Utilization of ultra-high performance concrete for bridge construction – a case study of Kg. Seberang Manong to Pekan Manong bridge

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Abstract. The utilization of Ultra-High Performance Concrete (UHPC) in bridge construction is considered to be quite a new technology in Malaysia and its usage is still in the early stage of implementation as far as bridge design and construction in this country is concerned. The Bridge Design Division, Public Works Department (PWD) has taken the initiative to study and begin utilising UHPC in designing a 300 m long bridge crossing the Perak River between Kg. Seberang Manong (Kg Menglembu) to Kuala Kangsar, Perak. The purpose of using UHPC is to reduce the number of intermediate piers that need to be constructed within the river channel in order to minimize the impact of debris flow disaster. This will allow free flow of logs thus avoiding them from being trapped and could possibly damage the piers during flooding. The bridge has 5 spans with the longest span of 70 m in length that uses UHPC in its construction. In this bridge construction, it is quite impossible to use typical normal concrete commonly utilize in conventional concrete bridge project that normally limits the span length to only 40 m. This project is also a pilot project in PWD that uses Malaysia Civil Engineering Standard Method of Measurement (MYCESMM), replacing the current Malaysian Standard Method for Measurement of Civil Engineering Construction. The MYCESMM covers a wider range of civil engineering works. This project is expected to contribute towards delivering cost effective civil engineering projects through the adoption of best practices in the preparation of the bills of quantities (BQ). The successful application and construction of this pilot project will have a great prospect in encouraging more projects to use UHPC and MYCESMM in the upcoming projects in Malaysia.

1. Background of the project
Kg. Seberang Manong (Kg. Menglembu) is located on the western bank of the Perak River at a distance of 45 km from Kuala Kangsar and Pekan Manong (Figure 1). In the past 30 years, more than 5000 villagers were using ferry boat services to reach Kuala Kangsar and Pekan Manong to carry out their daily businesses. The proposed bridge, however, will provide basic infrastructure facilities to the villages from Kg. Seberang Manong and the surrounding area in order to cross the Perak River to Pekan Manong and Kuala Kangsar. The proposed bridge will also ensure the safety of villages who have been using ferry boat services for daily transportation. Moreover, the proposed bridge will also provide alternative routes and serve as economic stimulus to rural communities.
The government through Road Branch, Public Works Department (PWD) has agreed to implement a bridge project that links Kg. Seberang Manong (Kg Menglembu) to Pekan Manong and Kuala Kangsar, Perak. The scope of the project includes the construction of a 3.0 km single carriageway road and a 300 m bridge according to JKR standards. The 300 m bridge was designed in house under Bridge Design Division (BDD), Road Branch, PWD. BDD decided to design multiple spans bridge with a longest span of 70 m. In order to build a longer span bridge, BDD decided to use UHPC precast beam to solve the solution of having a span that is too long for a conventional beam preference. UHPC was found to be effective in fulfilling the design requirements due to the extent in span length of the bridge structure because of its high strength [1]. The purpose of the long span bridge is to provide ample space between piers in order to allow free flow of logs thus avoiding them from being trapped and could possibly cause damage to the piers during flooding.

The bridge project is considered to be a pilot project that uses Malaysia Civil Engineering Standard Method of Measurement (MYCESMM) in BDD. For tendering purposes, the preparation of the Bills of Quantities (BQ) for the bridge project that uses MYCESMM allows standardized measurements that provide a base to produce a good Bills of Quantities (BQ) used as procurement or contract documents in a project [2-4]. In other words, MYCESMM is needed in producing a sound BQ which constitutes as procurement or contractual agreement in the bridge project. The use of an appropriate standard BQ will allow consistent and better estimating of pricing in bidding, cost control and records by construction players during the difference stages and process of construction [2-3].

