal.

Figure 14. General front view of the bridge structure in question.

The superstructure is composed of two 60 meter span lenght of the bridge connected to an abutment in each end. There are two pairs of columns per each 60 meter span length, joint with a primary column with a larger section standing in the middle of both spans. The latter column also withholds the weight of a decorative element representing the gnomon of a sundial. In a field inspection, the heights of the columns were measured and the following data was collected:

Smallest columns: 2,5 meters.

Intermediate columns: 4,5 meters.

Primary column: 7,84 meters.

Decorative column: 8,25 meters starting from +9.00 meters height.

The substructure is composed of two abutments with a length of 8 meters and same width as the deck slabs. The foundations are estimated, as no groundworks can be done without an independent project, which is not expected in this project. The dimensions of the foundations would be overestimated, as the budget considers the execution of real cubic meters removed, following are the listed measurements:

Abutments: 1,5 meters of minimum depth. Abutment area is 17,7 squared meters. Total volume is 26,52 cubic meters.

Small and intermediate column: 2,3 meter side length square form and 1,2 meters depth. Total volume of 6,4 cubic meters.

Primary column: 2,5 meter side lenght square area and 1,2 meters depth. Total volume of 7,5 cubic meters.

From a structural point of view, given the state of disrepair which the bridge presents; with some of the principal elements manifesting an advanced condition of degradation, repairing seems unfeasible, proposing thereafter as most effective measure the total demolition to free up space for further development of the area.

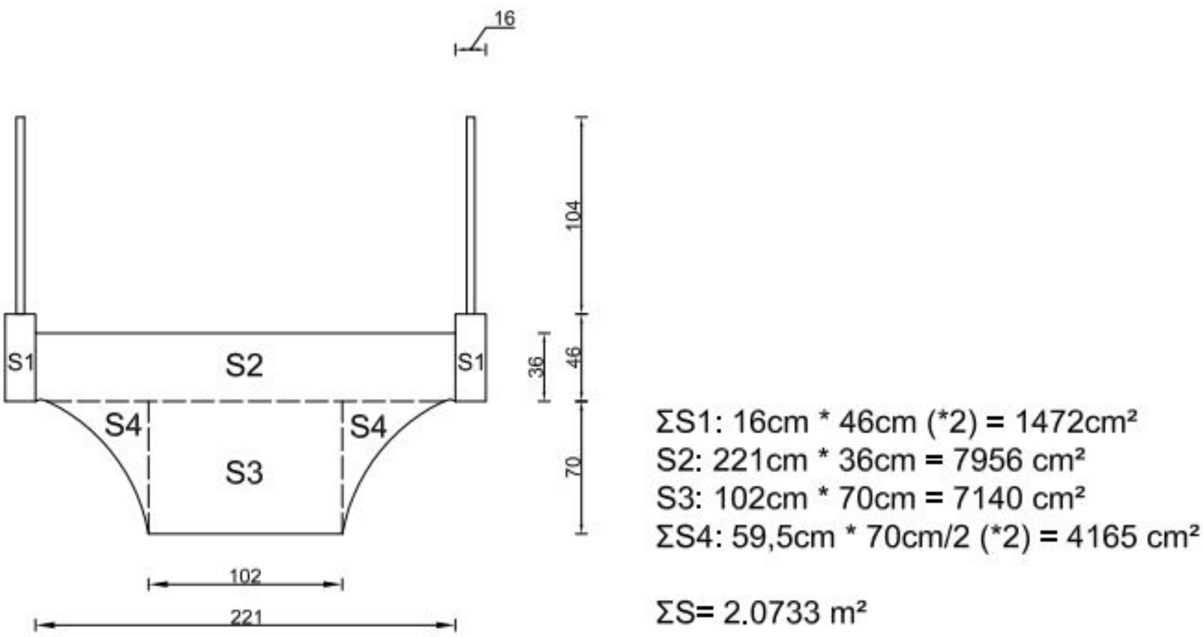
The columns present a problem in the lack of cover applied (Figure 15). Most of the columns have at almost ground level problems regarding the covering and exposing the reinforcements, and considering the aggressive environment due to the proximity of the ocean, corrosion from within seems to be a problem to take into account, as there is no form of knowing the damaged produced inside the structure. The deck slabs have a regular condition, but the joints between the spans lack the original materials, with gaps left. At close range, the structure seems stable and in equilibrium.

Figure 15. Photograph taken from a site visit. Main column´s reinforcements are exposed to the air.

The authorities responsible for the construction of the bridge were contacted, but they did not possess any plans from the original project. The information given was the time of construction; early 1980´s. From this information, it is safe to deduce that the bridge was constructed following the national construction guidelines from 1977 (PG-3. OM 06/02/1976), which implies that the concrete and steel reinforcements were appropiate at the time. Due to the arch the bridge forms and the lines in the deck slabs´ column, the bridge could be assumed to be a precast concrete structure.

Given the lack of knowledge about the original construction project of the bridge, and the impossibility of accurate measurement without resorting to destructive testing, an approximation of the dimensions of the beam is made by field inspection, resulting in the following section type:

Figure 16. Beam section type and area calculation.



Along with these measurements, the section type has been divided into geometrical sections in order to calculate the area of each section as well as the whole structure.

For a demolition process, to understand that the stability of the structure is a priority for the safety of anyone in proximity to the site is important. In order to achieve the maximum safety possible during the disassembly of elements, each independent element should be rid of other elements supposing a load onto it. In this case, columns shall not demolished until all the deck slabs above are removed, and the sections of deck adjacent must be braced with auxiliary supports. This safety guideline applies to any methodology selected, unless explosives are intended to be used, in which case, a customized safety guideline is required.

The disassembly process will be done sequentially in the reverse order to that followed for its construction (BOE-A-1975-3289). It would be safe to assume that the reverse order of construction shall be considered to be from top to bottom, as the structure is reinforced concrete poured on-site. Following this logic, the sequential order of the project would be in the following order:

- Sequential order:

1) Decorative element removal

2) Deck slabs removal

3) Columns removal

4) Abutments removal

5) Foundations removal

6) Groundworks and cleaning

3.2.2 AFFECTED SERVICES

Affected services are understood to be power lines, telecommunications lines, gas pipes, water supply pipes, sanitation pipes, etc. that are in the area of action and that could be affected in some way by the works contemplated in the project. These services may be public or private.

The purpose of this chapter is to list the existing services in the surroundings of the work area, to detect the possible flaws that could occur to them, and to define the necessary works for the protection or replacement of the services that are affected.

First, the services present in the area of action of the project are located, identified, and described. The area has been inspected for manholes and each line has been corroborated with the service plans. Under legal terms, and according to municipal ordinances, as this project was commissioned by the local authorities from within its own technical office, there has been no need to acquire authorizations, but only to contact and inform the service companies. Nevertheless, the contractor responsible for the project is entitled to inform the aforementioned companies of the measures taken and dates on which they intend to replenish or cut the lines.

The existing services under risk of being affected by proximity are the following:

1) Street lighting.

2) Water supply.

3) Sanitation pipes.

From the listed services, the presence of street lights and their respective connecting lines can be observed. These are currently not operative, as their removal was intended on a recent project in the area of study, hence, this project does not contemplate the affection on the supply line, nor the removal of these within this project. Near the south side of the site area, an electrical sub-station is present, serving all nearby hotels. It is necessary for the works not to interfere with the operation of this station.

In the case of irrigation pipes, there is a line crossing along the middle section of the bridge from a plan site view. This line is obsolete according to the information available in the technical office. Nevertheless, a manhole can be seen in the proximity of the primary column, and for safety reasons, the lid was lifted and verified to be inoperative.

There is no water supply line, sanitation pipes, gas supplies or telecommunication lines near the site area.

There are no affected services to take into consideration during the demolition project. The removal of these aforementioned services would fall onto a lesser administrative category for contractors and is not included in this project batch.

3.2.3 ENVIRONMENTAL IMPACT STUDY

Law 14/2014, of December 26th, of Harmonization and Simplification in terms of Protection of Territory and Natural Resources, verifies that the works contemplated in this project do not appear in Annexes I or II of the law, therefore it is not necessary to carry out an evaluation of environmental impact. This does not include the waste management under these provisions, as it is mandatory on all projects (Royal Decree 105/2008).

Nontheless, the use of methods like explosives require special permissions under Article 119, Title VII, of Real Decreto 130/2017, of February 24th, which approves the regulation of explosives. The respective department may require the contractor further documentation or studies for the project on the effect of the limitations of the site area or the sensitivity of the surrounding area (Royal Decree on Regulation of explosives 130/2017).

3.2.4 SPECIAL ECOLOGIC CONDITIONS

On the north side of the bridge, as previously mentioned, there is an autoctonous group of palm trees (Phoenix Canariensis), which are considered a protected species. (Real Decreto por el que se establecen medidas para favorecer la protección, conservación e identidad genética de la palmera canaria, 62/2006 – 688).

It is considered a priority to conserve these species and hence, protect them from any damages during the execution phase of the project. No machine is allowed to breach into the palm tree reserved area, only being able to work from the road´s side of the structure, by the same principle, no machine´s work span is allowed over the palm trees. The area must be left clean, this ought to be done by manual means.

