# APPLICATION OF ULTRA HIGH PERFORMANCE FIBER REINFORCED CONCRETE – THE MALAYSIA PERSPECTIVE

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## ABSTRACT

One of the most significant breakthroughs in concrete technology at the end of the 20th century was the development of ultra-high performance fiber reinforced concrete (UHPFRC) with compressive strength and flexure strength beyond 160 MPa and 30 MPa, respectively; remarkable improvement in workability; durability resembled to natural rocks; ductility and toughness comparable to steel. While over the last two decades a tremendous amount of research works have been undertaken by academics and engineers worldwide, its use in the construction industry remain limited and it is particularly true in the Malaysian context. Aiming to utilizing the technology as an alternative for conventional solutions and within the vision of sustainable construction, it is the intent of this paper to demonstrate how UHPFRC can be used as both a sustainable and economic construction material. In general, UHPFRC structures are able to give immediate saving in terms of primary material consumption, embodied energy, $CO_2$ emissions and global warming potential. The major focus of this paper is to present both the various completed and on-going examples of UHPFRC application in Malaysia.

***Keywords:*** *Ultra high performance, Fiber, Bridge, Retaining wall, Bridges*

## 1.0 INTRODUCTION

Remarkable development had been discovered during the last two decades in the field of concrete technology. One of the greatest breakthroughs was the development of ultra-high performance fiber reinforced concrete (UHPFRC).

What is UHPFRC? In short, Figure 14 shows UHPFRC belong to the group of High Performance Fiber Reinforced Cement Composites (HPFRCC), where HPFRCC defined as the kind of Fiber Reinforced Concretes (FRC) that exhibit strain-hardening under uniaxial tension force. In addition, UHPFRC is characterized by a dense matrix and consequently a very low permeability when compared to HPFRCC and normal strength concretes.

In Malaysia, UHPFRC was firstly introduced by Dura Technology Sdn. Bhd. in year 2007 with compressive strength and flexural strength of over 160MPa and 30MPa, respectively; however, it has only started its industrial-commercial penetration into the market as a new sustainable construction material since last 3 years. In general, UHPFRC is suitable for use in (i) the fabrication of precast elements for civil and structural engineering (such as bridge components), (ii) archi-structural features, (iii) durable components exposed to marine or aggressive environments, (iv) blast or impact protective structures, (v) strengthening material for repair/rehabilitation work for deteriorated reinforced concrete structures, (vi) portal frame building construction, and others. UHPFRC is a highly homogenous cementitious-based composite without coarse aggregates that can attain compressive strengths more than 160MPa. The standard mix design of UHPFRC is given in Table 7.

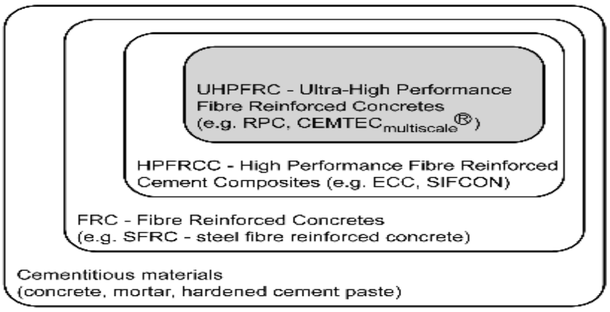



**Figure 14:** Classification of fiber reinforced concrete.

**Table 7:** Mix design of UHPFRC.

| Ingredient | Mass (kg/m$^3$) |
|---|---|
| UHPC Premix | 2100 – 2200 |
| Superplasticizer | 30 – 40 |
| Steel Fiber | 157 |
| Free Water | 144 |
| 3% Moisture | 30 |
| Targeted W/B Ratio | 0.15 |
| Total Air Void | < 4% |

Table 8 summarizes the material characteristics of UHPdC and is compared against normal strength concrete (NSC) and high performance concrete (HPC). The comparison shows that UHPdC have superior mechanical properties over NSC and HPC in all aspects.

