INTRODUCTION

The approach bridge whose construction is a continuous prestressed box girder is part of the Suramadu bridge as a link between the cause-way and the cable bridge (main span), and consists of two parts, namely the Surabaya side and the Madura side, each of which has the same geometric (symmetric). In the sequence of implementation, the Surabaya side is slightly different from the Madura side, where the Madura side still refers to the initial design, while the Surabaya side changes slightly with the aim of speeding up the implementation time. In principle, this change does not affect the strength, durability and safety of the construction, only limited to the issue of implementation time. The two approach bridges (Surabaya and Madura sides) consist of 2 parts, the first is a continuous box girder with a side span of 2 x 40.00 and a middle span of 7 x 80.00m, the second is a V-pier with a span of 32.00 m. The balanced cantilever construction method is applied to eliminate these difficulties. To shorten the implementation time on the Surabaya side approach, that is by rearranging the sequences in such a way that there are several closures that are done simultaneously without reducing the strength of the structure specified in the initial design. As for the Surabaya side, there are changes for both the West and East sides, theoretically this change will save about 10 days, which is the length of time it takes to complete 1 closure. The final optimization of the Suramadu Approach bridge is with a span of 80 m between piers with a longitudinal slope of 4%, with a single cell box girder shape that will speed up execution and reduce the quantity of work and has a hollow shaped pillar. There are several closures carried out simultaneously on the approach bridge on the Surabaya side. This is done to speed up the implementation, considering that the Surabaya side is already behind the schedule.

Keywords: box girder balance cantilever, construction schedule, implementation time, Suramadu bridge

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CONSTRUCTION METHODS

A. Balanced Cantilever

The two approach bridges (Surabaya and Madura sides) consist of 2 parts, the first is a continuous box girder with a side span of 2 x 40.00 and a middle span of 7 x 80.00m, the second is a V-pier with a span of 32.00 m. The implementation method applied for continuous girder is a balance cantilever with a cast-in-place system for each segment (figure.1), while the V-pier section is carried out by installing scaffolding and is an integral part of the V-pillar.

The balanced cantilever method was developed to minimize the scaffolding required for in-situ casting. Temporary shoring is too expensive, especially in the case of high elevation bridges and the use of scaffolding that
crosses rivers is very risky, so that on congested waterways, road traffic or railroads, the use of scaffolding is no longer economical. The balanced cantilever construction method is applied to eliminate these difficulties.

The segmental cast in place method is an implementation method that still uses the segmental construction method and the balanced cantilever but each segment is cast in-situ. The traveler formwork depending on the previous segment is used to form the segment. After the segment is cast, after the concrete is 4 days old, stressing is applied to hold the segment in place. The traveler formwork or simply traveler is then pushed forward to the next segment and the same process is repeated until the mid-span from the other pier direction, forming a cantilevered structure.

Figure 2 illustrates an implementation of a box girder bridge using the balanced cantilever method using a traveler. To facilitate cantilevering, a short cross-section slab with counterweights on the other side is cast into the formwork which is supported from the ground of each pier. A temporary bond is prepared to balance the other side to ensure an equilibrium. Ensure counterweight control in each sequence of cantilever execution.

There are many variations of the method described above. In the case of low elevation bridges it may be more economical to cast the ends of the span over the scaffolding. When the bridge floor joins the monolith with the pillars, the ties or struts on the counterweights can be
removed. The formwork for casting the cantilever is held by the gantry traveler. The gantry is propelled forward by rails attached to the finished bridge floor to the next segment. When the gantry is in the right place, a new segment is formed, cast and stressed on the previously completed segment. And the same process is repeated until the mid-span from the other pier direction, forming a cantilever structure.

The order of the cantilever construction methods is as follows:

a. Install and set up gantry
b. Install and place formwork according to proper elevation
c. Place the ribs and duck channel of the tendon
d. Segment casting
e. Install the pulling tendon and do stressing
f. Remove the formwork
g. Advance the gantry to the next position and start a new cycle.

For existing projects in Indonesia, modular formwork systems are among the most popular. This system is flexible for different cross sections and different casting lengths. In this traveler there is a lightweight mechanical and hydraulic system so that it does not complicate the assembly of the crane so that it can achieve the desired cycle time.

