1. Introduction

In the current economical and financial difficulties in Portugal and Europe, the construction industry is increasingly demanding, either in economic terms, or in social and environmental terms. It is necessary to invest more in the construction work planning in order to optimize resources and use them more effectively and efficiently. The planning of construction works can and should begin soon in the design stage, so that it could provide conditions to the optimization of financial, human and material resources.

The equipment for construction and in particular for the concrete industry is in constant evolution. Contrary to what may seem, the excess of offer should be taken with caution as it is available a wide range of equipment for the same scope of work, forcing the players in the construction industry to keep up to date in terms of new technologies. Only the constant updating allows to carry out the best equipment selection of equipment.

The concrete is the construction material most widely used in the world, and is very important for the economy. So is crucial to conduct a full and accurate control of processes involving concrete, such as the production, the transportation and the placement of concrete on-site. Controlling these processes necessarily involves controlling the concrete equipment - equipment for production, transportation and placement of concrete on-site. This document presents not only the concrete equipment in the several stages of the concrete cycle, but also presents their characteristics, being a contribution to the definition of selection criteria for concrete equipment associated to each stage.

In this document the concept of transporting concrete focuses on taking concrete from the production site to the construction site. Once the concrete is on-site the concept changes to - placement of concrete.

The use of equipment can lead to accidents. It is therefore important to identify the causes of these accidents to avoid them, so it is necessary to provide training on safety and hygiene at work, and also
in the equipment maintenance, because accidents are often due to the lack of equipment maintenance.

With this document it is intended to bring together diverse information related to concrete equipment, such as, technical questions about the operation, scope of work, advantages, limitations and issues related to maintenance and security, compile and analyze the information in order to contribute to the appropriate selection of concrete equipment for each case.

2. Concrete and concrete equipment

The concrete production, transportation and placement, relies on the use of very specialized equipment. The proper production, transportation and placement of concrete on-site is associated with the proper use of the existing equipment.

The concrete production equipment has an important role, since it allows performing mixtures of concrete constituents in several forms, moreover, allows performing appropriate mixtures regarding the required final properties of concrete.

After the concrete mixture, it presents itself in a state sufficiently homogeneous and plastic, which allows the concrete to be cast in several shapes, textures and for various purposes. The production, transportation and concrete placement on site processes, must comply with the selection criteria of the equipment, depending on the type of concrete and its purpose, as well as other conditions of each construction work activity.

The diversity in terms of production, transportation and concrete placement equipment, is result of technology evolution and the concrete itself. The constant research in the field of building materials, particularly in the area of concrete opens the way to new equipment, with the objective of optimizing production, transportation and concrete placement processes. It is presented the history of concrete in the context of demonstrating the progress made to nowadays and the clear evolution of the equipment and the concrete itself.

The evolution of concrete and concrete equipment brought the necessity to regulate the market regarding the safety in use. In this chapter is presented how concrete and concrete equipment are treated under National and European regulation.

2.1. Concrete

Concrete as we know it today is a relatively new material, consisting essentially of coarse granular material (mixture of aggregates) embedded in a hard matrix of material (binder composed by cement and/or ashes) that fills the space among the granular material and glues them together (other constituents may be added in accordance with the result to be achieved, as adjuvant and etc.). After placement the concrete it hardens and continues to gain strength. However, to obtaining a quality concrete is needed a lot of precaution, including the proper selection concrete constituents, determination of compositions that ensures the strength and durability required, the proper homogenization of the mixture, the proper application, vibration and curing and the use of appropriate equipment.
2.1.1 The evolution of concrete in history

Until the late 19th century construction systems were mostly composed by in wood, masonry and stone. Wood, although plentiful, has durability and combustion issues (many cities have suffered losses of major proportions due to fires). The stone or brick masonry was for a long time the structural system used in the most important construction works. However, to ensure stability and safety of masonry structures was necessary cohesion between stone or brick elements.

Louis Vicat, French engineer graduated from Ecole Polytechnique (1804) and from École des Ponts et Chaussées (1806) is considered the inventor of artificial cement. In 1817 he published the paper - Recherches sur les experimental chaux of construction, les Betons et les Mortiers ordinaires - which showed that by burning a mixture of limestone and clay was obtained a sealer. In 1818 the Academy of Sciences of Paris approved his discovery and authorized its application in the Souil-lac bridge construction (Carvalho, João, 2008).