3.3 DISSASEMBLY AND REMOVAL OF ELEMENTS – EXECUTION PROCEDURE 1

From this first proposed methodolgy, it is worth noting that the main procedure would consist on the cutting of the deck slabs in whole span sections and the transportation of the result to a waste management centre with the use of telescopic boom cranes. The main work activities will be presented in order as the execution process would proceed and the works required will be detailed in the following chapters (PG-3, OM 06/02/1976).

3.3.1 PREVIOUS WORKS

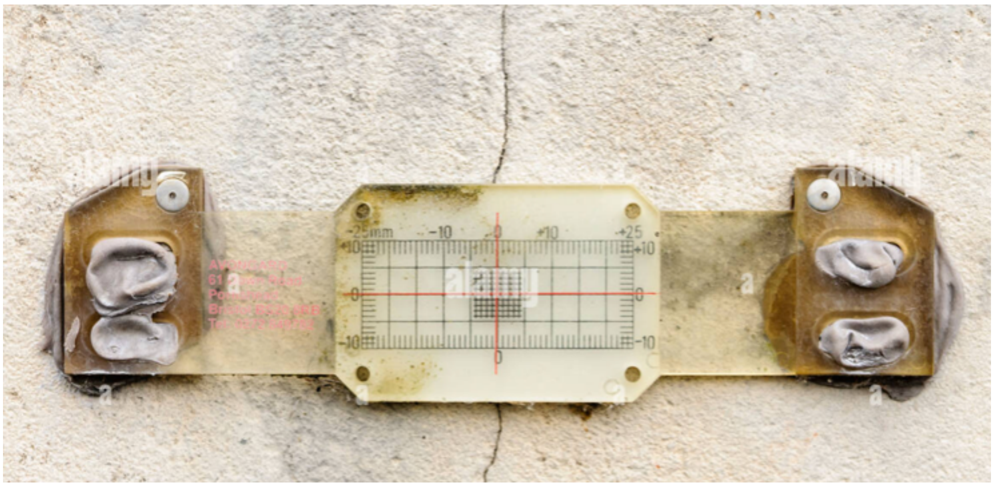
Prior to any demolition works, a series of activities must be done to ensure that preliminary safety conditions are met and guarantee the readiness to start the project. Following are listed the preliminary works required:

1. Signaling of traffic detours in affected roads with beacons and provisional signaling indicating the cutting of the road and new route according to Reglamento General de Circulación-article 139.3 and art. 140, as well as Norma de Carreteras 8.3-IC. The perimeter of the demolition site shall be enclosed with appropiate construction fences and other necessary collective and individual safety measures. The traffic detour for a total road closure is available in Appendix 2, along with shorter detour options that will be specified later in this procedure, lest the local authorities decide otherwise. (PG-3. Part 7)

2. Disassembly of the road´s safety barrier on the margins of the footbridge to prevent damages and salvage of the material. The safety barriers will be replaced with anti-tipping curbs (Implementation of new curbs is not intended for this batch of the project). This process would require an oxy-fuel cutting equipment and a crane (later specified) to load onto a lorry. In the case of the existing anti-tipping curbs, as they are connected with mortar to the ground, it would require breakers and a dumper to transport the waste.

3. Placement of centring for the two ramps of the footbridge and its prolongation. Due to the deterioration of the ramps and their pillars, it is considered necessary to rely on a temporary structure to guarantee its stability whilst the deck slabs are being removed. In order to control the stability of the bridge, it would become necessary to monitor the crack width variations during the superstructure demolition activities, installing glass tell tales (Figure 17). This device would require of constant supervision prior and after all dissasembly activities. The installment location is subjected to the contractors decision, recommended at the connections between deck slabs and columns, the joints being critical in the stability of the structure.

   Figure 17. Glass tell tale for crack width control.



4. Before any demolition procedure will proceed, the bounding, signaling and leveling of the work areas that the crane will need as well as the rest of machinery to be used needs to be clearly marked. The ground condition is not considered a priority as the road will be later demolished.

5. The tranport of machinery and required equipment to the demolition site is included in this section, as well as their installation and readiness.

In order to make a decision for cranes and logistics, different factors are to be considered. In the case of transporting heavy loads by road, the logistical aspect is subjected to Real Decreto 2822/1998, de 23 de diciembre, por el que se aprueba el Reglamento General de Vehículos, which states that the limits in volume and mass are the following:

The maximum authorized dimensions are:

• Length of more than 16.50 meters.

• Width of more than 2.55 meters.

• Height of more than 4 meters.

The maximum authorized mass limits:

• 18 tons for two-axle trailers

• Trailers with three axles: 24 tons.

• From 36 to 38 tons in trailers or four-axle road trains.

• 40 tons for trailers or road trains with 5 or more axles.

Is it important to note that, due to the special circumstances of the project, special permits may be required to be dispatched for the transportation of the bridge sections. The contractor would be required to have their own machinery capable of the work, or the capability to subcontract, and all licenses and permits need to be validated.

Based on the section type described in the study of the structure, the maximum weight of a beam span of 8 meters in length is estimated:

Table 2 and 3. Structural materials' calculation.

DECK'S CONCRETE WEIGHT		
Deck section =	2,0733	m^2
Deck lenght =	8	m
Concrete Density =	2,3	tn/m^3
Deck´s concrete weight =	38,14872	tn

DECK´S REINFORCEMENT WEIGHT		
Estimated quantity =	150	kg/m^3
Reinforcement weight =	2,48796	tn

Table 4. Handrails calculation.

HANDRAILS´ WEIGHT		
Handrails´ weight =	16	kg/m
Handrails´quantity =	2	m/m
Total Handrails´ weight =	0,256	tn

Table 5. Sum of previous weight calculations for an 8 meter deck section.

TOTAL DECK WEIGHT		
	40,89268	tn

Regarding the execution procedure of the deck slabs, a decision must be made as there are two options; directly cut the deck slab section or first reduce this section to ease the process. In order to justify the means to reduce the section, the following reducement calculation is done with the data collected previously in the theoretical section study:

Table 6. Reducement of deck slab section calculation.

BEAM SECTION REDUCEMENT		
ΣS	2,0733	m^2
ΣS1	0,1472	m^2
ΣS.red	1,9261	m^2
% reduced=		7,0997926

The cantilever sections which are represented as the sum of Sections 1, account for a total of 7.1% of the whole section. This area serves merely as anchorage support for the handrails with no structural function, but it would require of an initial inspection to verify and approve the execution. For the expected length of the spans, the consecuent reducement is calculated:

Table 7. Consecuent reducement justification for an 8 meter span.

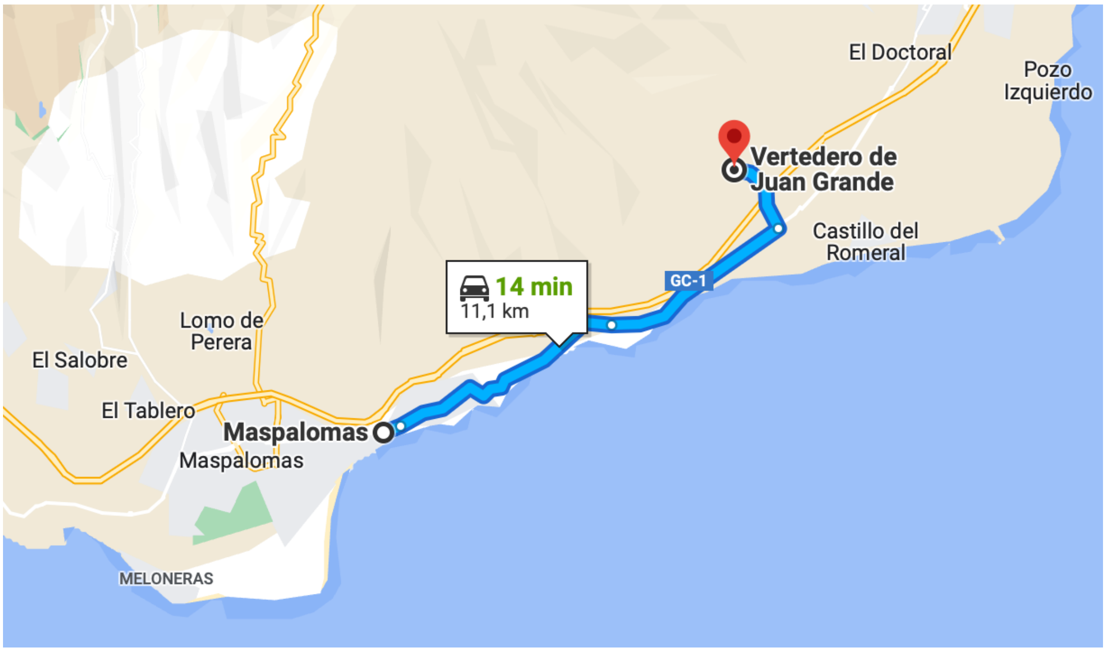
CONSECUENT REDUCEMENT (8 meters)			
Material:	Span:	Density:	Tonns:
Concrete:			
ΣS1	*8 meters	*2,3 tn/m^3	= 2,71 tn
Reinforcements:			
ΣS1	*8 meters	*150kg/m^3	= 0,18 tn
Handrail:			
	2 m/m	16 kg/m	= 0,26 tn
40,89 - 2,71 - 0,18 - 0,26 = 37,74 tn			

This operation could be considered efficient due to the weight limitations for the latter transport. From the previous limitation tables, it can be seen that the maximum allowed mass cannot exceed 40 tonns, thus requiring an exceptional permit. With a reduction of the section type, the requirement would be a special permit; reducing risks for the process, necessity for stricter supervision and allowing for a more accessible and fair tender notice. On the other hand, this process would be time-consuming, as the machinery required is not able to work simultaneously, moreover, the increment in cost and environmental impact would be also noticeable due to the increase in number of machinery, hence, the reducement of the section type is not taken into consideration.

