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# QUALITY CONTROL MANUAL FOR PRECAST CONSTRUCTIONS

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## Extended Abstract

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# 1. Introduction

Firstly, it is important to define the prefabrication concept. The Standard NP EU (European Norms) 13369:2010 defines a prefabricated element as a concrete product, fresh concrete and cured away from its final use location.

The use of precast concrete structures is occupying nowadays an increasing role in the construction industry, due to its quick manufacturing process, economy and potential quality, which leads to the enormous development of this sector. This progress reflects a growth of competitiveness amongst companies and thus a natural need for differentiation achieved through the improvement and the quality of processes and the final product. In order to succeed in this sector it is necessary to develop a quality control culture in the associated activities putting into practice more ways of minimizing the production of nonconformities (both at structural and aesthetic level) and implementing a certified quality management system in accordance with the International Standardization Organization (ISO) 9001, giving more prestige to the company.

In this research it was intended to call the attention of the precast companies to the benefits related to the application of a quality control program during the prefabrication cycle. It is important to stress the idea that this system will be an investment and not a loss. Often it can be assumed that the implementation of a system like this one will cause delays in normal factory production. However, it will not necessarily be the case. So, an attempt was made at developing a program that is thought to have an easy application without causing significant delays. The objective of this manual was to develop an system to be implement in precast concrete plants, promoting the quality control inspection of the precast products.

The developed system provides an analysis of nine records for quality control (example in attachment) during the prefabrication cycle concerning the pre-fabrication, fabrication and post-fabrication processes, which will be analyzed in a case study with the company *Pavilis Prefabrication, S.A*. (*Pavicentro group*). The definition of these records was thought to have an easy implementation and use in this industry, so that even unskilled workers could use it.

It is important to refer that in Portugal the large precast companies already exhibit quality management certificates. It is therefore clear that some existing procedures lead to a better improvement of their products and services with a high level quality in production conditions.

That’s why it’s important to stress the characterization of the prefabricated sector, regarding the percentage of companies of this industry which have been involved in quality management systems according to the ISO 9001, based on a study of the ANIPB 2008 (Figure 1.1)

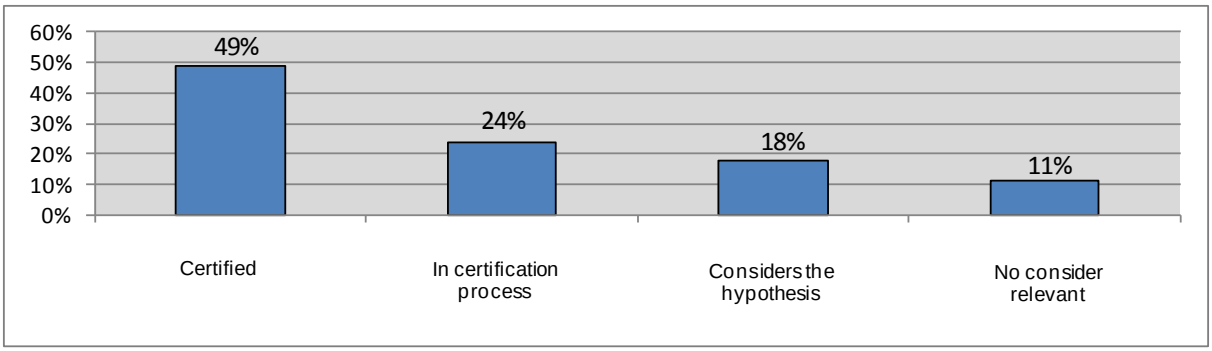


Figure 1.1 – Distribution of the companies according to the ISO 9001 Standard (PIRES, 2009).

Analyzing this chart we can see that “only” 50% of the companies have quality management systems and assuming that this percentage refers to large companies, then the Small and Medium-Sized Enterprises (SMEs) would be the ones which would mostly benefit from this research.