**Table 8**: Material characteristics of UHPdC compared to normal strength concrete (NSC) and high performance concrete (HPC)

| Characteristics | Unit | Codes / Standards | NSC | HPC | UHPdC |
|---|---|---|---|---|---|
| Specific Density, □ | kg/m$^3$ | [1] | 2300 | 2400 | 2350 – 2450 |
| Cylinder Compressive Strength, $f_{cy}$ | MPa | [2] | 20 – 50 | 50 – 100 | 120 – 160 |
| Cube Compressive Strength, $f_{cc}$ | MPa | [3] | 20 – 50 | 50 – 100 | 130 – 170 |
| Creep Coefficient at 28 days, $□_{cc}$ | | [4] | 2 – 5 | 1 – 2 | 0.2 – 0.5 |
| Post Cured Shrinkage | □□ | [4] | 1000 – 2000 | 500 – 1000 | < 100 |
| Modulus of Elasticity, $E_o$ | GPa | [5] | 20 – 35 | 35 – 40 | 40 – 50 |
| Poisson's Ratio, □ | | | 0.2 | 0.2 | 0.18 – 0.2 |
| Split Cyl. Cracking Strength, $f_t$ | MPa | [6] or [7] | 2 – 4 | 4 – 6 | 5 – 10 |
| Split Cyl. Ultimate Strength, $f_{sp}$ | MPa | | 2 – 4 | 4 – 6 | 10 – 18 |
| Flexural 1st Cracking Strength, $f_{cr,4P}$ | MPa | [8] (Four-Point Test on Un-notched Specimen) | 2.5 – 4 | 4 – 8 | 8 – 9.3 |
| Modulus of Rupture, $f_{cf,4P}$ | MPa | | 2.5 – 4 | 4 – 8 | 18 – 35 |
| Bending Fracture Energy, $G_{f,□=0.46mm}$ | N/mm | | < 0.1 | < 0.2 | 1 – 2.5 |
| Bending Fracture Energy, $G_{f,□=3.0mm}$ | N/mm | | < 0.1 | < 0.2 | 10 – 20 |
| Bending Fracture Energy, $G_{f,□=10mm}$ | N/mm | | < 0.1 | < 0.2 | 15 – 30 |
| Toughness Indexes $I_5$ | | | 1 | 1 | 4 – 6 |
| Toughness Indexes $I_{10}$ | | | 1 | 1 | 10 – 15 |
| Toughness Indexes $I_{20}$ | | | 1 | 1 | 20 – 35 |
| Rapid Chloride Permeability | coulomb | [9] | 2000 – 4000 | 500 – 1000 | < 200 |
| Chloride Diffusion Coefficient, $D$ | mm$^2$/s | [10] | 4 – 8x10$^{-6}$ | 1 – 4x10$^{-6}$ | 0.05 – 0.1x10$^{-6}$ |
| Carbonation Depth | mm | [11] | 5 – 15 | 1 – 2 | < 0.1 |
| Abrasion Resistance | mm | [12] | 0.8 – 1.0 | 0.5 – 0.8 | < 0.03 |
| Water Absorption | % | [13] | > 3 | 1.5 – 3.0 | < 0.2 |

## 2.0 APPLICATIONS

This paper gives an overview on the detail on some of the successful examples and on-going projects on the application of UHPFRC technology in Malaysia.