As the total length of the footbridge is 120 meters, divided into 8 meter sections, the result would be a total of 15-8 meter sections. From a plan view, and contrasted with a field inspection, the deck is formed by two 48 meter straight deck spans, after this, on the highest point of the deck structure, a 24 meter span forming a curve can be observed.

These curved sections present a problem due to the special conditions required by the national general vehicle regulation. An exceptional authorization from the authorities would allow the transportation up to 5 meter wide cargo. The total width of a curved 8 meter span is 6 meters, making the load unacceptable to transport by road. In order to achieve allowable measurements, the curved section would need to be reduced to 4 meter sections. The arrangement on logistics consists of the route the lorry will take towards the subcontracted waste management centre, the reassurance of the waste management centre to be able to unload the cargo, and a special police escort (Guardia Civil de Tráfico), if needed. Once the decision has been made on the contractor´s side, authorization from the local authorities ought to be also received (PG-3. OM 28/09/1989). A route example towards the nearest adequate waste management centre is provided (Figure 18), where the distance can be calculated from. The exceptional authorization expended by the traffic authorities would detail the maximum allowed speed for each specific load, which in no case would exceed 60 km/h (Royal Decree 2822/1998). The minimum speed allowed in motorways is 60 km/h, hence, secondary roads have been considered as the optimal solution.

Figure 18. Route map for element sections transport to nearest waste management centre.



From a field inspection, heights were measured, where the highest point of the deck reached 7,84 meters. This represents the cricital value for the crane´s operation, which added to the height of the deck´s section sums up to 9 meters.

It would be necessary to also calculate the capacity for the crane to operate on the highest point of the structure at 17,25 meters. The approximate calculated weight and the decorative element section (Figures 19 & 20) is also calculated as a critical point for the crane:

Figure 19. Side profile and weight calculation for the decorative column.

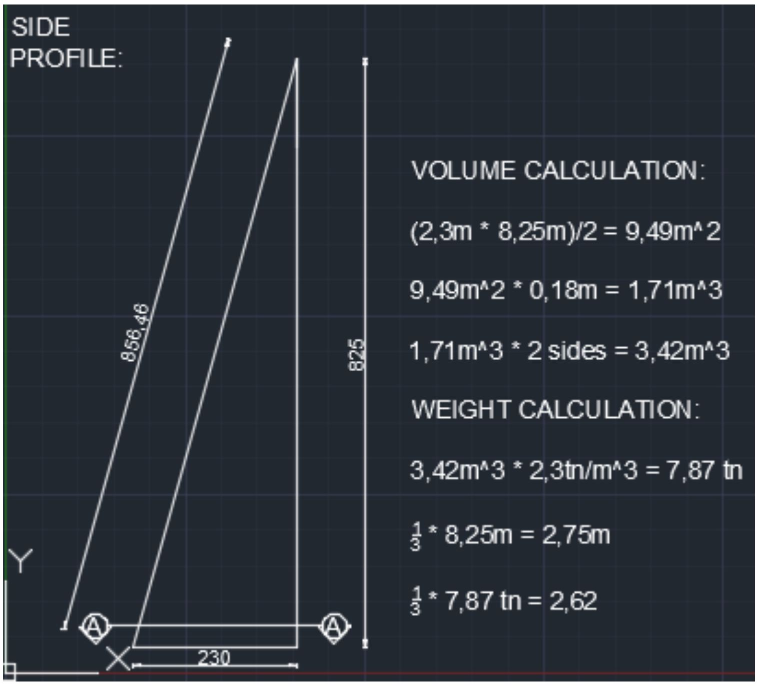
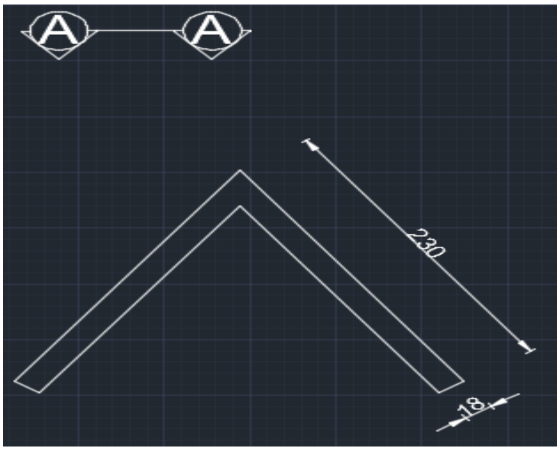


Figure 20. Decorative column cross-section.



Following are the lifting capacities (Figure 21) for a Liebherr LTM 1200-5.1 (Figure 22):

Figure 21. Lifting capacity chart for selected crane.

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m	13,2 m	17,7 m	22,2 m	26,7 m	31,3 m	35,8 m	40,3 m	44,8 m	49,3 m	53,8 m	58,3 m	62,8 m	67,3 m	72 m	m
3	143														3
3,5	131	125													3,5
4	122	122	121	107											4
4,5	113	113	113	105	85										4,5
5	105	105	105	103	84	70									5
6	92	93	92	91	82	69									6
7	80	81	80	76	71	67	52	40							7
8	69	70	69	63	61	56	51	38,5							8
9	60	60	58	56	52	48,5	47,5	37	30,5						9
10	50	52	50	49	45,5	45	41,5	35	29,3	24,4					10
11		44,5	45	43	42	40	37	33	27,9	23,7	19,2				11
12		38	39	38,5	38	35,5	33	31	26,4	22,8	18,8	15,6			12
14		29,5	30	31,5	31	29,3	27,2	25,5	23,9	20,9	17,6	14,9	12,6	10,6	14
16			25,1	25,4	25,3	24,4	22,6	21,9	20,3	19,1	16,3	14,1	12,1	10	16
18			20,8	21	20,9	20,5	19	19,4	17,8	16,6	15,2	13,2	11,5	9,5	18
20				17,7	17,6	17,1	16,2	16,7	15,2	14,5	14,1	12,4	10,9	9	20
22				15,1	15	15,3	13,9	14,5	13,8	13	12,1	11,6	10,3	8,5	22
24				13,1	12,9	13,6	11,8	12,5	12,7	11,3	11,1	10,6	9,8	7,9	24
26					11,3	11,9	10,9	11,6	11,2	10,1	10,1	9,3	9,2	7,4	26
28					9,9	10,5	10,3	10,4	9,8	9,5	8,8	8,7	8,2	6,9	28
30						9,3	9,6	9,2	8,6	8,8	8	8	7,2	6,4	30
32						8,3	8,6	8,2	7,9	7,7	7,4	7,1	6,3	5,9	32
34							7,7	7,3	7,4	6,9	6,8	6,3	5,5	5,4	34
36							6,9	6,6	6,6	6,4	6	5,6	4,8	4,8	36
38								6,2	5,8	5,7	5,3	4,9	4,2	4,2	38
40								5,6	5,3	5,1	4,7	4,3	3,6	3,7	40
42									4,7	4,5	4,1	3,7	3,1	3,2	42
44									4,2	4	3,6	3,2	2,6	2,7	44
46									3,8	3,5	3,1	2,7	2,2	2,3	46
48										3,1	2,7	2,3	1,8	1,9	48
50											2,3	1,9	1,4	1,5	50
52											2	1,6			52
54												1,3			54

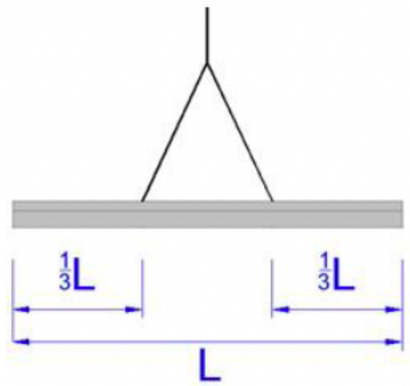
TAB 1552411

Figure 22. Proposed mobile crane.

For a 22,2 meter jib at 10 meters of height, the crane is able to lift 50 tons of weight. Hence, the crane to be used would consist on a LTM 1200 with 32 tonns of counterweight.

The hoisting of the beam with chains must be carried out in such a way that the fastening elements are one third of the total span of the beam from the ends (Figure 23). As the weight of each deck span is considerable, chains must be secured around the element instead of drilling and fastening. In the case of vertical elements, swinging of the piece ought to be controlled on all ends with auxiliary measures in the form of shoring.

Figure 23. Weight distribution in beam hoisting depiction.