Currently concrete is a material with a large component of technological progress, is subject of extensive research. There are studies with the aim of improve the performance of concrete to optimize its use. The concrete if properly used, can be used anywhere, under any conditions, for example, in places with extreme temperatures (high or low temperatures), and even underwater.

2.1.2 Legal and normative frame of concrete

Concrete as a building material of the utmost importance and responsibility, due to its properties and fields of application, is subject of national and international regulation in terms of production control and final use.

Decreto Lei 301/2007 of 23 August stipulates the conditions that marketing of hydraulic concrete binders must satisfy, as well as the provisions relating to implementation of concrete structures is defined by national legislation by the same law. The legislation establishes a new regulatory framework for the execution of concrete structures and construction by making mandatory the use of Portuguese standards (NP standards) and European Standards (EN standards), respectively, NP EN 206-1 and ENV 13670-1. Thus, hydraulic binders and steel reinforcement for concrete are subject to inspection and acceptance tests, procedures and rules which are described in Specific National Regulation of NP ENV 13670 - 1.

There are relation between the legislation and standardization relating to the regulation of concrete and its constituents in Portugal (Fig. 1).
The above Law (DL 301/2007) applies two main components: (i) the specification and production of concrete and (ii) the execution of concrete structures.

2.2.1 The evolution of the equipment associated to concrete

The construction sector is increasingly dependent on the use of machines. In the past there were required large amounts of hand labor and equipment for activities where currently are used machines with multidisciplinary capabilities, reducing the number of hand labor at construction works, promoting the effectiveness and efficiency in nowadays construction sector. Many of the great construction works we know today are the result of technological developments in the field of machinery.

Concrete equipment began its evolution along with the concrete itself, with civilization and with the human will to evolve and to challenge himself on building more, better and further. However, the concrete equipment would only become machines during the industrial revolution, which occurred in mid 18th century, expanding from 19th century.

In the mid-century 18th – 19th began the ideas for the first concrete plants and concrete mixers, however those ideas only come to reality in the next century in 1916 by Stephen Stepanian. At the time was used a cylinder to mix the constituents of the concrete. However, drum mixers of great efficiency not appeared until 1920. Presently there are very complete concrete plants, ready to produce large quantities of concrete in a short period of time.
2.2.2 Legal and normative frame of equipment associated to concrete

The machinery industry is an important part of the mechanical industry and construction. The social cost of the high number of accidents caused directly by the use of machinery can be reduced by introducing the concept of safe design in the construction of machinery, as well as a proper installation and maintenance. With the objective of reducing accidents due to the use of machinery and provide healthy competitiveness to the market there was a sound need to regulate the machinery placing on the market.

The Directive 2006/42/EC of May 17 (revised version dating from 1989), known as "Machinery Directive", aims to regulate the placing on the market and putting into service of new machines in the European market and used machinery from third world placed at first time in European countries. This directive being transposed into Portuguese law by the Law 103/2008, of July 24, defines a set of obligations for the manufacturer, giving great importance to implementation of security requirements, the emission of a declaration of conformity and CE Marking.

On the other hand, Directive 89/665/EEC, as amended by 2001/45/EC of 27 June, known as "Work Equipment Directive", specifies the minimum safety and health requirements for the use of work equipment. This change was transposed into Portuguese law the Law 50/2005 of 25 February, with emphasis on the Minimum Required Safety Equipment Work and Rules for the use of Work equipment. In this case the scope is not directed to the manufacturer of the equipment, but to the employer and to the actual conditions of the use of such equipment at work.

The concept of "Work Equipment" is much broader than the concept of "machine" because it implies all and any equipment, machine, apparatus, tool or installation used at work.

The Fig. 2 presents the objectives of the "Machinery Directive " and " Work Equipment Directive ", as well as the responsibilities of the relevant stakeholders in the processes of manufacture or use of machinery and work equipment.

Fig. 2 – Implementation responsibilities of Machinery Directive and Work Equipment Directive.
3. Concrete production equipment

According to specific conditions on the construction work, the needs of the user, the environmental and security conditions or economic factors, the concrete can be produced in the following categories related to location of production:

- Concrete plant in relative distance of the construction work;
- Concrete plant in the construction work;
- Concrete mixers on-site with small and medium dimensions.