1.1 Overview and Characteristics of UHPC

Ultra-high performance concrete (UHPC) is an innovative material that show great potential to improve performance of infrastructure projects. It has been applied in civil engineering projects, especially those in bridge engineering [9]. UHPC needs to undergo the transition from research and development to actual construction uses [1, 10]. Since the application of UHPC to real-world projects has been sluggish, UHPC usage needs to be aggressively promoted in the construction industry. At the meantime, in Malaysia, very limited producers have experienced in the utilization of UHPC for precast or cast-in-place applications.

UHPC is a high-strength material created by combining Portland cement, silica fume, quartz flour, fine silica sand, high-range water reducer, water, and steel or organic fibres [1,10-13]. A typical UHPC material has a design compressive strength of up to 200 MPa while ductile tensile strength range of 10–15 MPa [13]. Table 1 summarizes the typical compositions of concrete materials at
different levels of performance [5]. Ordinary and high performance concretes consist of cement, fine and coarse aggregates, and admixtures, compared to UHPC which is made up of cement, fine aggregates, admixtures, steel fibers, and nano-fillers. The coarse aggregate was replaced in UPHC with steel fibers and nano-fillers that enhance the mechanical strength of UHPC. The nano-filler increased not only the compressive strength but also the tensile strength [5, 11-12]. UHPC structures are capable of deforming and supporting flexural and tensile loads even after initial cracking. Figure 2 displays the compressive and flexural strength of UHPC in comparison to that of normal concrete [10]. With varieties of excellent material properties, UHPC applied to bridge structures can reduce the cross-sectional area, which decreases self-weight (dead load) and extension of service life due to outstanding durability [11-13].

| Strength | Porosity |
|----------|----------|
| Ordinary Performance Concrete | 20–40 MPa | 10–20% |
| High Performance Concrete | 50–100 MPa | 5–8% |
| Ultra-High Performance Concrete | 100–200 MPa | 2% below |

**Figure 2.** Behavior of Ductal in compression (a) and in bending (b) [10].

1.2 UHPC Segmental Beam - Deck System for Manong Bridge

The 300 m Manong Bridge crossing the Perak River was designed using Beam-Slab Bridge system with Multi-span continuous beam. The bridge was designed to withstand full traffic loading as per the Eurocode specification and comprises a total width of 11.5 metres that includes three spans of 70 m and two span of 45 m creating a total bridge length of 300 m (Figure 3). The loading of the bridge structures is designed according to BS EN 1990:2002[15] for permanent action and for the traffic loading according to BS EN1991-2 [16]. For traffic loading, combination of Load model 1 (LM1) which considers tandem system (TS) and uniformly distributed load (UDL) and Load model 3 (LM3) considering special vehicle (SV80) are used for the analysis in 3D Model MIDAS Civil. The global analysis of the bridge is carried out using a grillage model of the deck with the stiffness of the piers
and abutments represented by roller and pin. The superstructure and substructure are modelled together in a single 3D Model MIDAS Civil shown in Figure 4 and Figure 5. The superstructure of the bridge was designed and constructed using a post tension ultra-high performance concrete (UHPC) U-Girder semi integral beam-deck system, which was semi integral bridge with the substructure/foundation.

Figure 3. Longitudinal Section of the Bridge.

Figure 4. Bending Moment diagram using 3D Model MIDAS Civil for UHPC Girder beams.

Figure 5. Stress analysis using 3D Model MIDAS Civil for UHPC Girder beams.
The foundation of the bridge abutment was seated on 750 mm diameter bored pile while bridge pier was seated on 1500 mm diameter bored pile bonded in 18.5 m in hard layer with approximate pile length of 37 metres. Figure 6 shows the typical Pier elevation of the bridge. The UHPC beams are spaced 3.25 metres c/c and each span consists of 3 beams. A total of 9 beams of 70 m and 6 beams of 45 m were used.