To-date, many prototype UHPFRC structures have been constructed in various countries such as France, USA, Germany, Canada, Japan, South Korea, Australia, New-Zealand, and Malaysia. According to Adeline et al. [14], the first application of UHPFRC was the UHPFRC in-filled steel tube composite used in the construction of a footbridge in 1997 at Sherbrooke, Canada. Since then, UHPFRC has caught the attention of academics, engineers and many governmental departments worldwide. Deem [15] reported that the first fully UHPFRC footbridge spanning 120 meters in the world was constructed in Seoul, South Korea in 2002. Subsequently, a motorway bridge was designed by VSL (Australia) at Shepherds Gully Creek, Australia, and was opened to traffic in 2005 [16]. According to Graybeal [17], UHPFRC can be used in a broad range of highway infrastructure applications due to its high compressive and tensile strengths and its enhanced durability properties; thereby allowing a longer design/service life and thin overlays, claddings, or shells. In addition, UHPFRC is also being considered to be used in a range of other applications such as precast concrete piles [18], seismic retrofit of substandard bridge substructures [19, 20], thin-bonded overlays on deteriorated bridge decks [21], and security and blast mitigation applications [22, 23]. Accomplished bridge projects using UHPFRC such as Sherbrooke footbridge (in Canada), Seonyu footbridge (in South Korea), Bourg-Les-Valence Bridge (in France), and Shepherds Gully Creek Bridge (in Australia) emphasize the high capability of UHPFRC to be used in infrastructural projects [24]. Figure 2 presents a schematic drawing showing the evolution of UHPdC technology with respect to structural and architectural applications from 1995 to 2010.

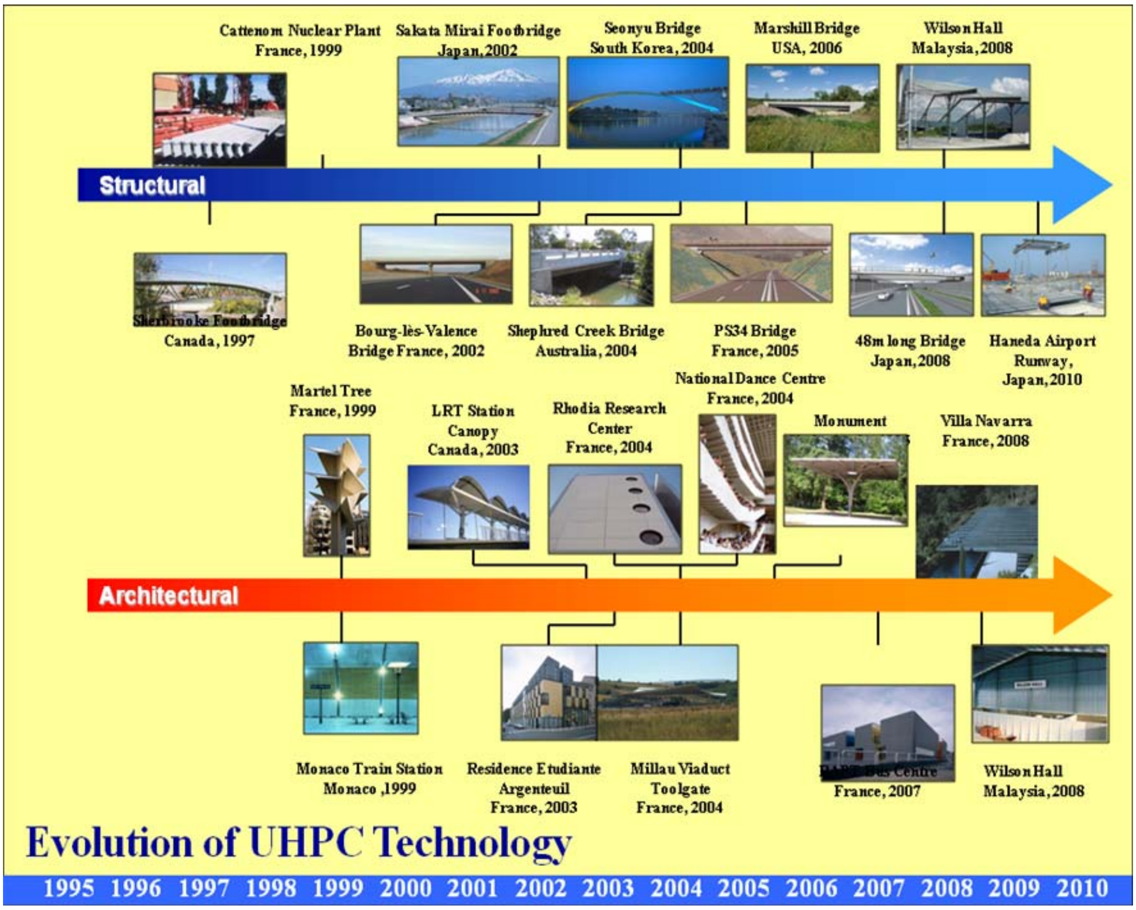
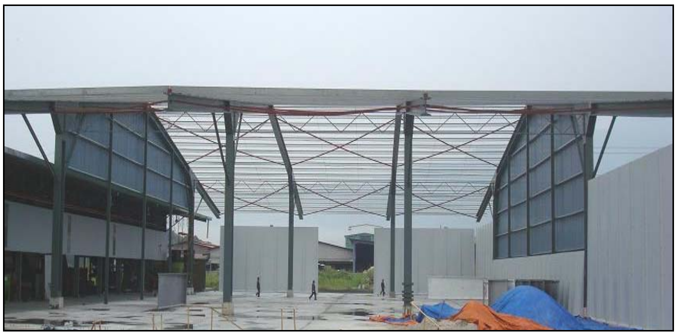