There are no significant technical differences in terms of production of concrete, in relative distance of the concrete plant and construction work and the concrete plant at construction work.

The relevant selection criteria for concrete production equipment, which can be divided in two distinct but interrelated levels are:

- Selection criteria regarding the location of concrete production;
- Selection criteria regarding technical aspects of each equipment comparable between each other.

In both cases, the decision is based in the required concrete quantity, concrete quality, concrete type, costs and deadlines.

The aspects related to equipment maintenance and safety of are very important because the concrete production equipment are also working machines with associated costs and dangers, which if not treated could cause injuries.

3.1 Description and characterization of concrete production equipment

3.1.1 Concrete production equipment on concrete plant

The concrete mixers are made of high resistance steel drums or tanks, especially on the inside where is coated with special steel plates. Drums or tanks are available in several dimensions. The dimension of the drum is the factor that determines the capacity of the mixer in quantitative terms. Inside are equipped with mixing paddles or blades on the shaft power transmission placed in arms that rotate around that axis. The power transmission axes can be in vertical or horizontal axis and there may be more than one mixer shaft. The introduction of relative motion with the right intensity and the proper proportion of constituents are used to reach to adequate concrete mixture.

Regarding the concrete production in concrete plant, there are two major categories of concrete mixing, these groups can be used for the classification of concrete mixers:

- Simple production mixers;
- Continuous production mixers.

The simple production mixers have the characteristic of producing one mixture at the time, therefore have to be completely emptied after each mixing cycle (and cleaned if possible) and recharged with
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materials for the next mixing. In terms of production capacity per cycle can reach from 1 m$^3$ to 6 m$^3$. The concrete mixer can be tailor-made for special cases. Within the category of simple production mixers still exists the reversible mixer that can achieve capacities of 9 m$^3$ per cycle. The simple production mixers has always been the most used, they exists in several types depending of the direction and number of rotation axes.

The continuous production mixers as the name implies, are continuously fed with the constituents of concrete at the same rate at which concrete is discharged. They are generally composed by not tilting drums and have blades or paddles rotating axis or axes in case of the mixer be a twin shaft mixer.

The continuous production mixers are used only when large amounts of concrete are required and when the required concrete quality is weaker, is the case of paving or tops of dams.

The main selection criteria to consider in selection of the concrete production equipment in plant are:

- Required concrete volume;
- Required concrete quality;
- Time and costs;
- Mixing speed;
- Level of automation;
- Number and type of mixing paddles (mixing system). Mixing systems are suitable for certain types of concrete, for example, concrete mixers with satellites mixing system are suitable for dry high-strength concrete usually suitable for precast concrete elements.

A good selection of mixing equipment is crucial to the success of the construction work, because it determines the compliance or non-compliance with deadlines, costs and quality of concrete.

3.1.2 Concrete production equipment on-site

The portable concrete mixers can be electricity, petrol or diesel powered, with capacities of mixing drum ranging from 100 liters to 750 liters. The concrete mixers used in the current construction works are, based on the needs of each project, the mixers of 180 liters, 260 liters and 400 liters.

There are many different types of portable concrete mixers ranging in characteristics such as capacity, number of cycles/hour, power supply and mobility. This equipment is characterized by its "portability" - i.e., ease of movement and deployment- this is due to their small size and weight. It can be easily transported from place to place in the same construction work.

The mixers can be classified according to the technical aspects of overall operation, namely:

- Mobility;
- Discharge method;
- Mixing system;
- Power supply.
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Mobility is an important aspect because it is very frequent finding jobsites with limited space and accessibilities. For this reason, the portable concrete mixers are widely used once they are easily deployed and easily moved and handled. In terms of location in the jobsite it is, whenever possible, close to raw material constituents of concrete, and near the discharge locations, since the drums must be loaded before each discharged immediately after mixing. A concrete mixer with great advantages in terms of work mobility is the mini-truck mixer.

The discharge method is also important because it determines the placement of concrete in its final position, and a defective discharge method can lead to loss of properties required for concrete, like the occurrence of concrete segregation.

The mixing system is important because there are concrete with characteristics that are only possible to reach by a specific blending method.

