THE APPLICATION OF SEMI-CONTINUOUS POST-TENSION PRE-STRESSING BOX GIRDER BRIDGES IN AFRICA

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ABSTRACT

With the rapid development of Africa, more and more bridges are to be built, a bridge type with characteristics of safety, stability, convenient of construction and less cost now is in huge demand. The paper presents an advanced bridge type with semi-continuous post-tension pre-stressing box girder, and introduces the design principles, construction procedures, and actual applications of the bridge type in Africa highway projects, such as the Addis Ababa-Adama Expressway of which is the first expressway in east Africa, and Kampala to Entebbe Expressway of which is the first expressway in Uganda.
In the paper, the design principles and construction procedures will be presented, girders of the bridge type can be precast in factory with post-tension pre-stressing concrete, and structural system can be transferred from simple supported system to semi-continuous system during construction. To simulate the mechanical behaviour of the bridge before and after structural system transformation, a numerical modelling is also built on the basis of finite element software.
Based on the theoretical derivation, finite element analysis and actual project application, the presented bridge type is proven to be safe, advanced and less cost, meet the corresponding specifications, the presented bridge type can be generalized to more Africa highway projects.

1 Introduction

The semi-continuous post-tension pre-stressing box girder bridge is an advanced bridge type, of which the girders are usually pre-cast in factory and transport to the site, at the beginning of construction stage, it acts like a simple supported bridge to carry the dead load of itself, after structural system transformation, it acts like a continuous bridge to carry the load of wearing course, attachments and vehicles, the main benefits of the bridges are listed below:

- Better quality, the girders can be pre-cast in factory, so the construction quality can be well controlled.
- Convenience of construction, because the girders are pre-cast in factory, compared to the cast-in-site bridge, it will save lots of site work, and mechanized equipment can be also widely adopted.
- Standardization design and construction, standard span and construction procedures can be adopted, of which can facilitate construction process.
- Less costly and improved efficiency, compared to cast-in-site bridges, the semi-continuous post-tension pre-stressing box girder bridges is less costly and more efficient, especially for large-scale projects.

- Compared to the simple supported bridges with a similar span, the girder depth is shorter, and less expansion joint is needed.
- Compared to the traditional continuous bridges with similar span combinations, the inner force is more balanced.
- Wide applicability, the semi-continuous post-tension pre-stressing box girder can be used in most terrains compared to cast-in-site bridges, because no full framing is needed.
- Higher stiffness, because high-strength pre-stress strand is adopted, the girder has higher stiffness than normal reinforcement girder.

In the paper, the mechanical characteristics, construction procedure and design principles of semi-continuous post-tension pre-stressing box girder will be presented, and based on an actual project, a numerical modelling is built on the basis of finite element software to simulate the mechanical behaviour of the bridge type before and after structural system transformation.
Based on the theoretical derivation, finite element analysis and actual project application, the presented bridge type is proven to be safe, advanced and less cost, meet the corresponding specifications, the presented bridge type can be generalized to more Africa major highway projects.

2 Construction Procedures and Mechanical Characteristics

2.1 Construction Procedures

For the construction of semi-continuous post-tension pre-stressing box girder bridges, there are normally 6 stages:

- **Stage 1**: Precast the girders in factory and tension the positive strands (Figures 1 ~4).

Figure 1 Install the Duct and Bars

Figure 2 Install the Frame

Figure 3 Precast the Concrete Girder **Figure 4 Tension the Positive Strand**

- **Stage 2:** Install the girders and temporary bearings on substructure. (Figures 5 ~7)