**Figure 15**: Application of UHPFRC.

## 2.1 UHPFRC PORTAL FRAME BUILDING (WAREHOUSE SOLUTION), COMPLETED

In year 2008, a portal frame building named *Wilson Hall* with a roof coverage area of 2,861m$^2$ was built using the prefabricated system of UHPFRC technology. The total transverse width and longitudinal length of the building is 67 m and 42.7 m, respectively. Each UHPFRC portal frame was spaced at 12.2 m c/c and the building consists of eight pieces of UHPFRC prestressed columns, internal rafters, cantilever rafters and connections as shown in Figure 16a. Details of the R&D works and construction sequences of the building can be obtained from Voo and Poon [25]. To-date, this building is the world first attempt to replace conventional steel beam with the UHPFRC prestressed beams/columns. This building has earned a place in the *Malaysia Book of Records* in year 2010. Besides that the paper Voo and Poon [25] also won the *JCI-OWICS Award 2008* where the paper was recognized as the most outstanding and original paper at the International Conference on Our world in Concrete & Structures.

Figure 16b presents the environmental impact calculation (EIC) of the UHPFRC portal frame system against the conventional steel portal frame system. In terms of material consumption, the UHPFRC portal frame system consumed 13% less material than the conventional steel portal frame solution. With regard to immediate construction cost, the UHPFRC system is 16% more economical that the conventional steel structural system. More cost savings can be realised for those factory buildings that are located in corrosive environment or places constantly subjected to chemical attack such as chemical plants, due to conventional steel structure would require periodic maintenance. In terms of environmental indexes, the UHPFRC solution has 24% less embodied energy and 19% less $CO_2$ emissions. For the 100-year GWP, the UHPFRC solution provides a reduction of 16% to the conventional solution. Thus this shows that the UHPFRC system can give a more sustainable solution against the conventional method.



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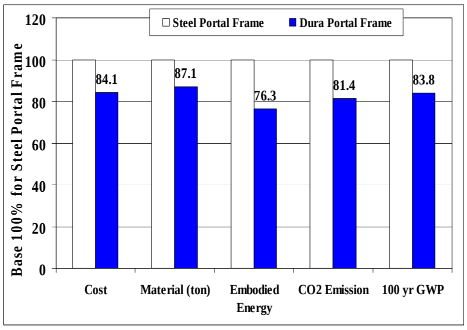



(b)

(c)

**Figure 16**: (a) UHPFRC portal frame (before completion at year 2008), (b) environmental impact calculation and (c) completed *Wilson Hall* (photo taken at year 2012).