3.3.2 SUPERSTRUCTURE DISSASEMBLY

Due to the state of the handrail, presenting signs of corrosion from a lack of cover, it is not considered relevant to recover the material for the reusal of it. Different procedures could be applied for the dismantling, as per the relevancy of it in terms of weight, it does not mark a notable difference concerning the selection of the crane, hence, the relevant factor for the decision would be the efficiency in terms of time and budget. An optimal solution would be to cut the handrail in the same section cuts as the deck, and the handrails lifted and carried away along with the deck. The equipment necessary for this cut is a metal-cutting circular saw.

1. Decorative column removal.

The first element to demolish would be the decorative column in the center of the structure. This element is not withholding any imposed loads, hence, the dismantling can be done ipso facto. Initially, the selected crane must secure the element vertically and restrict any horizontal moves, preventing an overturning or unpredicted swing of the element or crane itself. The colum section dimensions allow for a diamond saw cut, which usually does not allow for cuts of more than 72 centimeters of depth. The amount of cuts will be determined by the capacity of the crane; the capacity being the weight of the element itself plus the height of the restrictions that need to be calculated into it. The necessary means for this task would consist of diamond saw blades for the cuts, aided with a 20m articulated boom lift (Figure 24) and a telescopic boom crane. The procedure would consist of three cuts, dividing the element into 2,75 meter of height pieces. In order to secure the fastening of the column for the lifting and removal, holes would be required to be drilled in each separate piece prior to the cut.

Figure 24. 20 meter articulated boom lift.

2. Deck slabs removal.

The main limitation for the cut would be, apart from the height, the dimensions of the structure. Hydraulic chainsaws and diamond saw blades have a limited cut depth of 73 centimeters, which would not allow a clean or safe cut, as it would be required for operators to cut the sections at heights around the structure, which presents many risks to safety. A suitable solution could be the use of a diamond saw wire, with a correct installation, it would accelerate considerably the process compared to other methodologies. The contractor is responsible for the correct installation of the pulley arrangement around the deck slab, and the generator and motor must be at a safe location during the process. The operator´s safety is a priority, requiring of remote controls to work at a safe distance.

Auxiliary means are understood to be the scaffolding necessary to install the pulleys.

From the previous study of the structure mentioned before in this paper, the amount of sections would consist of 12-8 meter spans and 6-4 meter spans. The amount of cuts required to divide the structure into this amount of section spans would sum up to a total of 19, starting the execution from the middle point of the deck, where the decorative column element is located. The lifted sections will be placed on top of the corresponding special transport vehicle. Safety measures are to be strict during this process, and require the section to be in place and tightened. The section´s destination ought to be the waste management centre, where the piece will then be crushed and material will be separated. No lifting from the crane will be done until manual operators are outside the range of action.

3. Columns removal.

Once the columns are free from the imposed loads, it is possible to proceed to the cut and removal. This process may be done after the removal of all deck slabs or, if coordinated, alternating whilst the deck slab cuts are under execution, with the resulting elements to be extracted directly from site or piled on a designated area for extraction afterwards.

The column must be immobilized by the crane and shoring, grappling from the horizontal beam or punching shear area if possible. With the use of a diamond wire saw**,** all columns are to be cut at a height of 1 meter from the ground level, allowing the cut of the reinforcements connecting to the foundations.

Independently, each set of columns requires a calculation to prevent hazards for the crane.

In the case of the primary column, the upper section is considerably large, with dimensions doubling the cross-section at the bottom of the same, meaning 4,47 m^2. This enlargement would constitute for the top 2,84 meters of column. The total volume would result from the multiplication of these previous data: 4,47 m^2 * 2,84 m = 12,70 m^3. Considering a density of 2.400 kg/m^3: 12,70 m^3 * 2,4 tn/m^3 = 30,48 tn.

The remaining volume of the column consists of 5 meters of height and 2,4 m^2 of area, applying the same calculation procedure, results in a volume of 12 m^3 and 28,8 tonns.

Both calculations´ results fall under the critical weight for the crane and at a lower height than the deck slabs. A minimum of two cuts are necessary to extract the main column.

The intermediate columns stand at a maximum height of 4,5 meters, with a constant cross-section of 0,42 m^2. The total volume following the previous calculations would result in 1,9 m^3 and a density of 4,54 tonns. These columns would only require a cut separating the columns from the foundations at a height of 1 meter.

The smallest columns maintain the same cross-section as the intermediate, with a lower height by two meters. As the intermediate would not present a problem in terms of weight, it is safe to assume that the smaller ones would not either. The extraction procedure would be strictly necessary regardless of the volumes and heights.

Figure 25. Example of diamond saw wire installation for column cut.

3.3.3 SUBSTRUCTURE DEMOLITION

For the demolition of the substructure, in order to accelerate the process, four excavators would be required, working separately or jointly according to the stage of the project.

4. Abutments removal.

The abutments, once liberated from the deck span´s weight, will proceed to be demolished by mechanical means. Proposed machinery would be excavators equipped with percussion hammers along with compact excavators and dumpers for waste transport as well as oxy-fuel cutting equipment for reinforcement cutting once these have been exposed. The waste generated will initially be transported away with the use of lorries to the waste management centre, unless by decision of the project coordinator within the authorities allowing the reuse for filling of groundworks. In this case, the waste must be separated on site at a designated area and examined prior to any decision.

5. Foundation Removal.

Foundations are the last elements from the structure to be demolished, but they may start if no imposed loads (columns) are present and means are available. This phase relies almost completely on machinery, specially on excavators attached with hydraulic breakers and buckets. The excavators attached with breakers would tear through the element. The material will be crushed into smaller and manageable pieces, to be extracted with compact excavators. In order to cut the exposed reinforcements, an oxy-fuel cutting equipment will be required, with a specialized welder as an operator. Waste will be transported onto a designated area or directly loaded for extraction.

6. Groundworks and cleaning.

Groundworks and cleaning are the last steps in order to be able to conclude the project. The condition of the road afterwards is considered irrelevant as the project has intended the resurfacing in the second batch but the ground level must be flat and steady (PG-3. FOM 1382/2002). Machinery is used to fill the holes left from the foundation locations under authorities´ approval and the site must be cleaned as a result. The machinery consists of a 2 ton dumper to carry the aggregates and a truck to transport the aggregates to the site if the reusal of material is not approved. Compacting and vibrating the ground are manually done with the use of a vibrating plate compactor as the area of work is small.

3.3.4 WASTE MANAGEMENT AND SAFETY

An agreement with the waste management centre must be reached before any waste is transported. A crane sufficiently capable of lifting the same weights loaded onto the lorries must be prepared at the waste management centre. The maximum weight a lorry is allowed to carry will be of 41 Tn at once. The coordination and logistics must be adequate, satisfying the capacity and safety requirements. Waste dumping taxes are covered in the budget, paying for actual tons delivered.

The effect on traffic may be lessened if there is a possibility to keep the motorway link functional. For this, there are critical areas of the link (Appendix 2.2) which might be affected by the works. By maintaining these marked sections of the road operative, cars would be able to use the motorway link and have a safe and fast access to the motorway. In order to ensure safety for the traffic, the works must be supervised under all circumstances around these areas. The traffic must be regulated and supervised whilst operations of removal and transportation are undergoing. In order to avoid damages to third parties, under provision of the Royal Decree 1382/2002, fencing will be placed along the critical section.

Waste management and safety are mandatory for all activities during a project, being specified for each activity the corresponding plan. For this reason, it is necessary in the work schedules, as in the case of budgets, to display the need for these to prevail during all tasks.

A detailed annex in matter of safety is responsibility of the contractor, which should be presented after a favourable evaluation from the safety coordinator and approved by the local authorities prior to the start of the project. (Article 10, Royal Decree 1627/1997). This annex must contain previsions in safety for the tasks, machinery and equipment, as well as collective safety measures.

In order to reach a conclusion for the time schedules and budget required for each methodology, the work steps have been projected in CypeCAD program, which possesses a data list of current market prices for different activities country-wide. Along with the program, the commissioner of this project facilitated a personalized activities´ sheets for unitary costs and efficiencies used within the local technical office.

The budget (Appendix 3.2) is divided by folders, each folder representing a main group of works. Main activities are included; auxiliary measures are mentioned only in the case of machinery, the rest being considered indirect costs, in the form of a percentage of the task. The unitary costs of machinery and personnel are projected in each task. The procedure for calculations vary according to the tasks.

CypeCAD program estimates also the efficiency rates of the different procedures, which can be manually adjusted if the amount of machinery, personnel or equipment is changed. From this starting reference, it was possible to schedule the time frames of work (Appendix 3.1).

The presented Gantt charts in Appendix 3 aim to provide an idea of the development sequency of the main work activities for each of the phases of work, marking the schedule programs as merely indicative. The setting of the level of detail for the final work program will correspond to the awarded tenderer, taking into account the means and the performance of the equipment, which must have the approval of the relevant authorities.

It is important to remember that this procedure is a part of a larger project, where the whole road section is expected to be removed and built anew. The safety coordinator of this project is responsible for the decision to close the avenue for the entirety of all the project or allowing for reopenings in intervals, subjected to the approval of the authorities.