Figure 6. Typical Pier Elevation (a) Pier elevation (Abutment A to P1, 45 metres span beam), (b) Pier elevation (Abutment A to P1, 70 metres span beam)

Figure 7 shows the typical details of an UHPC U-Girder beam. A 45 m UHPC U-girder beam was designed with 2.25 m deep, 2.75 m wide at the top while 70 m UHPC U-girder beam was designed with 3.0 m deep, 2.818 m wide at the top (see Figure 7a, 7b, 7c and 7d). The beam is made from 2.5 m small panel box girder beam being assembled and become 70 m and 45 m U-girder beam (Figure 8).
a. Anchorage Section for 45 metres UHPC U-Girder beam

b. Joint Section for 45 metres UHPC U-Girder beam

c. Anchorage Section for 70 metres UHPC U-Girder beam
d. Joint Section for 70 metres UHPC U-Girder beam

**Figure 7.** Typical details of U-Girdir Beam (a) Anchorage Section for 45metres UHPC U-Girder beam, (b) Joint Section for 45metres UHPC U-Girder beam, (c) Anchorage Section for 70metres UHPC U-Girder beam (d) Joint Section for 70metres UHPC U-Girder beam.

**Figure 8.** Elevation of full girder assembly.
1.3 Applications of Malaysia Civil Engineering Standard Method of Measurement (MYCESMM)

In January 2013, the Malaysian Government officially implemented MYCESMM in standardizing the method of measurement for civil engineering works in all public and private projects [17]. MYCESMM is intended to be a national document that features the rules of measurement, definition, coverage and description for civil engineering projects to be used as a basis in the preparation of the Bill of Quantities. Malaysia as a nation must seriously adopt the use of one standard method of measurement for civil engineering works. The adoption of one standard provides clarity in the preparation of the Bill of Quantities which leads to improved understanding of the work items hence enabling pricing of those items to be undertaken in a more accurately manner [3; 17-21]. Potential contractual claims and disputes due to ambiguities and discrepancies in the Bill of Quantities that can arise during the construction stage can thus be minimized which ultimately leading to a cost-effective in the delivery of civil engineering projects and smoother preparation of final certificates hence final payment [2-3].

This bridge project is a pilot project that uses MYCESMM within BDD in preparing the Bills of Quantities (BQ). At the moment, the bridge is in the construction phase and until present, there is no additional cost incurred due to the missing item in BQ as normally occurred in conventional method of BQ. The construction cost of the Manong bridge was approximately RM23.0 million (US$5.65 million). This construction cost included the foundation/piling, substructure, superstructure, temporary works, and machinery and labor needed for the completion of the bridge. The cost, however, did not include road works, slope protection, and relocation of existing utilities and services. In terms of the cost rate per square meter, the structural component cost for the bridge was US$1650/m². This figure is quite comparable to the costs for conventional reinforced concrete construction in Malaysia which are approximately US$1,500/m² to $1,900/m², depending on the accessibility conditions and difficulties in constructing the bridge.

2. Conclusion

The purpose of this pilot project using UHPC superstructure is to accelerate the UHPC usage in Malaysia construction industry. While Manong bridge is still under construction, the successful construction of the Manong Bridge later on, could encourage the usage of UHPC bridge in Malaysia’s construction industry. Besides that, to encourage the application of this material, more research needs to be carried out particularly on the types of projects that the UHPC is best for its application and how it could be used to attain its fullest potential. Therefore, in order to build a longer span bridge, UHPC has been found to be effective in fulfilling the design requirements due to the extent in span length of the bridge structure compared to the conventional reinforced concrete bridge design.

This bridge project is also a pilot project that uses MYCESMM in bridge construction within BDD. The purposes of preparing the Bills of Quantities (BQ) using MYCESMM are to allow the adoption of standardized measurements which will provide a base in producing a good BQ that shall be incorporated as procurement or contract documents in a project. The successful construction of Manong bridge without missing item in BQ will encourage the usage of MYCESMM in the future bridge construction industry in Malaysia.

3. References

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