Thus, the main objective of this study is the conception of a Quality Control Manual for precast constructions working as a very useful tool in establishing and implementing a Quality Management System. It is very important to point out that this work fills in for the lack of information in Portugal for this industry concerning the issue of a quality control, already developed internationally, like in U.S., by the *Prestressed Concrete Institute (PCI)* and the *National Precast Concrete Association (NPCA)*.

# 2. Quality control in prefabrication

Stressing the situation previously mentioned, it was noted, with this study, that the current financial and economic crisis has affected many sectors and the construction sector too, so the prefabricated companies need to differentiate themselves by developing the quality, which is reflected in the need of adopting quality programs. On the other hand, a growing number of customers are no longer tolerating low quality products, which means it is even more urgent to guarantee the production of high quality products.

Furthermore, we can define the essential activities divided into three (3) phases, in order to promote more effective controls.

**I. Pre-fabrication phase**

1. Materials (reception, storage and preparation)
2. Concrete manufacturing

**II. Fabrication phase**

1. Concrete and materials handling
2. Elements production
    a. Casting

b. Vibration
c. Curing
d. Stressing
e. Demoulding

3. Handling and internal transport of the elements

4. Finishings

5. Elements storage

6. Final product

**III. Post-fabrication phase**

1. Final transport

2. Erection

The speed of execution of this constructive method is, in general terms, the main argument for its choice, however, thinking that it is possible for these elements to go through a severe quality control in the prefabrication cycle, should be seen as a very strong reason for their preference. A correct quality control application should be performed during all the fabrication phases to ensure that the specified requirements are being met by customers, in addition to ensuring higher rates of productivity and minimizing the fabrication costs and the losses related to waste, making it more competitive in the market.

Nowadays there are several companies that already have quality control systems (Figure 1.1), however this might not be optimized as it is still largely based on the workers' experience. There is also the fact that by mere ignorance certain processes may be disregarded (e.g. storage), thus causing deficiencies in its application which will create a negative impact on the final product.

Apiece from its existence, the control actions must be characterized (showing specific values) and must have a certain position in the prefabrication cycle. It is very important that the relationship between the controls and its consequences (the result of a bad control may explain the reason for any damage produced in the piece) may indentify more easily the real causes for the emerging of nonconformities and boosting the development of recommendations/measures for more accurate control.

Finally, the importance of a written record of the result of several inspections was highlighted, where the identification of the piece should be registered, as well as the fabrication date, the steel and concrete type used and the approval of the inspectors responsible for each production phase. It was recommended that nonconformities must be recorded, as well as the corrective actions

suggested/accomplished. As referred, this control system consists of nine (9) quality control records, distributed by all three defined phases and applied in a study case (AXIS, 1996), (TRIGO, 2000).

It is also relevant to mention that in this study was considered that all equipment is subjected to an inspection plan and regular monitoring, and for this reason they are calibrated.

## 2.1. Materials

It was intended with the definition of this chapter to list the precast concrete building pieces, focusing on the reception, storage and preparation inside the factory. The analyzed materials are listed below:

1. Concrete materials
    a. Cement
    b. Aggregated
    c. Admixtures and additives
    d. Water
2. Prestress and reinforcement rebars
3. Moulds
4. Miscellaneous materials

In these industries, most of the materials are acquired from outside companies. For this reason, there must be a very tight quality control to the materials when they arrive at the plant. A general description of each material was developed, joining the requirements and the properties which have to satisfy its application. Simultaneously, were outlined the care to ensure that their characteristics are maintained.

In this chapter it became clear how important the quality of the materials is to the quality of the final product. Whenever there is a selection of materials with poor properties it naturally results in a production of pieces lacking the required quality; it is essential to check all its characteristics.

As an example, in the Figures 2.1 and 2.2, we can see two situations where there is a proper process of storage.

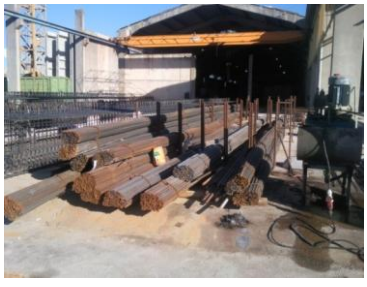

Figure 2.1 – Proper storage of reinforcement rebars.