Conclusion: This methodology depends mainly on the use of a telescopic boom crane and diamond wire saw, accompanied with a direct transport of the bridge sections to the waste management centre, which can significantly increase the speed of the process theoretically. Even tough the deck slab´s section is considerable, the use of a diamond wire saw would fulfill the task, as the installation is possible and the cut is relatively fast. Regarding safety, there are critical moments during the process which are considered dangerous due to working at height and specially for the crane. The main concern would be the lack of knowledge of the properties of the materials, allowing only for an estimation of weight, even tough this assumption was overestimated.There is no need for an environmental impact study, but the use of excavators to demolish foundations, would produce vibrations and dust and become incovenient during these last works. The basis for the cost relies mainly on the special characteristics of the process, implying the need for special machinery and experienced personnel to execute the cuts, to lift the heavy sections and to be able to transport them, becoming the most expensive procedure studied. This methodology would require more coordination as it has the most variety of machinery and equipment. It has the lowest environmental impact as the waste managed in-situ is the minimum possible and no waste is produced for the superstructure demolition process.

3.4 COMPLETE STRUCTURE DEMOLITION – EXECUTION PROCEDURE 2

In this second proposed methodology, the process would consist on the demolition of the footbridge with mechanical means, mainly consisting on excavators with variable attachments.

3.4.1 PREVIOUS WORKS

Prior to any demolition works, a series of activities must be completed to ensure that preliminary safety conditions are met and guarantee the readiness to start the project. Following are listed the preliminary works required in this demolition process:

1. Signaling of traffic detours in affected roads with beacons and provisional signaling indicating the cutting of the road as well as a new route. The perimeter of the demolition site shall be enclosed with appropiate construction fences and other necessary safety measures. The traffic detour for a complete road closure is available in Appendix 2.

2. Disassembly of the road´s safety barrier on the margins of the footbridge to prevent damages and salvage of the material. The safety barriers will be replaced with anti-

tipping curbs (Implementation of new curbs are not intended for this batch of the project). The means necessary would be the same machinery later specified for the main works, consisting on a single excavator to tear apart the barriers and load mechanically onto a lorry.

3. In order to control the stability of the bridge at all times, it would become necessary to monitor the crack width variations during the superstructure demolition activities, installing glass tell tales (Figure 17). This device would require of constant supervision prior and after all disassembly acctivities. The installment location is subjected to the contractor´s decision, recommended at the connections between deck slabs and columns, the joints being critical in the stability of the structure.

4. Before any demolition procedure will proceed the bounding, signaling and leveling of the work areas that machinery will require, the ground condition is not considered a priority as the road will be later demolished.

5. The transport of machinery and required equipment to the demolition site is included in this section, as well as their installation and readiness.

3.4.2 SUPERSTRUCTURE DEMOLITION

Due to the state of the handrail, presenting signs of corrosion from lack of cover, it is not considered relevant to recover the material for the reuse of it. An excavator would be required to demolish the handrail exerting force inwards, tearing the connections apart without due regard to the salvage of materials. The fallen waste shall be carried away with compact excavators to be pilled on a designated area and treated separately.

1. Decorative element demolition.

Considering the height of the decorative element (17,25 meter), it would require a long-reach excavator with a demolition multi-processor attachment (Example Figure 10) to start from the top downwards crushing and tearing down the element. The base is too wide for demolition multi-processor to cut through directly, thus another excavator with a breaker attachment would be expected to be used for the deck slab demolition. This process is quite pollutant in terms of dust and noise. In order to prevent the spreading of dust, from the falling and crushing of the concrete, it would become necessary to auxiliate the process with water tank lorries, which waters over the falling waste coordinated with the excavators, minimizing the dust created.

2. Deck slabs demolition.

It would be expected for seven excavators to work simultaneously on the demolition of the deck slab (Figure 26). Out of these excavators, four would be equipped with hydraulic breakers, whilst the other three are equipped with demolition multi-processors, alternating between them according to the state and needs of the section. Along with this machinery, two compact excavators and two dumpers are expected to support with the tasks of waste management for the waste fallen during the work. The columns should not be affected during these works, leaving approximately a meter of distance from the deck slab cut to the columns (Figure 27) to ensure stability and avoid unexpected actions.

Figure 26. Sketch of machinery positioning for demolition works.

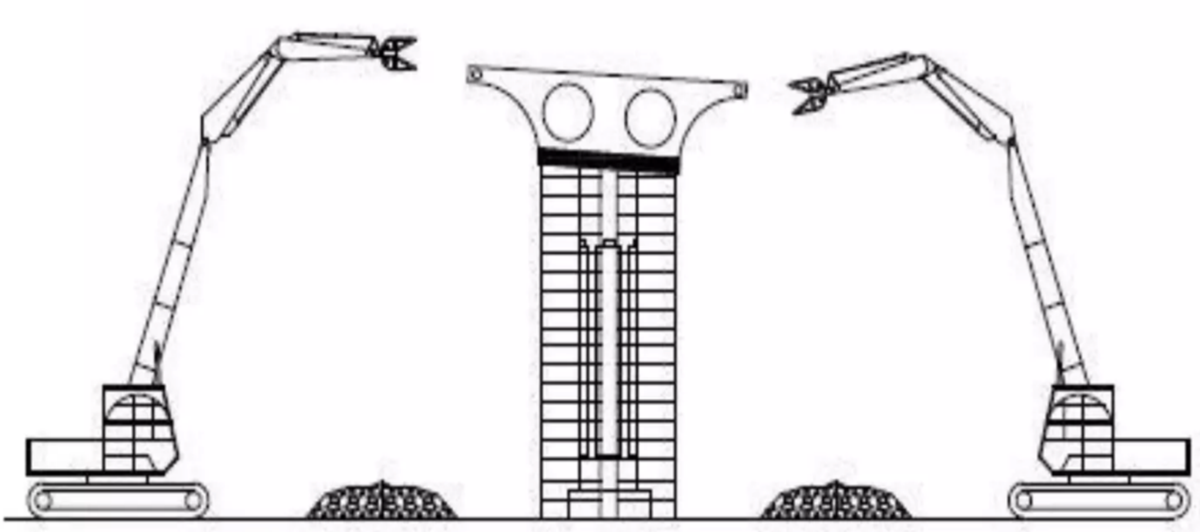


Figure 27. Cut and demolition works of a bridge project in Andernach, Germany.

The excavators must reduce the deck slab area starting by sections 1 (P.34) and inwards from both sides. The overhanging spans might present the risk of collapse, requiring constant supervision. The demolition must proceed linearly along the deck slab span, starting from the central and highest point downwards. If the resulting pieces are too large to maneouver, the same excavators demolishing would proceed to break these pieces and ease the process of extraction. Watering during this process is also necessary to reduce the dust created.

3. Columns demolition.

In the case of the load-bearing columns, any action can be taken only after all imposed loads have been removed. The machinery required for this activity would be the same excavators equipped with demolition multi-processors and breakers. The upper section of the main column would be required to be diminished via breakers, whilst the lower section and all secondary columns may be demolished exerting force outwards or with the help of another excavator to force a collapse. As the amount of machinery on site is considerable, a coordination of work would be necessary to speed up the process and reduce risks. Once the deck slabs have been demolished at two thirds of their span from the top, as in at a height lower than the two middle columns, the machinery will be divided. Two excavators with breakers and two with multi-processors ought to continue the deck slab demolition, whilst the spare two may start the demolition of the primary column.

Once the deck slabs have been completely removed, the machinery will immediately continue with the demolition of the remaining columns. These activities are continuous, meaning that if one task has been completed, and authorities have given approval, machinery ought to move on directly to the next planned activity. This coordination can be applied between the column demolition and abutments, as long as one does not interfere with the other. Watering should proceed as in the previous activities.

3.4.3 SUBSTRUCTURE DEMOLITION

4. Abutments demolition.

The demolition of the abutments may start as soon as the final deck slab spans have been removed. The machinery applied would be the same as that for the columns, and can be done simultaneously.

The excavators attached with breakers would tear through the element. The material will be crushed into smaller and manageable pieces, to be extracted with compact excavators. In order to cut the exposed reinforcements, an oxy-fuel cutting equipment will be required, with a specialized welder as an operator. The amount of machinery expected to be used in this stage would be four excavators attached with breakers.

Waste will be transported onto a designated area or directly loaded for extraction.

5. Foundations demolition.

Foundations are to be removed last, but in order to accelerate the process it is possible with the aid of excavators equipped with breakers and an oxy-fuel cutting equipment to start demolishing if they are not withholding any imposed loads (columns). The foundations are expected to exceed one meter of depth, proving dangerous for compact excavators to operate at. In order to extract the waste generated, an excavator would swap gear and attach a bucket, allowing for a longer reach and stronger means.

Waste management shall be carried out as in other activities listed before.

6. Groundworks.

Once the foundations have been completely removed, the filling may be done with the same compact excavators and recycled aggregates, to be prepared for further works (PG-3. FOM 1382/2002).

Regarding waste, the falling materials during the process ought to be collected and transported to the corresponding dump truck or extraction point only once the watering has been done and the excavators responsible for the demolition have halted. The use of compact excavators is sufficient to complete this activity. A correct cordination between all machinery involved is fundamental to avoid risks and for the process to be time-efficient. This process would require supervision in order to divide and classify the types of waste generated prior to any transport.

With the use of CypeCAD program, an estimation on regards of this procedure´s cost and time requirements can be calculated (Appendix 4).