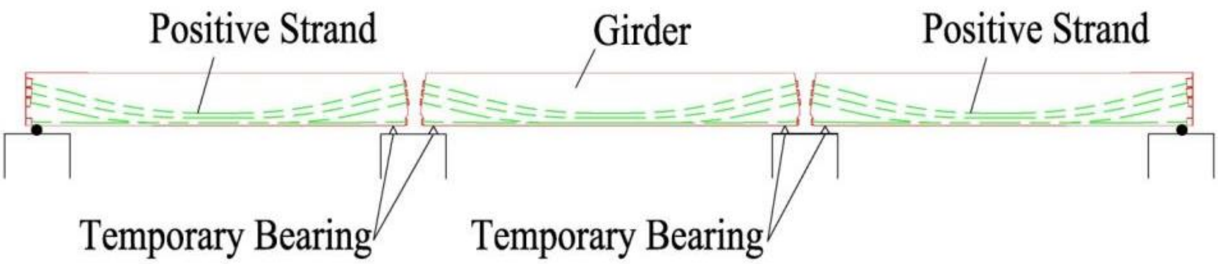

Figure 5 Construction Procedure Diagram (Stage 2)

Figure 6 Install Girders **Figure 7 Install Girders**

- **Stage 3**: Cast the longitudinal wet joint. (Figures 8 and 10).

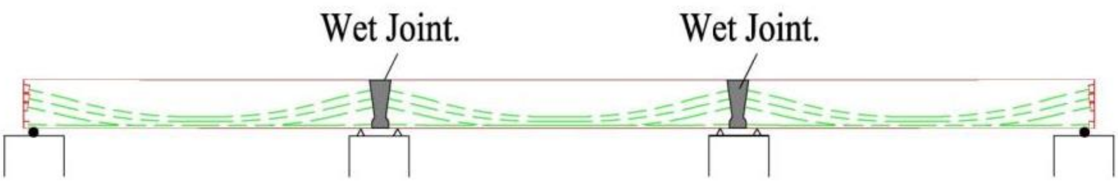

Figure 8 Construction Procedure Diagram (Stage 3)

Figure 9 Cast Wet Joint **Figure 10 Cast Wet Joint**

- **Stage 4:** Tension the negative strands on the top of girders. (Figures 11~13).
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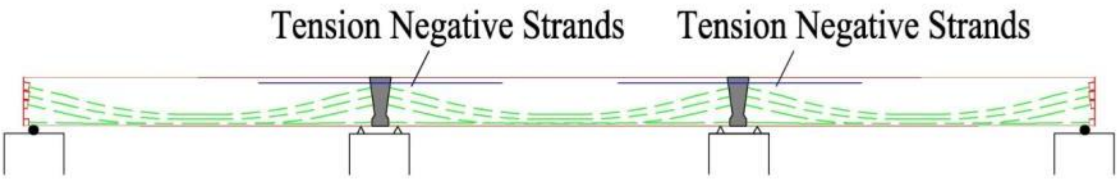

Figure 11 Construction Procedure Diagram (Stage 4)

Figure 12 Tension Negative Strand **Figure 13Tension Negative Strand**

- **Stage 5**: Change the temporary bearing to permanent bearing, complete structural system transformation. (Figures 14).

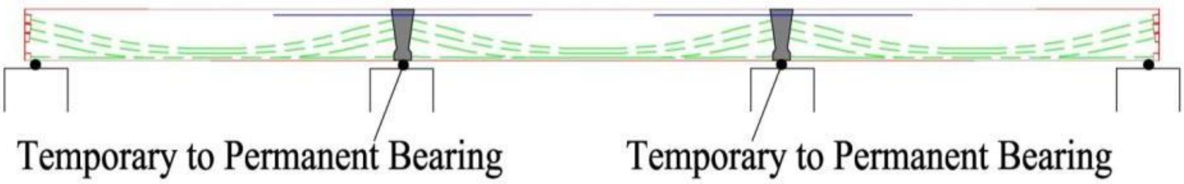

Figure 14 Construction Procedure Diagram (Stage 5)

- **Stage 6**: Cast the transverse wet joint, make the girders as a whole part and then construct the wearing course and attachments. (Figures 15~17).