Stressing steps:

a. Tendons are inserted into the prepared tubing of the sleeve into the concrete.
b. The tendon is pulled using jacks at both ends where for the longitudinal direction of the anchor used both live anchors. Shortly after pulling the tendon, there has been a loss of prestressing force in the form of:
c. Elastic shortening, stress loss due to friction, and some dead load moments are already acting as a result of the bending position of the tendon. Thus, the jacking force must take into account matters concerning the stress loss. The limiting allowable stresses at the transfer and service stages are taken in the same way as those given for the pre-draw mode.
d. When bonded tendons are used, especially for corrosive environments, the empty space in the pipe surrounding the tendon is filled with cement paste by means of grouting after the tendon is pulled and before the live load is applied. If this is the case, then the stress due to live load is calculated based on the transformation cross-section as was done in the pre-drawing method.
e. In general, the end anchors after being locked (turned off) need to be covered or protected with a protective layer.

To anticipate the possibility of an unbalance moment at each step of implementation, here is used a temporary bearing (temporary bearing) to withstand the compressive force while the tensile force is held by a temporary anchor (see the analysis of the calculation of the unbalance moment in appendix-3). In the field, this unbalance moment is caused by several things, namely:

(i). unbalanced wind pressure
(ii). unbalanced form traveler weight, especially during maneuvers
(iii). unequal weight of concrete
(iv). implementation burdens

In conditions where the unbalance load is still small, here the unbalance moment is still borne by the laying system where the two placements are still under pressure, for more details this can be seen in the following calculation:

Unbalance moment calculation:

For existing projects in Indonesia, modular formwork systems are among the most popular. This system is flexible for different cross sections and different casting lengths. In this traveler there is a lightweight mechanical and hydraulic system so that it does not complicate the assembly of the crane so that it can achieve the desired cycle time.
B. Closure

If the unbalance moment that occurs exceeds the bearing capacity, the temporary anchor begins to work, that is, on the one hand, it is pulled by the security guard and the other side that is under pressure is carried by the position.

It is recommended that in practice, the capacity is not fully utilized, considering that there are other unforeseen possibilities. When the steps for implementing the segment have been completed for each pillar (full cantilever), the next stage is closure, which is the connection of one end of the cantilever with the other end of the cantilever. There are several closure methods that can be applied, where in principle all methods must refer to the requirements, namely the load to be used is not too large (preferably made the same as the closure reaction at the end of the cantilever) and placement.

The load is made in such a way that it does not cause deformation of the closure. An example of load placement carried out on the Suramadu Bridge is as shown in Figure 5, here the magnitude of the load $P_{ft1}$, $P_{ft2}$, $P_{w1}$ and $P_{w2}$ is the same, namely the weight of the closure divided by two.

This condition is balanced either before the casting of the closure or closure has been completed. In order to maintain balance and prevent deformation of the closure during casting, $P_{w1}$ and $P_{w2}$ should consist of the water load and the tank, so that at the time of execution, the concrete is poured along with the same weight of water being removed. If the casting is carried out in stages, the balance will be maintained both before, during and after casting.

![Diagram of closure stages](image)

Figure 6: Stages of closure
As ballast, P1 and P2 can use the form traveler by dismantling the inner form-work to reduce weight to balance Pw1 and Pw2.

For more details, the implementation steps can be seen in Figure-3, namely the sequence of making segments that apply to each pillar. Here each segment manufacture consists of 4 steps, namely transfer of form-traveler, manufacture of form-work and reinforcement, casting and stressing of prestressed cables.

The time required for the manufacture of one segment normally is: For segment A0 is 36 days, A1 = 17 days and A2 – A8 is 9 days including concrete curing for 4 days. Especially for segment A0, the implementation of making this segment is done by making scaffolding. This scaffolding can be done by placing it on the pier head or by making supports anchored to the top of the pillar, the second method is more economical considering the distance between the pier head and the bridge floor is quite high.

