The influence of construction and service stages on the internal forces of prestressed precast beams

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Abstract. The accurate design of prestressed precast beams is correlated with the proper evaluation of construction and service stages. On usually are considered the following construction stages: casting, transfer of prestressing, storage time, transport and mounting stage. In the presented paper, it will be illustrated the stress development on the beams by altering the specific times between different construction and service stages as a result of using different construction technologies as well as a consequence by imposing in advance different requirements during the design phase. To highlight these particularities IDEA StatiCA software was used, and a comparison between various cases is presented.

1. Introduction
Proper design of prestressed prefabricated beams represents a difficult task, the number of parameters involved in design being correlated even with the construction stages. A construction stage represents a point, period, or step in a process of development. The shallow evaluation of the construction stages may lead to a non-conforming element, materialized through degradation, failure or irrational use of materials.
Evaluation of construction and service stages plays a significant role in the efficient design of prestressed prefabricated beams due to the fact that external forces that act on to the element vary according to them. The main construction and service stages that must be taken in consideration when designing prestressed prefabricated concrete beams are: casting (casting of fresh concrete of design member), transfer of prestressing, storage yard, transport, final support, superimposed dead load and end of design working life.
There are currently no studies that address this topic. By performing this study it is desirable to highlight the differences that are occurring when different times intervals are imposed as a result of using different construction technologies as well as a consequence by compelling in advance different requirements during the design phase. The purpose of this study is to establish if a significant differences occurs regarding the development of internal forces, and in which manner these differences influence the design of the prestressed precast beams. Another aspect of this topic is to determine if general rules regarding stress development can be established.

2. Experimental phase
To illustrate the difference occurring when design prestressed prefabricated concrete beams a study was carried out on a number of 12 beams. The IDEA StatiCA software was used to accomplish the simulations.
Given that the design of prestressed prefabricated concrete beams is a meticulous task it was necessary for a number of conventions to be made. By imposing a certain number of parameters to be fixed, it can be focused only on the principal parameters that are correlated with the stages of the construction, in this case, the imposed duration between them.
In Section 2.1. are detailed the fixed parameters and in Section 2.2. are detailed the variable parameters.

2.1. Fixed parameters
From this category the following parameters are fixed:
• beams length: 25.5 m;
• the static scheme, sections as is shown in figure 1, figure 2 and figure 3;
• concrete strength class (according to Eurocode 2): C50/60;
• the concrete curing was considered naturally (not the case of heat curing);
• strands used: Y1860S7-15.2;
• strands layout (a total of 16 strands as it is shown in figure 2 and figure 3);
• debonded strands (as shown in figure 2 and figure 3), debonded length (3.00 m);
• initial stress in strands: 1100.0 MPa;
• passive reinforcement: steel grade (B500C), the layout of passive reinforcement;
• load cases (self-weight, permanent load: 9.1 kN/m, variable load: 15.4 kN/m, load per construction stage G 5: 1.0 kN/m).

Figure 1. Static scheme

Figure 2. Section 1 as is shown in figure 1 (mm) and strands layout

Figure 3. Section 2 as is shown in figure 1 (mm) and strands layout
2.2. Variable parameters

As it was stated before, a study was carried out on a number of 12 beams, the time between the construction stages being altered as a result of using different construction technologies as well as a consequence by imposing in advance different requirements during the design phase.

To better understand how the time interval was considered, there are shown in the following:

**Table 1. Construction and service stages for considerate beams**

| Beam     | ST(1) | T1   | ST(2) | ST(3) | ST(4) | ST(5) | ST(6) | ST(7) |
|----------|-------|------|-------|-------|-------|-------|-------|-------|
| G 1.1.1  | 0     | 25   | 1.92  | 2     | 29    | 30    | 60    | 36500 |
| G 1.1.2  | 0     | 25   | 1.92  | 2     | 59    | 60    | 120   | 36500 |
| G 1.2.1  | 0     | 30   | 2.9   | 3     | 29    | 30    | 60    | 36500 |
| G 1.2.2  | 0     | 30   | 2.9   | 3     | 59    | 60    | 120   | 36500 |
| G 1.3.1  | 0     | 35   | 4.5   | 4.6   | 29    | 30    | 60    | 36500 |
| G 1.3.2  | 0     | 35   | 4.5   | 4.6   | 59    | 60    | 120   | 36500 |
| G 1.4.1  | 0     | 40   | 7.4   | 7.5   | 29    | 30    | 60    | 36500 |
| G 1.4.2  | 0     | 40   | 7.4   | 7.5   | 59    | 60    | 120   | 36500 |
| G 1.5.1  | 0     | 45   | 13.3  | 13.4  | 29    | 30    | 60    | 36500 |
| G 1.5.2  | 0     | 45   | 13.3  | 13.4  | 59    | 60    | 120   | 36500 |
| G 1.6.1  | 0     | 50   | 28    | 28.1  | 29    | 30    | 60    | 36500 |
| G 1.6.2  | 0     | 50   | 28    | 28.1  | 59    | 60    | 120   | 36500 |

where:
- ST(1) – casting (days);
- T1 – concrete resistance at the moment of stress transfer (MPa);
- ST(2) – transfer of prestressing (days);
- ST(3) – storage yard (days);
- ST(4) – transport (days);
- ST(5) – final support (days);
- ST(6) – superimposed dead load (days);
- ST(7) – end of design working life (days);

The structural response is presented schematically in figures 4–15, depending on time for each beam considered in the simulation.

From them it can be noticed:
- the effects of permanent load applied in construction stage “i”;
- the rheological effects between construction stages “i-1” and “i”;
- and the effects of prestressing applied in construction stage “i”.

From the schematic representation, it can be noticed when the external forces act on the beams according to each construction stage and how the sum of forces contributes to the overall design of members. According to figures 4–15 it can be noticed that certain types of loads specific to a specific construction stage are rheological. The prestressed members are analyzed considering all the phenomena that are occurring in the design working life (concrete shrinkage, stress losses, etc.).
Figure 4. Constructions stages for beam G 1.1.1

Figure 5. Constructions stages for beam G 1.1.2

Figure 6. Constructions stages for beam G 1.2.1
Figure 7. Constructions stages for beam G 1.2.2

Figure 8. Constructions stages for beam G 1.3.1

Figure 9. Constructions stages for beam G 1.3.2
Figure 10. Constructions stages for beam G 1.4.1

Figure 11. Constructions stages for beam G 1.4.2

Figure 12. Constructions stages for beam G 1.5.1
Figure 13. Constructions stages for beam G 1.5.2

Figure 14. Constructions stages for beam G 1.6.1

Figure 15. Constructions stages for beam G 1.6.2
2.3. Results
Due to the high volume of simulations, the results are presented graphically. To simplify the presentation of the results only the eloquent comparisons are part of this paper.

In the current section are presented the following:
- the development of axial force according to construction stages in characteristics sections;
- the development of bending moment according to construction stages in characteristic sections;
- shear force, stress limitation, crack width and deflection ratio.

Not all 12 analysed beams fulfil the requirements of EUROCODE 2.
For a proper understanding of the characteristic section consider, they are detailed below:

In the case of the axial forces, 3 characteristic sections were considered:
- section 1 (coordinates: 0.00 m);
- section 2 (coordinates: 2.75 m);
- section 3 (coordinates: 12.75 m).

![Figure 16. Axial force (envelope) for beam G 1.1.1](image)

![Figure 17. Axial force (envelope) for beam G 1.6.1](image)

In the case of the shear force, there were no significant differences between the simulated beams, resulting that the shear force is not influence by the construction stages.