The type of power supply is an aspect that can be important depending on the availability of energy resources on site.

The main technical aspects (selection criteria) for portable concrete mixers are:

- Mobility;
- Mixing capacity;
- Mixing speed;
- Mixing Method;
- Discharge method;
- Concrete Properties

3.2 Maintenance and safety of concrete production equipment

Regular maintenance is essential for the reliability and service life of concrete production equipment. The proper maintenance also helps to eliminate the hazards associated to workplace due to the typical supervision activities of the maintenance processes.

Lack of maintenance or improper maintenance can cause dangerous situations, accidents and health problems. So there is a direct link between maintenance and safety.

This type of equipment has a high mechanical rotation operation. This rotational movement and easy access to input and output local of concrete feeding devices makes it dangerous process. The active maintenance of this equipment is considered of high risk and must be performed safely. Before any maintenance the equipment must be disconnected from any power source.

4. Concrete transportation equipment

The process of transporting concrete is an extremely important and determining step for the success of a construction work. It is necessary to run an effective and efficient transport to ensure that the concrete reaches its final destination in the prescribed conditions, i.e. without losing properties inherent to its fresh state and later its hardened state.
The transportation of concrete shall be done with equipment suitable for the type of concrete, the distance between the place of production and the jobsite, the type of route, the weather and other conditions that could be predicted, such as traffic or times hold due to other deliveries of concrete. The perishable material such as concrete requires careful planning with respect to transportation and placement so the discharging process should not coincide with the arrival of other concrete fillers. The time factor is crucial, it is necessary to be a preparation even in the level of correction of unexpected equipment failures, for example, a flat tire can be sufficient to delay the delivery. Currently there are several fleet management software that aids the fleet management and even the preventive and corrective maintenance.

Given the importance of the transportation process it is also important to define selection criteria, with the objective of adapting the equipment to the construction work and to the type of concrete. The aspects of selection are related to transportation capacities, required concrete quality, time and costs.

4.1 Discription and characterization of concrete transportation equipment

Within the concept of transportation the equipment used for this purpose is the concrete mixer truck. The concrete mixer truck is characterized by being transport equipment and simultaneously a mixing equipment, the mixing process is usually useful to maintain the consistency of concrete.

The concrete mixer truck is a vehicle with a drum/mixing tank mounted on its chassis or on semi-trailer, are generally mounted with hydraulic pump piston with variable displacement and fixed hydraulic motor.

Drums are available with capacities varying from 1 m$^3$ to 12 m$^3$, and its interior is controlled in terms of temperature, humidity, pressure and consistency. The rotation speed of the drum is controlled and is also a very important factor for the mixture control. The mixing drums are fitted with helical blades that are an integral part of the drums and are responsible for mixing the concrete when revolve around one direction and are responsible for unloading and cleaning when turning in the reverse direction. These blades are made of highly resistant steel because they are in permanent contact with the concrete.

The selection criteria for concrete transportation equipment are very important to ensure the success of the construction work, being necessary to consider the transport equipment taking into account the location of the construction work, its size required properties for concrete and deadlines to meet. Thus the selection criteria should include:

- Required quantity and quality of concrete - This criteria is important to determine the capacity of the concrete mixer truck and/or the type and the number of trips required for completion of the concrete placement;

- Use method - this relates hypothesis of hire only concrete mixer trucks or concrete mixers truck for transportation and production or concrete truck mixers with pump system.

4.2 Maintenance and safety of concrete transportation equipment

The maintenance of concrete transportation equipment is critical to the success of the construction work. These equipments are technically complex due to the number of components and parts.
Concrete mixers trucks are expensive, so it is important to do everything to prolong its operational life, and it is one more reason not to overlook a careful and regular maintenance.

Since the time factor is crucial for the timely and correct delivery of concrete, the maintenance will always have an important role. The concrete plants must have specialized personnel in automobile mechanics and electricity to be able to respond promptly to eventual faults.

The nature of this type of equipment in terms of mass and size makes it very dangerous, so special precaution is needed in all operations with it.

5. Concrete placement equipment

The process of concrete placement in the jobsite - concreting - is one of the most important in the concrete cycle because if the requirements and rules are not followed all the work so far can be putted in question even if the concrete has left the production in excellent condition and transportation has been successful. This stage is therefore one of the most demanding in terms of supervision.