Figure 2.2 – Proper storage of different aggregated in gravel bails.

## 2.2. Concrete manufacturing

Due to the natural importance of Concrete in this industry we have to omit a chapter on this issue, emphasizing the control in its production and the produced concrete. In general terms, the manufacturing is composed by two (2) phases:

- Concrete dosage;
- Concrete mixture.

It was understood that to the perfect realization of these steps and in order to get a concrete in accordance with the requirements, we would have to take into consideration the materials used. It is necessary to know the characteristics of the referred materials, in order to avoid any discrepancies in its properties.

In general, in these industries the concrete manufacture is made internally in concrete mixing plants, which have high levels of automation (Figure 2.3).

Figure 2.3 – Automation of concrete manufacturing process.

With this type of production, there is an optimization of the concrete quantity required for each element; however, the main advantage is the application of more effective control measures as well as the concrete dosage and mixture (the above mentioned phases).

Generally, with the definition of the concrete program, the quantities of aggregates, water, cement and admixtures/additives are automatically regulated and are placed in mixers. On the other hand, the mixing operation is also oriented automatically defining the mixing time. However, the importance of observing the mixture was emphasized; the worker is responsible for identifying a possible unusual occurrence. Other criteria, which could be verified, are the determination of the W/C ratio (water-cement) and the moisture in the aggregates. The W/C ratio is even considered a key element that needs to be checked in order to obtain high-quality concrete, and it is vital to limit it to reduced values.

Regarding the control of the produced concrete, we were aware that in this industry, this method can be simplified. For each unit produced in its fresh state the concrete consistency (workability) is determined by the Slump Test, while for its hardened-state the test of resistant to compression is made.

Summarizing the development of this issue, the basic factors responsible for obtaining a high-quality concrete are listed below:

- Main materials (cement, aggregated etc.);
- Dosage accuracy (mainly W/C ratio);
- A proper mixing procedure.

It was concluded that it is not difficult to produce a high-quality concrete, because a low quality concrete also results from the mixing and dosing of cement, aggregates and water. The materials and procedures used in the definition of a bad concrete are exactly the same as a good concrete. The difference is, in fact, whether there is an effective quality control program or not.

## 2.3. Manufacturing process of the pieces

This is the most important phase of prefabrication cycle, because its finishing is associated with the physical definition of the piece. All the steps in this process were analyzed in detail and a very tight control was made, so that is done with the least possible number of failures.

The fabrication phase includes several operations, from the transport of the materials and concrete to production lines, up to the storage of the final product. Thus, this process is subdivided into three (3) steps:

1. Materials and concrete handling
2. Manufacturing
    - 2.1. Moulds preparation;
    - 2.2. Preparation and placement of rebars;
    - 2.3. Casting and vibration of concrete;
    - 2.4. Curing;
    - 2.5. Stressing;
    - 2.6. Demoulding of the elements.
3. Handling, finishing, internal transport and storage

It is understood that an efficient production and control will depend on the physical space of the factory, being important to satisfy the following requirements:

- Minimize the distances from the concrete plants to the line of production;
- Provide an adequate working space;

- An adequate storage space for the different materials;
- Determine an area for inspection and repairing of all produced pieces.

A standard layout of the organization of the production cycle in prefabricated units is shown below, to enable a clearer understanding of this process.