In conclusion, this methodology is highly efficient in terms of time and budget. The main reason for this would be the installation of machinery on site and the use of these along all the activities within the whole process, simplifying the coordination requirements external to the site. Machinery able to tear apart the reinforcements would accelerate up the process greatly. Regarding safety, the conditions are good, as no operator would be required to be near the structure whilst undergoing demolition works, except the case of the oxy-fuel cutting team, which would not be affected under correct coordination and supervision. To ensure the safety of the operators on the bridge, crack control must be supervised rigorously during all activities involving the deck slabs. As per the negative effects of the methodology, the main disdvantage is the enviromental impact the works produce, because although the accumulation of dust can be tackled, the noise and vibrations would exceed that of a normal comfort. As a possible solution, it would be required to use hydraulic breakers instead of pneumatic, reducing the environmental impact. The works must be carried out only during daytime.

3.5 EXPLOSIVES METHOD – EXECUTION PROCEDURE 3

Proposing explosive means could be considered inefficient as the means necessary are unknown initially. Due to the lack of knowledge in regards of the reinforcement placement; an initial destructive test would need to be carried out in several different locations of the structure to know how to place the cartridges, and only afterwards, the use of explosives, if justified by a professional, can be commissioned. For this initial evaluation, a representative from the authorities ought to be present and approve the continuation of this method.

As previously mentioned in chapter 3.2.3, no environmental impact study would be required due to the law requirements, but, analysing the environment of the site, where nearby hotels, a petrol station and an electric sub-station in the proximity of the bridge can be found, authorities would require to dispatch an order for it.

The list of environmental impacts have been detailed previously in the theoretical part of this thesis. Some of the most critical impacts concerning this project are:

Flyrocks: The area of work on a daily basis is highly transitted by traffic and pedestrians. traffic would be redirected from underneath the bridge, but pedestrians would still be able to walk around relatively close to the site area. An uncontrolled explosion would present a high risk for flyrocks to impact on the pedestrians and parked cars nearby. The possibility of flyrocks damaging nearby structures is low due to distance, but the hazard should not be discarded.

Vibrations and air shock wave: Considered the most critical point under evaluation for this situation, special attention must be payed to the sensitivity of the petrol station and its tanks, the electrical sub-station is considered critical and its operation cannot be halted (as seen before, this might also affect the efficiency of the equipment for different detonators).

Hotels may also seem affected, specially by low frequency vibrations or a direct air shock wave against their façades.

Due to the proximity of electromagnetic hazards in the form of an electrical sub-station, it would be considered safe to assume that the selection of detonators would be limited to shock-tube or electronic detonators, proposing electronic detonators as an efficient solution due to the precision in the time intervals of the explosions, reducing the risks of environmental impact.

3.6 OTHER EXECUTION PROCEDURES

In this section, hypothetical changes to different activities of works from the previous proposals are presented, as well as other methodologies:

3.6.1 PRESENTED PROPOSALS´ VARIABLES

For the first execution procedure, it is possible to acquire more means to increase the rapidness of the process, so that another diamond wire saw equipment could be able to work simultaneously on the deck slab cuts. Once the columns are free from their imposed loads, one diamond wire saw could focus on the column cuts while the other continues with the works on the deck slabs, as the crane’s efficiency is high and the cuts are relatively slow. This decision would imply a considerable increase in costs as the machinery is expensive. The coordination for the cuts and lifting of elements would require constant supervision to ensure that safety prevails during the process.

Protective elements: The asphalt underneath the bridge is not new, and planned to be repaved, nevertheless, the possibility to install a protective layer can be considered. In order to achieve this, a layer of thin aggregates, such as sand, can be spread on the area where debris may fall, with the help of a lorry (Figure 28). This material is poured and caution must be taken at the time of clean-up (PG-4. 20.5.8). This activity concerns the works related to “Execution Procedure 2”, as the amount of debris is considerable.

Figure 28. Example of spreading procedure of sand.

In the case of the curbs, expected to be demolished in the early stages of the project, the local authorities may esteem appropiate to leave in place, in this case, protection mats (Figure 29), which ought to be placed before any demolition above all curbs. The mats absorb the impact of falling debris and are easily placed and removed with a excavator or manually depending on the measurements.

Figure 29. Mechanical installation of protection mats over road barriers.

Deck slab elements.

For the case of the demolition with excavators (Execution procedure 2), the amount of waste generated is greatly increased, and the sole use of manual means to deal with these materials would require of great amounts of time. It is possible to combine the expected use of hydraulic breakers for this activity along with help of manual demolition hammers to reduce the size of the fallen pieces into more manageable dimensions. This process is highly pollutive, as both noise and dust exceed allowable measures. The attachment of noise suppressors would influence this impact for both manual and machinery. For the case of dust, instead of a water truck, it would also be possible to rely on manual means, operators with hoses being a possible replacement.

It is important to note that safety measures and supervision are to be strictly followed when both machinery and workers are at the site at the same time, and in order to reduce risk factors and be time-efficient, a good coordination is required. One possibility would be to recollect and transport all the fallen waste onto a different area on site with compact excavators where the works are not interrupted by the main work activities and manual means can be applied safely. The loading of the waste onto dump trucks could also be changed to manual means, replacing excavators with buckets or compact excavators.

Column elements.

It is viable, with a reduced amount of tools; a compressor, a pneumatic breaker and an oxy-fuel cutting equipment, to demolish column elements. The process would consist of breaking the concrete and exposing the inner reinforcements. It is important to ensure the stability of the element. Once the concrete has been teared apart, fragmentation of the materials into smaller pieces is necessary to carry and load the waste onto a dump truck. For tall columns, auxiliary means in the form of scaffolding or lifting machinery would be required.

Abutments.

During the activities involving the demolition of abutments, manual demolition hammers could work simultaneously with excavators to speed up the process, aiding in the fragmentation of loose concrete pieces and manual transport of waste.

Groundworks.

The filling variables would rely on the decision from the local authorities (PG-3. OM 28/09/1989) to reuse the aggregates result of the demolition. This decision would substract the transport costs of aggregates and the purchase of these.

Conclusion: The increase of manual means would not be justifiable in any aspect. Safety of the workers would be compromised due to the proximity of machinery, requiring a greater coordination and supervision. As for the budget, all proposals require machinery for mostly all activities, so the efficiency of these compensates the unitary costs. The main weighing factor which leads to discard the use of manual means is time, as manual activities are time consuming, which cannot be justifiable because there is no reasonable advantage.

3.6.2 ALTERNATIVE METHODOLOGIES

Two alternatives for the project are presented in this section:

Bursting technique.

An alternative to explosives is the application of a bursting technique. This methodology would consist on drilling holes at calculated locations in each element, following the demolition procedure requirements. An expanding mechanism of choice is selected: gas expansion burster, expansive mortar or with hydraulic means in the form of wedges and pistons. This methodology would imply the partial or complete collapse of the structure.

The technical procedure has not been contemplated in this project due to lack of information regarding the materials and method of calculation. It would be necessary to rely on an external party to apply this methodology. The decision from the technical office has been not to proceed with this methodology.

This method is considered very safe, as no operator is near the structure during the collapse. The environmental impact is minimal, as this process does not produce noise, vibration nor dust apart from the impact of the structure against the ground once collpased.

Wrecking ball method.

Another alternative proposal would be use of a wrecking ball to force the collapse of the bridge. The weight of a wrecking ball ranges from 450 kg up to 5.400 kg. The required weight cannot be estimated due to lack of information in this field.

The procedure would consist of a complete structure collapse by parts. For vertical elements (columns), the wrecking ball ought to be swung laterally, destabilizing the structural component. In the case of the deck slabs, the wrecking ball must be placed in between overhanging spans. The steel ball is locked and lifted at this position, proceeding to release the wrecking ball for a free fall and direct impact to the deck slab upper surface. These procedures must be repeated as many times as required.

It is important to note that this procedure only functions for the demolition of the superstructure, having to rely on mechanical means as mentioned in the second proposal (P.55) for the demolition of the substructure.

The waste management procedure would follow that of the second proposal, fragmentating the material and transporting these with mechanical means to a dump truck for extraction.

The environmental impact would be noticeable for this methodology, the impact of the wrecking ball would produce great amount of noise, vibrations and dust, as would also happen in the collapse of the structure against the ground. The palm tree area could be subjected to unexpected hits from flying particles during the process. It is a safe and fast procedure. No operator is near the structure apart from the wrecking ball operator, which is located at a safety distance. In order to know the budget required, it would be necessary to contact a contractor who could supply this information as the characteristics are very specific for each project. The decision from the technical office has been not to proceed with this methodology.

4 CONCLUSION AND RECOMMENDATIONS

There currently exists many innovative materials and methodologies available in the market, this refers to both construction and demolition applications. The advances in construction technology, paired with the lack of space within cities, require the need for fast and efficient demolition methods. The decision-making to define the most appropiate methodology selection relies completely on the human factor, due to this, it is important to understand the criteria applied for a case-to-case scenario.