It is understood by concrete placement on-site, the unloading of concrete to its final position, compacting and finishing. The finishing of the concrete is done through leveling, grinding and possible application of products in its surface layer.

The main ways of placing concrete in its final position are:

- Discharged by the concrete mixer truck in to its final position;
- Through concrete gutters discharge;
- Discharged by buckets, after reception of concrete mixer truck and crane transportation;
- Pumped using concrete pumps and discharged in its final position by means of piping.

5.1 Description and characterization of concrete placement equipment

The equipment concrete placement equipment most used are:

- concrete pumps and concrete pump trucks;
- Concrete projection equipment;
- Buckets for concrete;
- Gutters for concrete;
- Vibrators for concrete;
- Graders and trowels;
- Cutters, rectifying equipment and core drills.

The formwork is not considered concrete placement equipment but is an important accessory, because it shapes the concrete in its final form and is related to some aspects and care during the concrete placement.

The selection criteria for an effective selection of concrete placement equipment are:

- Required concrete quantity and quality;
- Concrete placement distances(horizontal or vertical);
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- Location and accessibilities of the jobsite;
- Properties of concrete;
- Costs.

5.2 Maintenance and safety of concrete placement equipment

The maintenance and safety of concrete placement equipment is extremely important. Due to the nature of work concrete placement is one of the most dangerous stages for workers. There are equipment moving in all spots of the jobsite.

The main parts subjected to maintenance and safety of concrete placing equipment are:

- Hydraulic parts;
- Electrical parts;
- Pipes.

6. Conclusions

The markets of construction and construction equipment are constantly evolving. The increasing requirements for sustainable constructions make us rethink how we build, with what, when and why.

The concept of construction planning has always existed. However, there are still some gaps in effective planning of some construction activities, particularly in the selection of the most appropriate equipment for each activity related to concrete.

Legislation and standardization of concrete and associated concrete equipment, allows a safer and more accurately the production, transportation and placement of concrete because forces the actors in the concrete industry to meet quality and safety requirements for the activities performed at different stages of the concrete cycle.

There are, for example, several types of concrete mixers, so it is required to select the most appropriate for a given situation. To this end shall be defined and analyzed selection criteria for each group of equipment. The selection criteria are relevant for the following stages of concrete cycle:

- Local production of concrete (on concrete plant or on construction work);
- Mixing stage/production (concrete mixer type, on concrete plant);
- Mixing stage/production (type of mixer, on construction work);
- Transport stage (type transport);
- Concrete placement (type of concrete placement and finishing);

These selection criteria are always associated with the following factors:

- The amount of required concrete;
- The concrete required quality;
- To purchase equipment costs;
- Schedule of construction work.
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The technical parameters for each equipment are linked to the following parameters:

- Capacity and mixing speed;
- Ability to transport;
- Ability to placement of concrete (concrete pumping and handling on site);
- Capacity and quality of concrete finishing.

The equipment for production, transportation and placement of concrete is considered dangerous due to their high component of mechanical operation. So it is important to ensure that the rules and specifications of the manufacturers are followed, especially in terms of maintenance and safety. The maintenance is not only important for prolonging the life of the equipment, it is directly linked to safety in its operation.

The equipment for production, transportation and placement of concrete should be selected according to the particularities of each project, taking into account the characteristics and selection criteria presented.

The factor - costs - is one of the most important. Thus it is considered important to continue the work in this area with more emphasis on exploring the selection criteria - costs. This selection criteria is very important not only to support the selection of appropriate equipment but also to project sustainability and competitiveness to construction sector and construction equipment industry.

Under this proposed future development is suggested to focus on, among others, the following:

- Comparative analysis of costs in concrete production on concrete plant and on site, with a focus on productivity;
- Comparative analysis of costs between different devices to a particular construction work. For example:
  - Use of concrete mixer truck for transportation and stationary pump for pumping and concrete placement;
  - Use of concrete mixer truck with pump and boom, making this equipment the transportation and concrete placing.
- Comparative analysis between the buying and renting of equipment, describing the factors that influence that decision;
- Part of costs for operation and maintenance of equipment in the construction work, since it is this subject that often occurs some unexpected situations in terms of unforeseen costs.
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