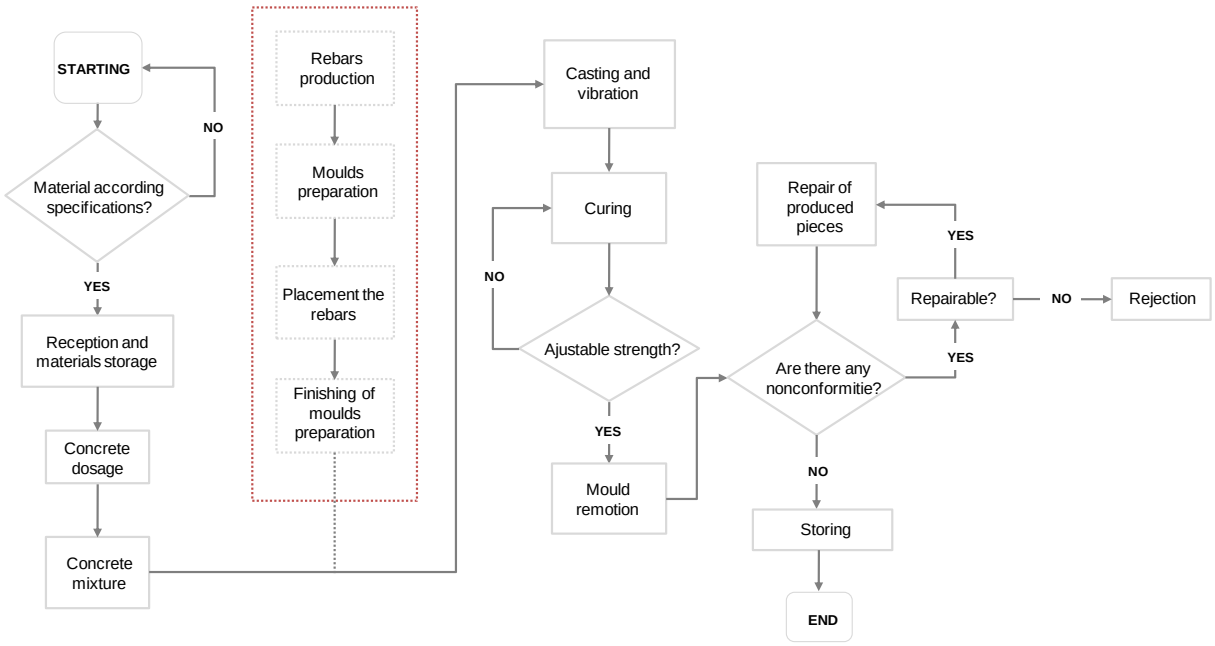


Figure 2.4 – General scheme of prefabrication production in industries (Adapted by MOREIRA, 2009).

The completion of this chapter also allowed the possibility to understand the complexity of this process due to direct influence of some operations, which explains the importance of having adequate facilities and a proper control, in compliance with normative determinations.

In conclusion, this is the phase where there is more human intervention and where consequently more failures may occur, which could influence the final product. In this context, the quality control has to play a very important role in solving any unforeseen circumstances and ensuring a consistent production in terms of quality.

## 2.4. Final transport and erection

One of the main aspects of these two processes is the limitation concerning dimensions and weights of precast elements.

The transport of the pieces is made by road (trucks), the type used in Portugal. It was clear to understand that the design of the pieces had to be limited to their load and dimensions (Figure 2.5):

- Capacity of the means of transport and existing roads (ex: maximum loads allowed on bypasses);

- Access and space available in the construction site;
- Road transport according legislation.

Normally this transport is made by contractors, who are responsible for the delivery of the pieces on the scheduled dates. Consequently, the manufacturing company needs to guarantee the correct preservation of the pieces on the vehicle ensuring that the product reaches the customer in perfect conditions.

Figure 2.5 – Truck transporting a precast beam (Solenha, 2005).

It was stressed that before pieces are authorized to do the final transport of the elements, they should be submitted to a severe inspection at the storage space. In any case, it is recommended that a visual inspection of the pieces be made immediately before loading and after placing them on the delivery vehicles.

Regarding the erection process, it was noted along this section that it is essential to plan in detail, based on the guarantee that the following conditions are observed:

- Compliance with the erection sequence defined in the project;
- Optimized location of lifting equipment;
- Fixing place conditions of lifting equipment;
- Maximum permissive deviations;
- Avoidance of collisions and rough movements of the pieces.

Besides the movement and placement of the pieces, this step will ensure its adequate storage, whenever deemed necessary.

It is obvious that proper transport of precast elements is associated with numerous benefits, being important that all the existing conditions are checked, so that the product can reach the customer at the established time and without anomalies. Erection, the last phase of the prefabrication cycle, should follow a standardized and controlled process to optimize the natural advantages of this solution and minimize the possibility of rejection of the piece, which will be harmful for the manufacturing company.