As the main objective of this thesis, as well as the results seen from the comparison of different criteria studied, it is possible to state in conclusion the following guideline and recommendations:

a) It is important to acquire as much technical information from the structure as possible; heights; element dimensions and locations; materials and span lenghts in the case of bridges. The more information is compiled, the easier the understanding of the structural behaviour would be, allowing for a more efficient and safe approach. A general approach implying the aqcuantaince of the structural behaviour would be the diminishment of elements supposing a dead load without affecting the stability and equilibrium of the structure.
b) The location and surroundings of the structure play a critical role. This is understood as the proximity of nearby structures; the types of structures which could be affected by the works or environmental impact, the affection on services like pipes or lines, and the accessibility and condition of the site itself.
c) Evaluation on the equipment and machinery required, as well as the expertise of the operators according to the complexity of the project. The working equipment and tools´ maintenance must be considered in the budget, preventing failures and risks, which undirectly influences on the time and progress.
d) Constant execution coordination, respecting the time schedules, budget and application of means towards the structural demolition, which ultimately would ensure an efficient demolition process.

As per the guidelines relevant to preliminary stages of a project, to which commissioners and planners are subjected, are the following:

a) Selection criteria arranging the main factors of relevance: Time, environmental impact and budget. Safety should be considered primordial on all projects.
b) Exhaustive and realistic planning of time schedules, budget and safety plans, requiring an acknowledgment of the efficiency rates, unitary costs and capabilities of work in the studied project.
c) Control of the possible environmental impact, in which waste management is included, trying to prevent or mitigate the negative effects of this as much as possible.
d) Feasibility of the works and activities expected, as well as availability of the means required.
e) Total regard to general safety guidelines of construction regulations, which must be respected on all stages of the project as it varies and according to the characteristics of project.

For the case of the practical study discussed in this paper, as a project for public interest, the relevant factor criteria were decided prior to any decision-making, resulting in the following: Safety, time, environmental impact and budget, respectively.

A brief recapitulation on the final decision for each methodology studied is the following:

The first execution procedure, regarding diamond tools and a mobile crane for the main work activities, is considered the cleanest process within the environmental impact study. On the other hand, the time required due to the characteristics of the works could tend to present more problems during the execution. Concerning budget, it is the most expensive methodology. In regards to safety, the procedure contains risks derived from the lack of complete knowledge of the structure, which is considered critical.

The second execution procedure presented is the fastest, safest and cheapest. The negative side of this procedure is the negative environmental impact produced by the works.

The use of explosives would be highly restrictive and dangerous for nearby services and structures, it has been decided to discard this proposal on regards of safety and lack of knowledge to project.

Other methodologies, in the form of a bursting technique and wrecking ball method, have been discarded due to the complexity to estimate and project, being specialized concepts.

Considering the relevancy of the factors within this scope, it has been decided to present as final and most optimal solution according to the criteria selected the second proposal of this case study: Complete structure demolition – Execution Procedure 2.

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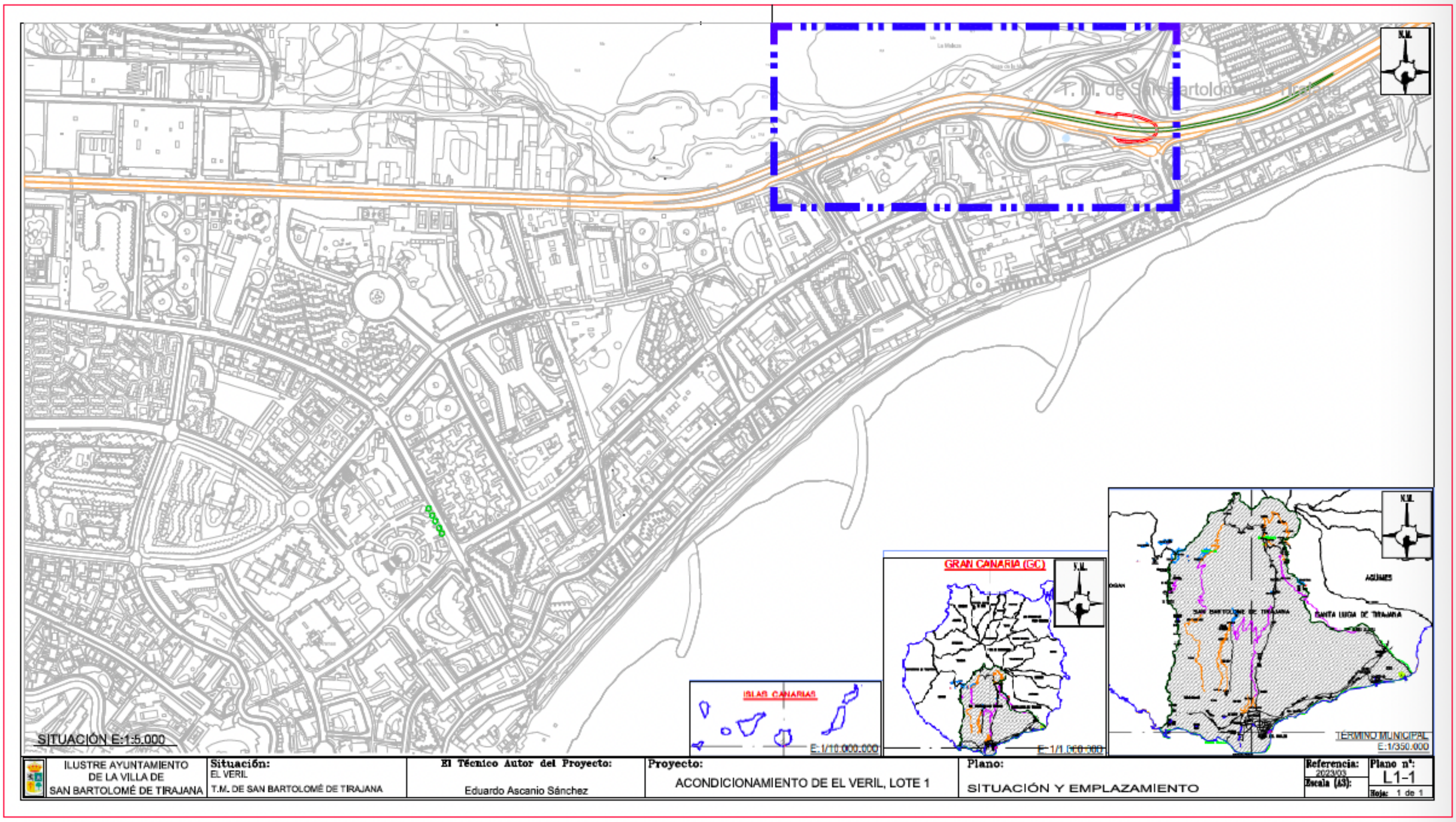
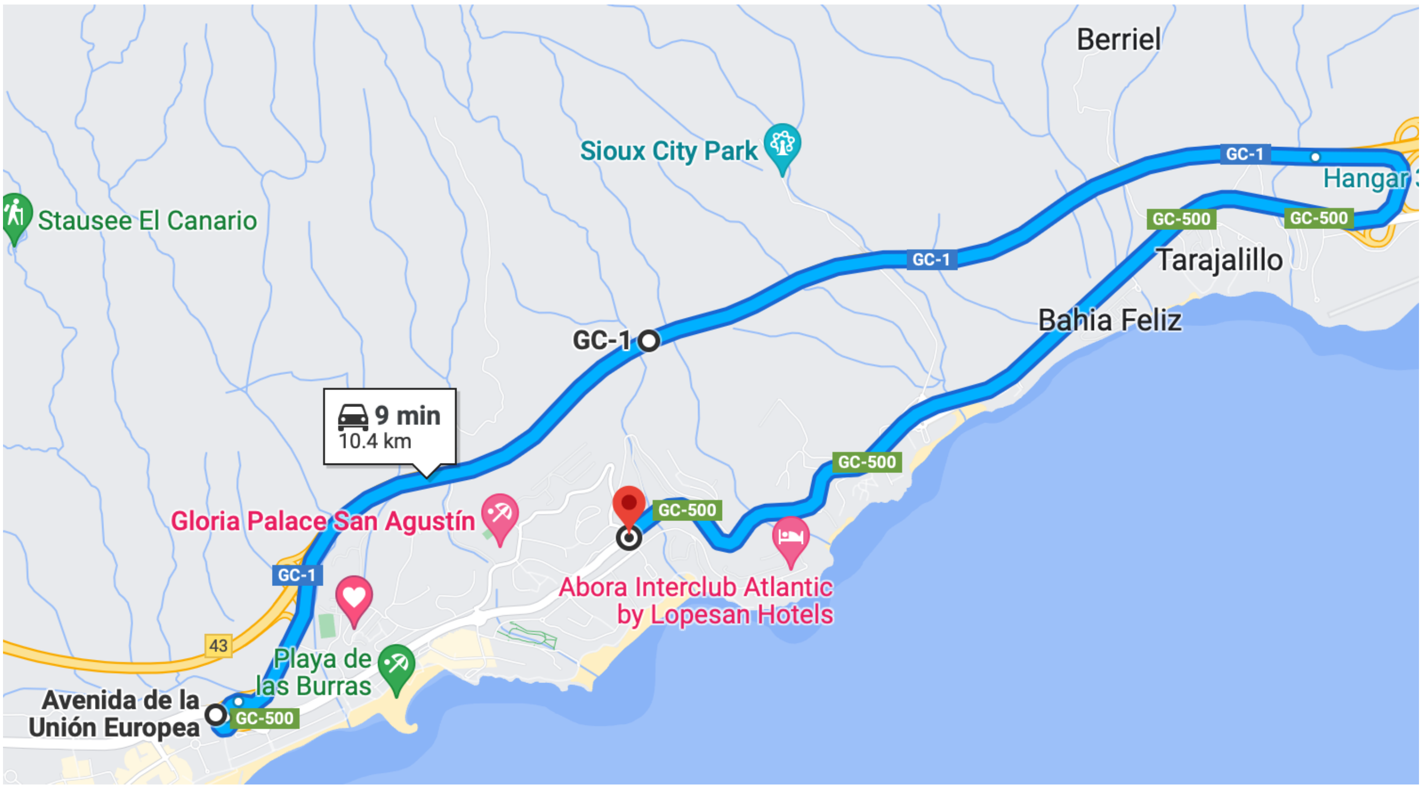
Appendix 1: Location Plan