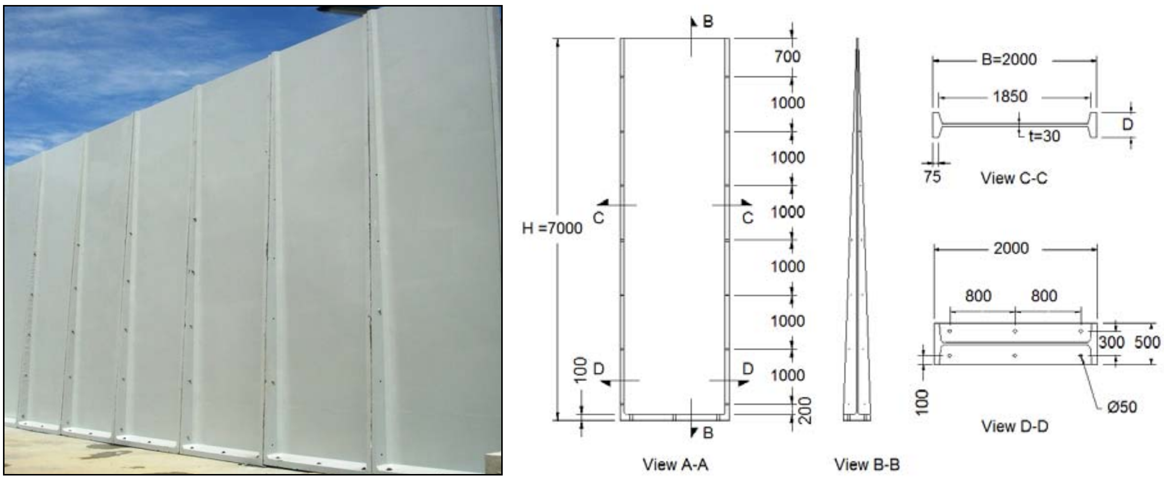
## 2.2 ULTRA-LIGHT WEIGHT WALL PANEL (SECURITY SOLUTION), COMPLETED

One of the remarkable properties of UHPFRC is, it is a highly workable (i.e. flowable) composite material and it has great self-compacting ability. Its superior mechanical properties such as flexural strength made it an ideal material for the manufacturing of thin and light-weight wall panels where conventional steel reinforcements are entirely removed from the panels. Unlike conventional RC wall panel, the UHPFRC wall panel has negligible concern about corrosion issue as conventional steel reinforcement is absent in any parts of the structure.

Figure 17a shows an example of a total of 56 m long free standing anti-climb protective wall panels that was installed at the *Wilson Hall*. The wall was constructed in year 2008. Each wall panel has a total height of 7 m and a total width of 2 m, and comes with a self-weight of 2400 kg per piece. The wall panel consists of thin wall panel of 30 mm in thickness, two ribbed beams as wide as 75 mm and a base pad of 100 mm in thickness (refer to Figure 17b).

The wall panel has multiple applications such as it can use as thin wall panel against wind/rain/sun-shine/dust/spy. Besides, the wall panel also serves as acoustic panel against noise; security or anti-climb panel against thief; protective panel against minor blast and impact loading; impermeable membrane against highly corrosive compound and fire. The benefits of the UHPFRC wall when compared to conventional RC wall is that it is highly durable and impermeable, thus suitable for use in extremely aggressive environments such as marine environments or chemically active plants. The wall is easy to install as simple conventional drop-in anchors or pre-positioned bolts and nuts are used to connect the wall panel to the floors (except some grout may be needed for uneven floor base). No scaffolding, props or formwork are required over the entire installation, thus reducing construction site activities, improving safety margins and eliminating in-situ casting work. Besides, it is many times lighter than conventional RC wall system.