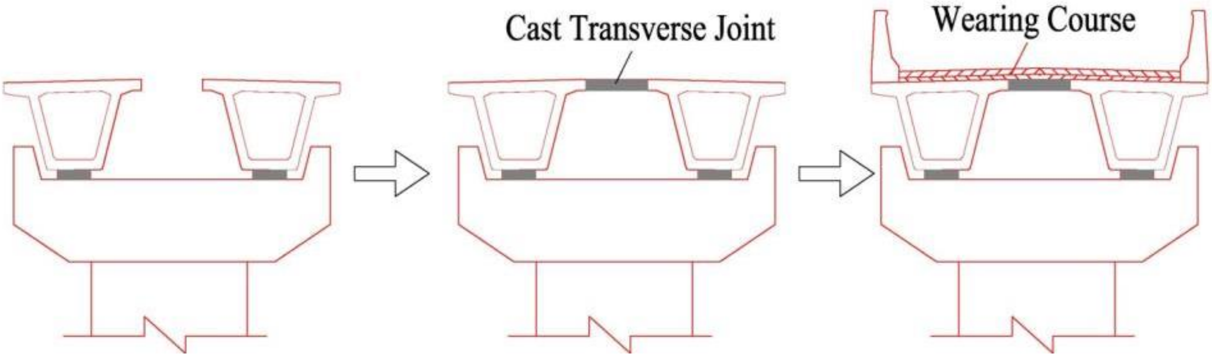

Figure 15 Construction Procedure Diagram (Stage 6)

Figure 16 Cast Transvers Join

Figure 17 Construct Wearing Course

1.1 Mechanical Characteristics

The main mechanical Characteristics of semi-continuous post-tension pre-stressing box girder bridges is listed below:

- Before structural system transformation (construction stage 1 to stage 2), the bridge acts like a simple supported bridge to carry the dead load of girders.
- After structural system transformation (construction stage 4 to stage 6), the bridge acts like a continuous bridge to carry the loads of wearing course and attachments.
- Because the girders and wet joints are casted at different time, time-dependent parameters such as shrink, creep has great influence to the final inner force of the girders.
- The inner force of every construction stage should be added up to get the final inner force at completion stage, the final inner force at completion stage is different from the traditional continuous bridges.

3 Design Principles

The semi-continuous post-tension pre-stressing box girder bridges are stage-constructed and statically indeterminate, so it is sensitive to the design accuracy, the design principles listed below should be strictly obeyed:

- The construction stage should be accurately stimulated, in order to get the correct final inner force at completion stage.

- The time time-dependent parameters such as shrink, creep should be considered accurately, because they have great influent on the result.
- The loss of pre-stressing should be calculated accurately.
- The bending moment at span middle and wet joint should be carefully checked according to specifications.
- The stress at span middle and wet joint should be carefully checked according to specifications.

4 Actual Applications in Africa

Due to the benefits mentioned above, the semi-continuous post-tension pre-stressing box girder bridges has been adopted in many major projects in Africa, the following discussion introduces the application of the bridge type, based on an actual project to demonstrate the modelling and calculation strategy, and to check the safety of the bridges.

3.1 Bridge Information

The PK24+425 bridge is in the Addis Ababa – Adama Expressway project of which across a river with 200 m width, it's very difficult to use cast-in-site girder, because the highest pier is about 30 m. So for this bridge, 5 x 25 m + 5 x 25 m span semi-continuous post-tension pre-stressing box girder has been adopted. The typical bridge section is shown in Figure 18:

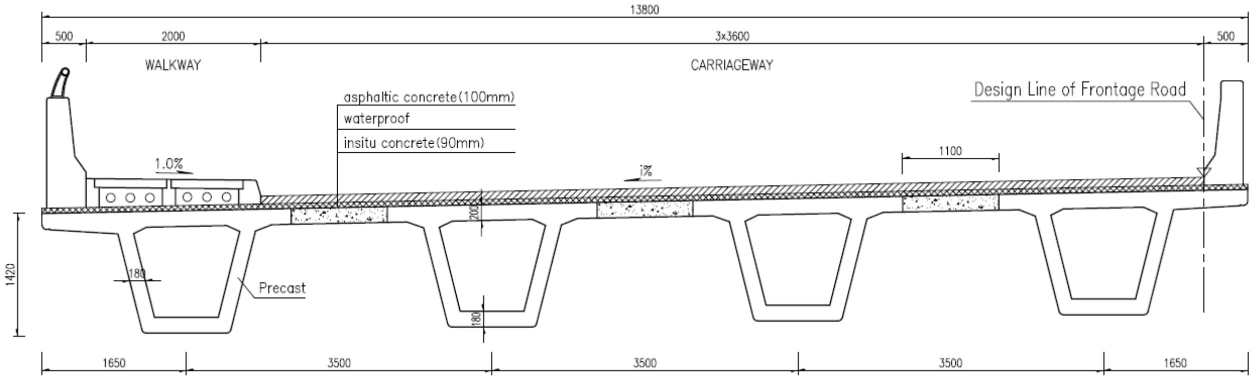

Figure 18 Typical Bridge Cross Section

3.2 Materials Property and Design Load

- Concrete with cube strength 40 MPa at 28 days.
- Strand with low relaxation, Type 1x7 (15.2 mm) with tensile strength 1860 MPa.
- Reinforcement with 420 MPa Strength.
- Design Load：HL-93（AASHTO）[1]

3.3 Girder Details

The depth of the girder is 1.42 m, the dimension and strands configuration are shown in Figures 19 and 20 and Table 1:

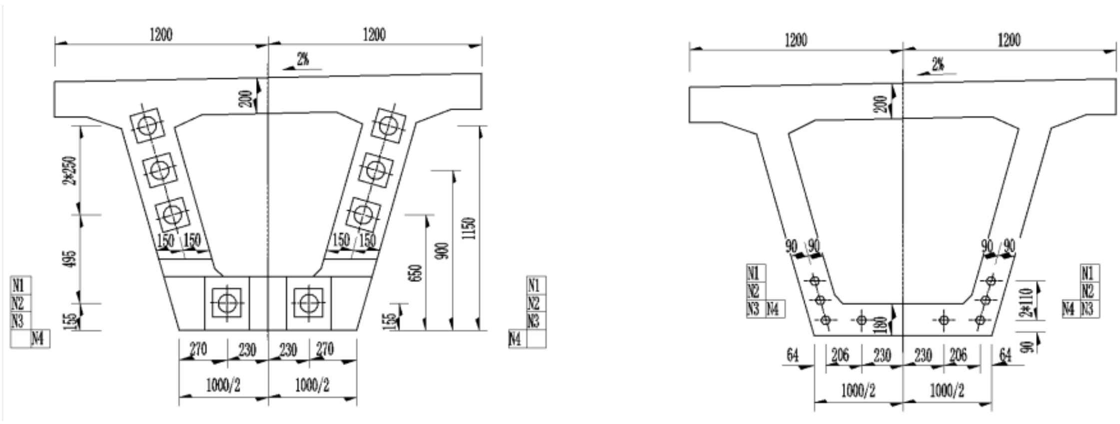

Figure 19 Positive Strands Drawings

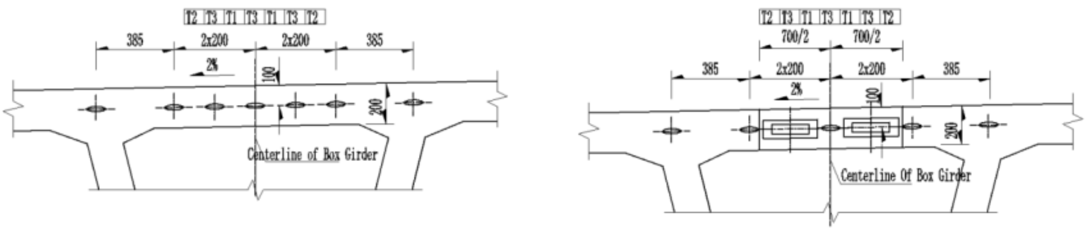

Figure 20 Negative Strands Drawings

Table 1 Strands Configurations

Item	Tendon No.	Diameter(mm) of Strands	Number	Length(mm)	Length(m)	Weight(kg)
Positive Strand	N1	4 Ø 15.2	2	25771	51.5	226.8
	N2	4 Ø 15.2	2	25781	51.6	227.2
	N3	4 Ø 15.2	2	25791	51.6	227.2
	N4	4 Ø 15.2	2	25638	51.3	225.9
Negative Strand	T1	4 Ø 15.2	2	6600	13.2	58.1
	T2	4 Ø 15.2	2	9600	19.2	84.5
	T3	4 Ø15.2	3	14600	43.8	192.9

3.4 Numerical Modelling Strategy

A multiple span semi-continuous 5 x 25 m has been modelled in Midas Civil using advanced beam element so that complex properties are automatically calculated and assigned. Every construction stages are simulated in order to get accurate inner force both in construction state and completion state. The program will calculate the influence surface for a given load at a given location, once the influence surface are generated, the load optimization will be carried out to automatically compile a highway-loading pattern for each influence surface, which gives the worst load effect for the relevant influence effect at the respective locations. The principles and procedures of the modelling are listed below:

- Principles: The structure is statically indeterminate, and the time-dependent parameters such as shrink, creep has great influence to the final inner force, so the construction stage should be accurately simulated.
- Input the material and section properties.
- Input the time-dependent parameters.
- Input the dead loads.

- Define every construction stage.
- Calculate the inner force in every construction stage and completion stage.
- Input the live load such as vehicles and Temperature Gradient.
- Check the ULS and SLS results according to specifications.

The modelling is shown in Figures 21 and 22:

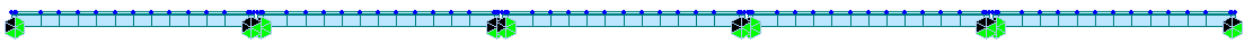

Figure 21 Modelling before System Transformation

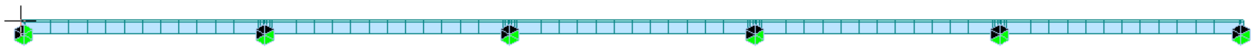

Figure 22 Modelling after System Transformation

3.5 Calculation Results

Based on the basic information above, the calculation results are shown in Figures 23 to 26:

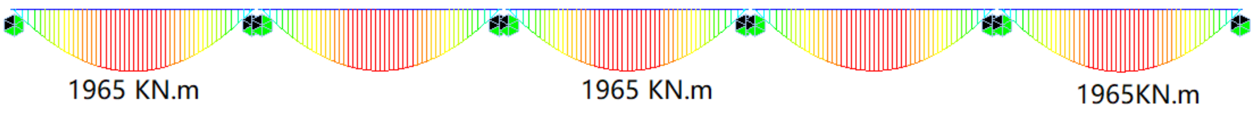

Figure 23 Bending Moment in Stage 2 (Caused by Girder Dead Load)

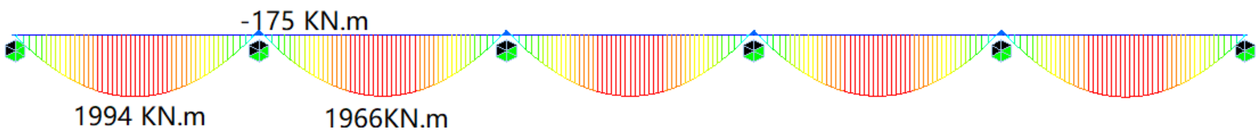

Figure 24 Bending Moment in Stage 5 (Caused by Girder Dead Load and Wet Joint)