Appendix 2:


Berriel
Sioux City Park
Stausee El Canario
GC-1
Hangar
GC-500
GC-500
Tarajalillo
GC-1
Bahia Feliz
GC-1
9 min
10.4 km
GC-500
Gloria Palace San Agustín
GC-500
Abora Interclub Atlantic
by Lopesan Hotels
GC-1
43
Playa de
las Burras
Avenida de la
Unión Europea
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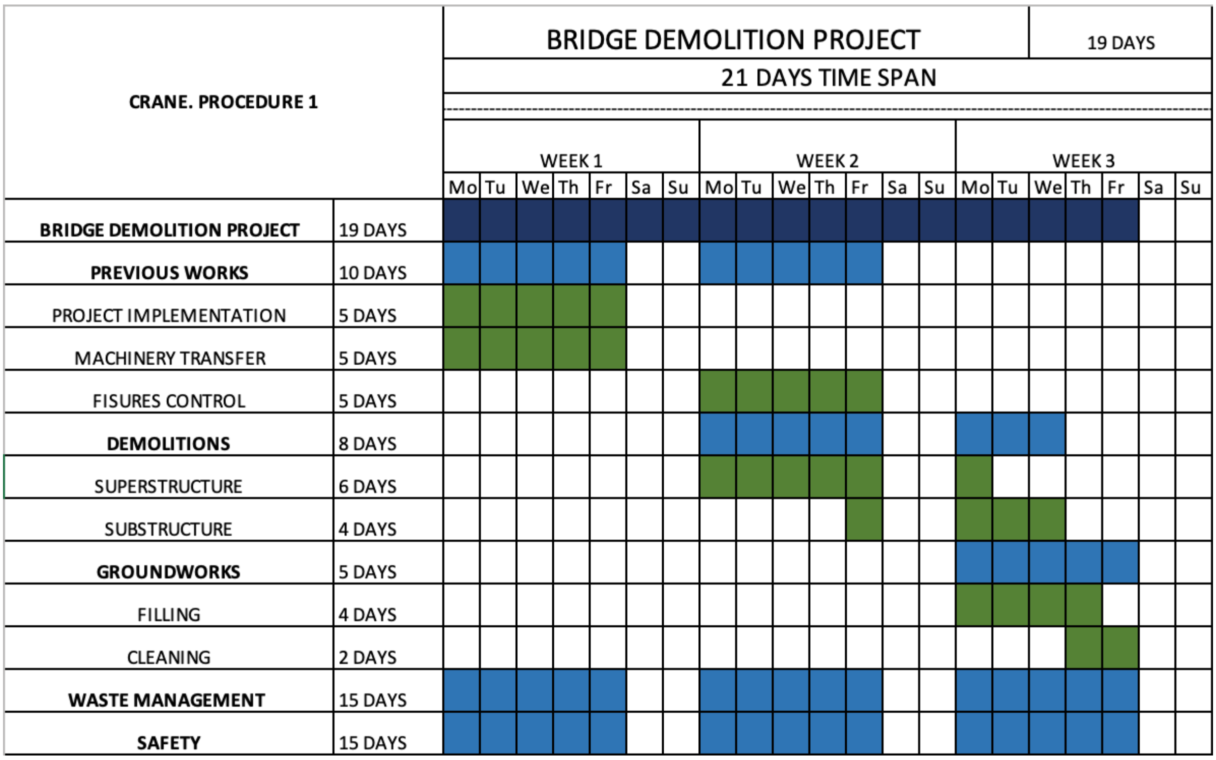
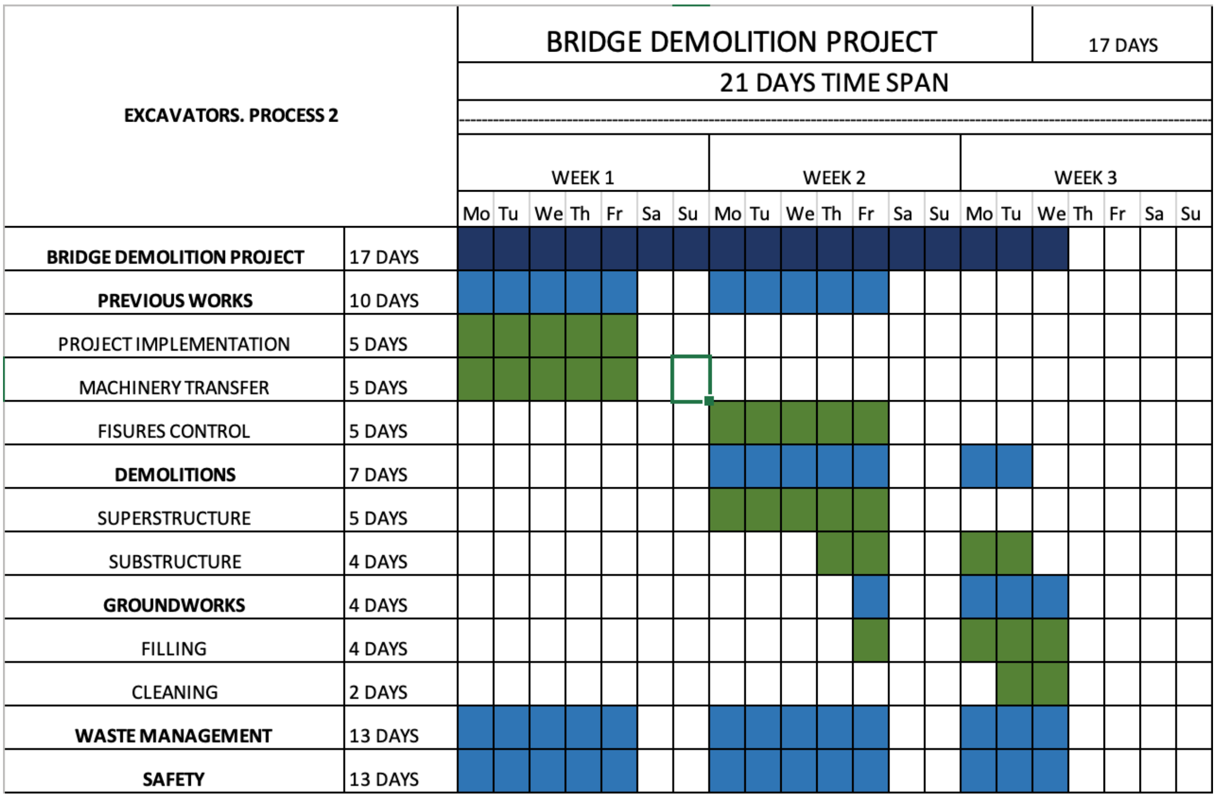
Appendix 3.



DEMOLITION PROJECT: EXECUTION PROCEDURE 1			
MATERIAL EXECUTION BUDGET			
		AMOUNT (€)	
1	PRELIMINARY WORKS..	€	6.000,00
2	DEMOLITION WORKS..	€	149.994,81
3	WASTE MANAGEMENT..	€	42.623,18
4	GROUND CONDITIONING..	€	3.618,65
5	SAFETY..	€	11.000,00
	TOTAL		213.236,64 €
THE MATERIAL EXECUTION BUDGET RISES TO THE TOTAL MENTIONED AMOUNT OF TWO HUNDRED THIRTEEN THOUSAND TWO HUNDRED THIRTY SIX EUROS AND SIXTY-FOUR CENTS.			

Appendix 4.



DEMOLITION PROJECT: EXECUTION PROCEDURE 2			
MATERIAL EXECUTION BUDGET			
			AMOUNT (€)
1	PRELIMINARY WORKS…………………………………………	€	6.000,00
2	DEMOLITION WORKS…………………………………………	€	116.709,55
3	WASTE MANAGEMENT…………………………………………	€	36.027,82
4	GROUND CONDITIONING…………………………………………	€	2.318,65
5	SAFETY…………………………………………	€	14.000,00
		TOTAL	175.056,02 €

THE MATERIAL EXECUTION BUDGET RISES TO THE TOTAL MENTIONED AMOUNT OF A HUNDRED SEVENTY-FIVE THOUSAND FIFTY-SIX EUROS AND TWO CENTS.