Other advantages are that the wall is guaranteed to be geometrically stable as they are steam-cured to minimized creep and long-term shrinkage and in term of finishing, it is aesthetically pleasing as its finish surface is smooth. More details of the wall panel can be found in Poon et al. [26].




(a) (b)

**Figure 17**: (a) UHPFRC anti-climb wall panel, (b) detail of UHPFRC anti-climb wall.

## 2.3 MONSOON DRAIN (HYDROLOGY SOLUTION), COMPLETED

Figure 18a shows a total of 180 m long by 1.5 m high retaining wall was used in the construction of a 90 m long monsoon drain for a housing development project in Ipoh, Perak. The L-shaped wall comes with thin panels of 30–50 mm thick (see Figure 18b). Unlike conventional RC L-shaped wall which is precast in a standard 1 m length and weights 1200 kg/m of wall, the UHPFRC retaining wall is made in 3 m lengths per piece (see Figure 18c) and has a self-weight of 260 kg/m, which gives a factor of five times lighter than the conventional solution. Prior-to construction of the wall, the local council (i.e. Majlis Bandaraya Ipoh) requested a load proof test on the wall with a surcharge load of 10 kPa at service and 15 kPa at ultimate. The wall was tested with back filled soil up to 1.5 m and an additional surcharge load of 25 kPa, which is 66% greater than the strength limit requirement and still it did not fail! Thus, the wall performance was deemed to satisfy with the design service and strength requirements.

Figure 18d shows a comparison of the EIC results of the UHPFRC retaining wall system against the conventional L-shaped RC wall as given in Figure 18c. In terms of material consumption, the UHPFRC retaining wall consumes 73% less material than the conventional RC wall. In terms of the environmental indexes, the UHPFRC wall requires less embodied energy and produces 49% less CO2 emissions. In terms of the 100-years GWP, the UHPFRC solution provides a reduction of 43%. This it is another good example of how with innovative design UHPFRC technology supports sustainable construction solutions.