Therefore, carrying out this process effectively depends on the existence of an implemented and organized plan ensuring a rigorous, fast and safe operation (Figure, 2.6).

a)

b)

c)

Figure 2.6 – Erection of precast beams ( a) e b) – VIEGAS & SARAIVA, 2010), ( c) – Solenha, 2005).

# 3. Case Study

The main aim of establishing this case study is related with the need for awareness of the applicability of the “Quality Control records” and checking if the measures defined are being taken.

In this context were analyzed several operations of processes of production, transport and erection of a T-beam for the construction of an overpass of the Public Works, in the highway of Baixo Alentejo, in charge of a contractor SPER, a consortium formed by Edifer, Dragados, Iridium, Tecnovia and Conduril. It should be noted that due to some repeated delays of the work, it was not possible to be present at the processes of transport and erection of the beam. Therefore the engineer of the *Pavicentro group*, responsible for these two (2) processes, was in contact and a simulation of the application of respective records of quality control took place.

The records are as follows:

1. Quality control record for materials.
2. Quality control record for concrete production.
3. Quality control record for produced concrete.
4. Quality control record for fabrication process.
5. Quality control record for handling and transport in local site.
6. Quality control record for final product.

7. Quality control record for storage of the pieces.
8. Quality control record for final transport of the pieces.

The results obtained were generally quite positive, since the verification of most criteria was accomplished. It was the expected result, because *Pavilis Prefabrication, S.A.*, was one of the first companies in this sector to complete the Quality Certificate for its system, bearing the quality certification and CE marking of products, which indicate the existence of procedures that lead to the improvement of their processes, providing conditions of production with a high level of quality.

Some examples of quality control are presented in Figure 3.1, 3.2, 3.3 and 3.4, listed below, in accordance with the elaborated records, namely, number 4 and 6.

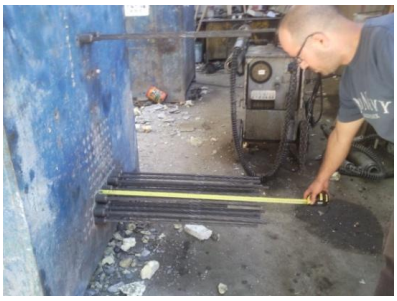

Figure. 3.1 – Values control of elongation suffered from strands.

Figure. 3.2 – Lining control of strands.

Figure. 3.3 – Piece before application of the aesthetic treatment (honeycombed).

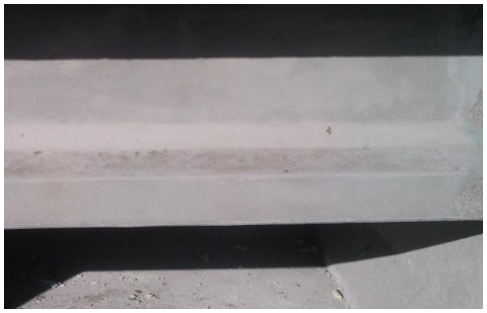

Figure. 3.4 – Piece after application of the aesthetic treatment.

Even so and in analogy with the elaborated records, some control errors were found, though logically analyzed.

# 4. Conclusion

The main objective of this study was to develop a quality control manual applicable to precast constructions, accomplished with the quality control records. Thus, it would be important to study the principles of this sector and understand and develop quality control measures to be applied on plants.

Several visits to *Pavilis Prefabrication, S.A*. were made, so that this research could be the closest possible to the prefabrication sector in Portugal, as well as a case study of a T-beam (manufactured at this company) to be used in the construction of an overpass.

In order to get a better application of the quality control system, the prefabrication cycle was divided into three (3) phases: pre-fabrication, fabrication and post-fabrication.