![Figure 18. Shear force (envelope) for beam G 1.1.1](image)
Figure 19. Shear force (envelope) for beam G 1.6.1

In the case of the bending moment 3 characteristic sections were considered:
- section 1 (coordinates: around 0.50 m);
- section 2 (coordinates: around 2.75m or 3.50 m depending on the highest values of the bending moment);
- section 3 (coordinates: 12.75 m).

Figure 20. Bending moment (envelope) for beam G 1.1.1

Figure 21. Bending moment (envelope) for beam G 1.6.1

Note: To simplify the presentation of the results the next conventions were made:
- internal forces developed in construction stage ST(1) are not represented;
- internal forces developed in construction stage ST(2) are presented in position 1;
- internal forces developed in construction stage ST(3) are presented in position 2;
- internal forces developed in construction stage ST(4) are presented in position 3;
- internal forces developed in construction stage ST(5) are presented in position 4;
internal forces developed in construction stage ST(6) are presented in position 5;
internal forces developed in construction stage ST(7) are presented in position 6.

Figure 22. Axial force development in characteristic section 1

In figure 21 were detailed the axial force development in characteristic section 1 (coordinates: 0.00 m) depending on the concrete strength at the moment of stress transfer and the interval between construction stages. The maximum axial force is obtained in beams G 1.6.1 and G 1.6.2 where the stress transfer was realized at 28 days (concrete reached the strength of 50 MPa). The minimum axial force is obtained in beams G 1.1.1 and G 1.1.2, where the transfer was realized at 1,92 days (concrete reached the strength of 25 MPa).

The axial force is decreasing from the moment of stress transfer to the end of design working life (as it can be noticed in figure 21) due to the effects of the applied loads and rheological effects. Related to the construction stages: transport, final support and superimposed dead load, it can be noticed that axial forces present in the element are slightly higher when the time between them is smaller. At the end of design working life, the axial forces have rough same values, the difference mentioned before not having a significant role for this case (section 1).
In figure 23 were detailed the axial force development in characteristic section 2 (coordinates: 2.75 m) depending on the concrete strength at the moment of stress transfer and the interval between construction stages. It can be noticed that in the case of the beams with higher time interval between constructions stages the values of axial forces tends to be the same for certain stages: for example in the case of beam G 1.1.2 the value of axial force in the construction stage transport is the same as the value obtained in the construction stage final support. In the case of the beams with a shorter time interval between construction stages, this particularity cannot be noticed: for example in the case of beam G 1.1.1 the value of axial force in the construction stage transport is higher than the value obtained in the construction stage final support. It can not state that this is a particularity resulted from shortening the time intervals between construction stages, a higher number of simulations being necessary to be carried out.

Also, the values of axial forces obtained in the case of beams with shorter intervals between constructions stages (for section 2) are higher than the values of axial forces obtained in the case of
beams with longer intervals between construction stages except for the construction stage *end of design working life*, as illustrated in figure 23.

![Axial force development in characteristic section 3](image)

**Figure 24.** Axial force development in characteristic section 3

In figure 24 were detailed the axial force development in characteristic section 3 (coordinates: 12.75 m) depending on the concrete resistance at the moment of stress transfer and the interval between construction stages. It can be noticed that similar behaviours are taking place as in the previous cases (section 1 and section 2). The highest value of the axial forces at the end of design working life is obtained in beam G 1.6.1. A particularity for this section consist of that axial force does not decrease linear as the construction stages are taking place, an increased being noticed for construction stages *final support* and *end of design working life*.

Some inconsistencies referring at the previous statement identified for beams G 1.6.1 and G 1.6.2. Further simulations must be carried out.
In figure 25 were detailed the bending moment development in characteristic section 1 (coordinates: around 0.50 m) depending on the concrete resistance at the moment of stress transfer and the interval between construction stages. The highest values are obtained for the beam G 1.6.1 and the smallest for the beam G 1.1.2. For all the beams can be noticed that bending moment does not decrease linearly as the construction stages are taking place, an increased being noticed for construction stage final support.

A higher bending moment is obtained in the case of beams with shorter intervals between constructions stages (for section 1) than in the case of beams longer intervals between them.