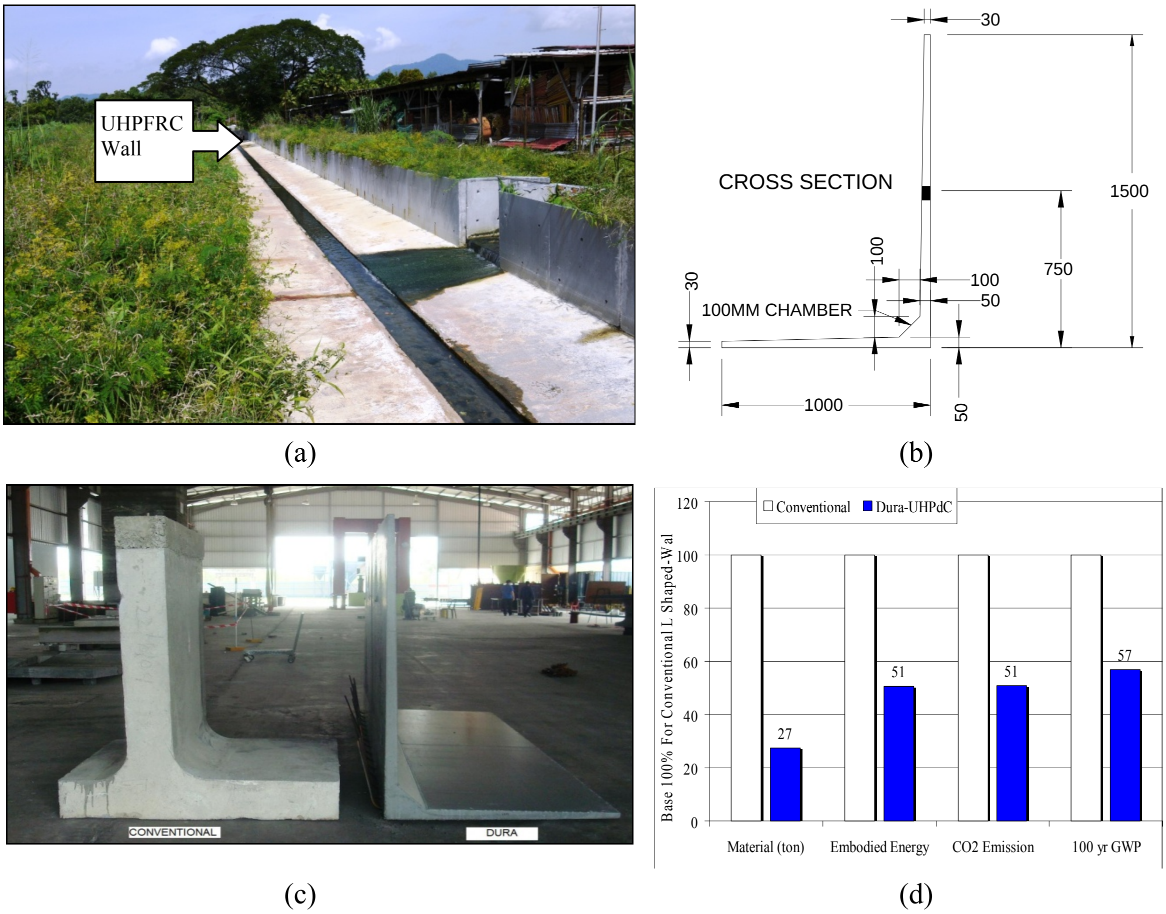
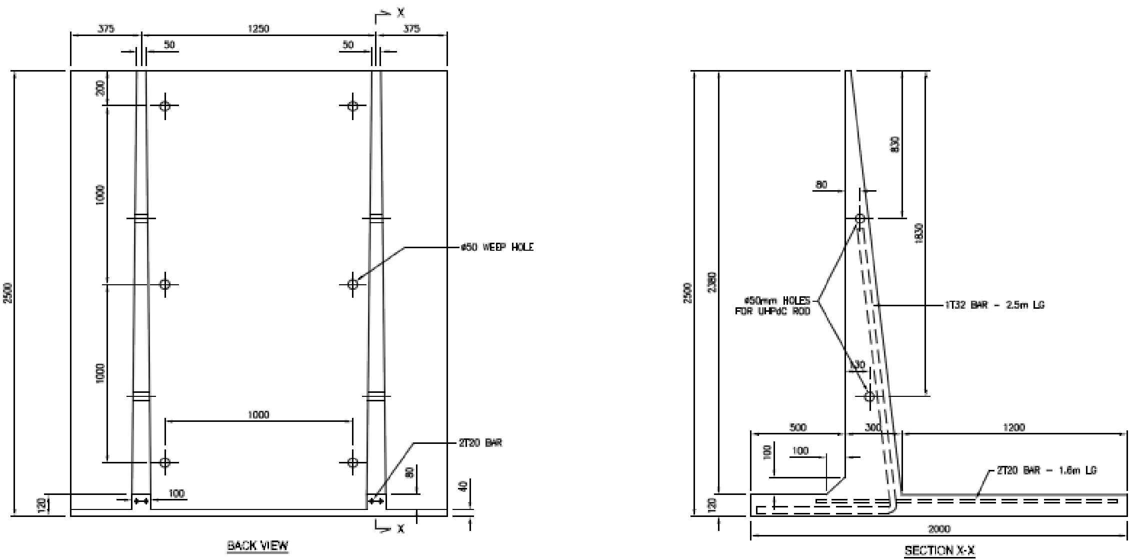



**Figure 18**: (a) 90m long monsoon drain using UHPFRC retaining wall, (b) cross-section detail; (c) comparison of conventional precast L-shape retaining wall against ultra-light weight UHPFRC retaining wall, and (d) EIC of UHPFRC retaining wall.