During the pre-fabrication phase it was analyzed the need to ensure the use of materials that meet certain requirements, a pre-requisite for defining pieces of the desired quality. A chapter was reserved for the control of concrete manufacturing, because of its relevance in these elements. It was concluded that the production of a high quality concrete depends largely on the establishment of a monitoring and a scheduled plan in the process, namely in the mixing and dosing processes. It is important to note that this step already has an intrinsic control, since it is generally oriented in an almost totally automated way.

Following the prefabrication cycle, the controls to be used in some operations at the fabrication phase were carefully analyzed. This phase is characterized by a greater propensity to the occurrence of some failures at the multiple operations, as a high human involvement is verified and longer and more complex activities take place in the factory.

Analyzing the last phase – post-fabrication – the processes of the final transport and erection are examined. A successful completion of the last phase is pieceicularly important, due to the fact that at this time any damage to the pieces may determine its rejection, causing a high economic loss to the manufacturer. These processes must be subject to a rigorous organization plan, so as to respect both schedule and quality.

After completing the description of the three stages of prefabrication cycle, a case study was developed, observing the applicability of the proposed system with the use of the quality control records. In this case study all the prefabrication cycle related to a prestressed T-beam, component of an overpass, was analyzed. Its development allowed the observation of a high applicability of the implemented program, thus providing one of its goals for this dissertation. The quality control records are easily applicable, which is a great advantage of this system that can be easily and quickly implemented. Another relevant aspect is the possibility of checking most of the proposed criteria in a company that had the certified quality management system, some years ago, based on the ISO 9001, which goes to show the good adaptation of this manual to the reality of the prefabrication sector in Portugal.

It was also considered in this study that all the equipment, included in the three different phases, should be subjected to an inspection plan and regular monitoring, and therefore being calibrated. In this second phase of conclusions, the usefulness of this study is analyzed. Beginning with the main aim of this dissertation, it is understood that the companies, which do not implement the quality management systems, will benefit most from this study. The scope of this dissertation is the

companies that do not have a quality control system and consequently, a quality management system. In Portugal, in general, SMEs will be the ones that fall into this category, since of course the large companies already had implemented quality management systems, certification based on ISO 9001.

The advantages of applying this control program are easy to manage with an application that is thought to be simplified and be an essential tool in implementing a quality management system and consequently obtaining the quality certification of the company. It should be noted that the idea of this quality control program increases the prestige of the company, being seen as reliable, competitive and synonymous with quality.

The contact with the prefabrication sector led to the realization that in the current situation, the modernization and the development of this sector is no longer a trend but a reality and a necessity. It is perceived that actions which lead to the reduction of costs, increase in productivity and quality improvement in the production, transport and erection processes, and consequently in the precast final product, depend on a continuous evolution and improvement of different activities constituents of processes. Therefore quality control cannot be accepted as a cost but as an investment.

In summary, to evolve in order to improve as an industry is a way to follow in the construction sector, where the concepts of organization, planning, repeatability and efficiency of processes, are essential for its evolution. The use of prefabrication brings these concepts together. Its production in environments governed by the quality control of all its processes distinguishes these elements from the traditional construction.

In conclusion, it is stressed that precast solution should be seen as a reliable alternative for efficient planned and organized development of high quality constructions.

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# 6. Attachments

Example of a quality control record.

| | | |
|---|---|---|
| A.Cunha | **DESIGN OF PRECAST CONCRETE ELEMENTS**<br>**7.** QUALITY CONTROL RECORD OF STORAGE | Piece: _____<br>Date: ____ / ____ / _____ |

Country / District: _____ Ref. Drawing / Part: _____

Ref. Work / Customer: _____

| **Approval criteria** | **YES** | **NO** | **REMARKS** |
|---|---|---|---|
| State of storage local (firm, clean, etc.). | ☐ | ☐ | Prompt correction. |
| Putting the pieces out of contact with the ground. | ☐ | ☐ | Prompt correction and check possible anomalies. |
| Checking the stability of parts. | ☐ | ☐ | Prompt correction and check possible anomalies. |
| Protection of the corners of the parts. | ☐ | ☐ | Prompt correction and check possible anomalies. |

APPROVAL ☐ YES ☐ NO

Reason (s) to the disapproval: _____

Responsible: _____
(Signature)