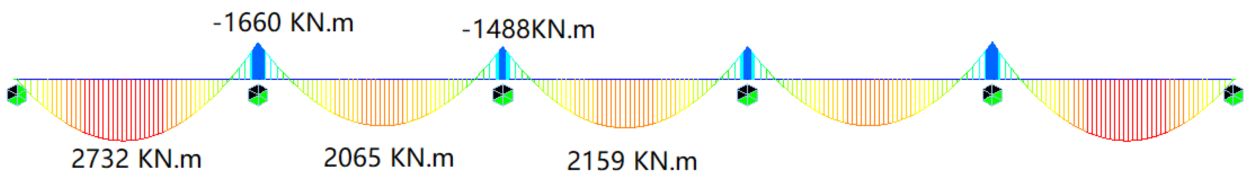

Figure 25 Bending Moment in Stage 6 (Including Dead Load, Wearing Course, Attachments, Shrink, Creep, Secondary effect of Strand)

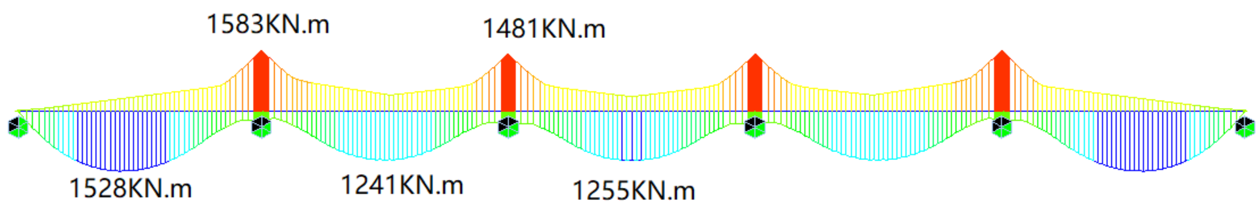

Figure 26 Bending Moment Caused by HL-93 Vehicles

The strength and stress of the girders are also checked according to AASHTO specifications as indicated in Table 2.

Table 2 Strength and Stress Check under ULS and SLS Combination

Location	Strength Check		Compression Stress		Tension Stress	
	ULS(kN.m)	Strength(kN.m)	Max(MPa)	ALW(MPa)	Max(MPa)	ALW(MPa)
Span	6132	10626	9.28	13.96	-0.89	-2.785
Wet joint	-5584	-9870	13.1	13.96	-0.18	-2.785

Table 2 shows that the strength and stress meet the AASHTO specifications, the bridge type is safe.

3.6 Other Applications in Africa

With the benefits mentioned before, the semi-continuous post-tension pre-stressing box girder bridges are also used in other Africa highway projects by the author, and have been proven to be safe, advanced, less cost and convenient for construction. Figures 27 to 29 show the applications in some major Africa projects:

Figure 27 PK22+000 Bridge in Uganda Kampala-Entebbe Expressway (1 450 m,10 x (5 x 25 m) + 2 x (4 x 25 m))

Figure 28 PK1+583 Bridge in Uganda Kampala-Entebbe Expressway (520 m, 3 x (5 x 25 m) + 3 x 25 m + 2 x 35 m)

Figure 29 PK24+425 Bridge in Ethiopia Addis Ababa Outer Ringroad Project (250 m, 2 x (5 x 25 m))

5 Conclusion

Based on the theoretical derivation, finite element analysis and actual project application, the presented bridge type is proven to be safe, advanced and less cost, meet the corresponding specifications, the presented bridge type can be generalized to more major Africa highway projects.

References

AASHTO, 2014. LFRD Bridge Design Specifications 7th edition, Section 5: Concrete Structures. American Association of State Highway and Transportation Officials Washington DC, p.93-112.