**Figure 25.** Bending moment development in characteristic section 1
In figure 26 were detailed the bending moment development in characteristic section 2 (coordinates: around 2.75m or 3.50 m depending on the highest values of the bending moment) depending on the concrete resistance at the moment of stress transfer and the interval between construction stages. The highest values are obtained for the beam G 1.6.1 and the smallest for the beam G 1.1.2. Specific for this section is the that in the construction stage superimposed dead loads the highest moments develop is located at the bottom fibre of the beams or at the top fibre of the beam as the case may be as is shown in figure 25.

In figure 27 were detailed the bending moment development in characteristic section 3 (coordinates: 12.75 m) depending on the concrete strength at the moment of stress transfer and the interval between construction stages. The highest values are obtained for the beam G 1.1.1 and the smallest for the beam G 1.6.1 for the construction stage end of design working life. From figure 26, we can not determine a general rule that applies to all simulated beams.
In figure 28 were detailed the ratio resulted from shear force (external loads) and the maximum shear force capable. For the beams G 1.6.1 and G 1.6.2 were obtained the smallest values while for beams G 1.1.1 and G 1.1.2 were obtained the highest values. The influence of constructions stages (*storage yard, transport, final support, superimposed dead load and end of design working life*) do not seem to have a significant influence on this ratio.

Figure 29 describes the ratio resulted from maximum allowed stress and the maximum capable stress. For beams G 1.1.1 and G 1.1.2 the ratio is higher than 100%, meaning that the elements do not satisfy the criteria of EUROCODE 2. These simulations were carried out on purpose to highlight this aspect. Also in the case of the beams G 1.2.1 and G 1.2.2 similar results were obtain ed with the ratio being close to 100%. The smallest ratio is obtained in the case of the beam G 1.5.2, meaning that the construction stages plays a significant role. This value was obtained when the stress transfer was done when the concrete reached a value of 45 MPa (at 13,3 days). A general rule cannot be established, further investigations were necessary to be carried out.
In figure 30 were detailed the ratio resulted from crack width (existing on the beams) and the maximum accepted crack width. The highest ratio was obtained in the case of the beam G 1.1.2, meaning that construction stages play a significant role, although the maximum crack width was not reached. In the case of beam G 1.6.2 are not presented any cracks on the members.
Figure 3 describes the ratio resulted from the existing deflection and the maximum deflection accepted. Due to the fact that the values are closer, a general rule cannot be established.

3. Conclusions

After interpreting the previous results we can state the following:

While designing a prestressed prefabricated concrete member (beam) it is necessary to evaluate all the influences resulted from construction and services stages. Inadequate evaluation of these stages may lead to a faulty design. The service and construction stages (which are those and the time interval between them) are dictated by the imposing demanding. Reported to the current demanding, it is necessary that the stress transfer has to be made in a one or two days after casting in place. This procedure is not feasible due to the technological time required for the concrete to have a minimum strength unless are used special methods to speed up the curing of concrete. Such methods are very expensive involving special treatment of concrete by using special technologies (for example heated formwork). By using such methods, the member (beam) is subjected to more stress losses, resulting in elements with lower capabilities than in case of the elements who are subjected to stress transfer at an age of curing of 28 days.

The influence of construction and service stages are detailed graphically and tabular in Section 2. General rules cannot be formulated due to the complex processes that takes place. From previous results, it can be noticed that the stress transfer can be realized to an early age of curing and the beam still having similar performance with beams who had the stress transfer at the age of concrete curing of 28 days. In certain situation using special technologies with the purpose of reaching the highest concrete strength in the shortest time may lead to an element with weaker performances but manufactured in a shorter time. To clarify this aspect is necessary to conduct a technical-economic analysis.

The time between construction stages plays a significant role due to the rheological effects that are involved in the exploitation of a prestressed prefabricated concrete beam. Due to the complex process of design, it was not possible to identify a pattern.

4. References

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