In the implementation of making segment A1, here the form-work is hung with a steel bar with a diameter of 32 mm with a relatively high quality, namely \( f_y = 7800 \) MPa. As holding this hanger is a steel truss (Bailley) whose length covers both segments A1 (Surabaya direction and Madura direction). Next, for the execution of making A2, A3, A4, A5 . . . and so on is to replace the steel truss-bailley with a form-traveler.

### C. Closure Order Changes

To shorten the implementation time on the Surabaya side approach, here is a change in the sequence of closures. That is by rearranging the sequences in such a way that there are several closures that are done simultaneously without reducing the strength of the structure specified in the initial design (see figure-4). As a result of this change, of course there is an effect on the bearings that have been set in advance and the pre-camber which has been calculated based on the sequence in the initial design. Checking whether the existing presets can still be used, the calculation can be seen in tabulated form as can be seen in table-1 and table-13 is the sequence of closures for the Madura side and the Surabaya side.

The sequence of closures on the Madura side is still in accordance with the initial design, so there are no changes here. As for the Surabaya side, there are changes for both the West and East sides, theoretically this change will save about 10 days, which is the length of time it takes to complete 1 closure.

In the numbering sequence of closures it appears that there are the same number, this means that the closures can be executed simultaneously. Meanwhile, the left & right sides of P51-P52 and P41-P42 indicate that the closure work can be done independently. In fact, in the field, the installation of formwork and reinforcement is done simultaneously so there is no waiting for each other, with a note that the locking device is not locked first.

| Table 2. Sequence of closure Approach Surabaya Side |
|---------------------------------------------|
| **West pillar side** | **East pillar side** |
| Number of sequence | Number of sequence |
| P36–P37 | P36–P38 |
| 1 | 2 |
| P37–P38 | P39–P40 |
| 2 | 3 |
| P38–P39 | P40–P41 |
| 3 | 4 |
| P39–P40 | P41–P42 |
| 4 | 5 |
| P40–P41 | P42–P43 |
| 5 | 6 |
| P41–P44 | P43–P44 |
| 6 | 5 |
| P42–P44 | P43–P45 |
| 7 | 6 |
| P44–P45 | P45–P45 |
| 8 | 7 |

| Table 3. Sequence of closure Approach Madura Side |
|---------------------------------------------|
| **West pillar side** | **East pillar side** |
| Number of sequence | Number of sequence |
| P48–P49 | P48–P49 |
| 1 | 2 |
| P49–P50 | P49–P50 |
| 2 | 3 |
| P50–P51 | P50–P51 |
| 3 | 4 |
| P51–P52 | P51–P52 |
| 4 | 5 |
| P52–P53 | P52–P53 |
| 5 | 6 |
| P53–P54 | P53–P54 |
| 6 | 7 |
| P54–P55 | P54–P55 |
| 7 | 8 |
| P55–P56 | P55–P56 |
| 8 | 9 |
| P56–P57 | P56–P57 |
| 9 | 10 |
Figure 7. Elevation of the box girder approach of the Suramadu National Bridge from pier 36 to pier 45

Figure 8. Dimensions of segment A0 are 7m long, A1-A3 is 4m long, A4-A8 is 4.5m long.

Figure 9. Layout of prestressing tendons W, T and B from the side view. That are W1-W7 and TC, T0-T8 and B4-B14.

Figure 10. Layout of W, T and B prestressing tendons from above.
CONSTRUCTION METHODS

A. Suramadu Approach Bridge Data

The final optimization of the Suramadu Approach bridge is with a span of 80 m between piers with a longitudinal slope of 4%, with a single cell box girder shape that will speed up execution and reduce the quantity of work and has a hollow shaped pillar.

Change no. 20 is a change in the sequence of closures, where there are several closures carried out simultaneously on the approach bridge on the Surabaya side. This is done to speed up the implementation, considering that the Surabaya side is already behind the schedule.

Any changes in this sequence will affect the elevation control and pre-offsetting placement that has been installed so that it needs to be re-analyzed. An analysis for the pre-offsetting of the placement has been carried out and the conclusion is that the change in the sequence does not affect the settings that have been applied in the field, this can be seen from the calculations in the next chapter.

For elevation control during implementation stages, re-analysis is not carried out, but the results of the previous analysis are adjusted again (adjusted to the new sequence).

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