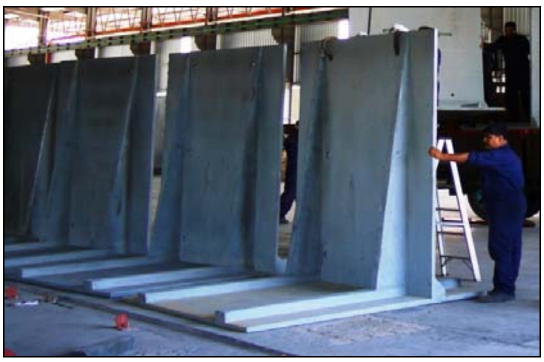
## 2.4 CANTILEVER RETAINING WALL (GEOTECHNICAL SOLUTION), COMPLETED

UHPFRC is ideal for short retaining wall construction (for H < 3m) due to its ultra-high strength-ultra-light-weight feature. Figure 19a gives an example on the detail of a 2.5 m tall UHPFRC wall. The L-shaped wall comes with a total height of 2.5 m and a total width of 2 m per piece. Each of the walls weighs 1200 kg (i.e. 600 kg/m). Unlike conventional RC wall, the UHPFRC wall does not have transverse reinforcements or crack control bars in any part of the concrete section. The only conventional steel reinforcement used is the major longitudinal reinforcements located at the ribbed beams (i.e the stem and the base) to resist the critical design moment effect resulted from the imposed loadings.

Figure 19b shows the prototype of the UHPFRC L-shaped retaining wall. In December 2010, the JKR Perak has constructed a 76 m long with 2.5 m tall retaining wall at Jalan Kota Bahru (Daerah Gopeng, Perak) using the above mentioned UHPFRC retaining wall and it took five working days to complete the entire construction work, which included site clearing work, preparation of the granular base, placing and assembling of the walls, and back filling of the earth. This exercise shows the UHPFRC retaining wall system is able to provide speedy construction solution.




(a)



(b)

(c)

**Figure 19:** (a) Detail of 2.5 m high by 2 m wide UHPFRC retaining wall, (b) prototypes prior to transportation (back view), (c) 76 m long retaining wall installed at Jalan Kota Bahru, Gopeng, Perak.

## 2.5 50 M KAMPUNG LINSUM BRIDGE (MEDIUM TRAFFIC BRIDGE), COMPLETED

The JKR Negeri Sembilan was the first to use UHPFRC in the construction of a medium span motorway bridge at Kampung Linsum crossing a river call Sungai Linggi (see

Figure 20). The road bridge was completed in January 2011. To date, this bridge is the first in Malaysia and may also be the world's longest composite road bridge made from UHPFRC. The bridge was constructed using a single U-trough girder 1.75 m deep, 2.5 m wide at the top, topped with a 4 m wide cast in-situ reinforced concrete deck 200 mm thick. The UHPFRC girder ends were encased in normal strength concrete abutments at the bridge site and made integral with the abutment seating. The girder was built without any conventional shear reinforcement as the UHPFRC had considerable shear capacity. The UHPFRC used has achieved up to 180 MPa of compressive strength and 30 MPa of flexural strength. The bridge has also earned a status in the *Malaysia Book of Records* in year 2011. Detail of the construction of the composite bridge can be found in Voo et al. [27].

The precast girder consists of a total of seven segments, which consists of five standard internal segments (IS) each 8 m long that weighed 18 tons, and two end standard segments (ES) each 5 m long that weighed 15 tons (see

Figure 21). Unlike conventional precast concrete girders, the UHPdC girder does not have vertical shear link in its thin webs. The only conventional reinforcements used are the bursting reinforcement at the anchorage zone, lifting reinforcement at the tendon deflector positions, and horizontal shear reinforcement at the top flanges where connection with the RC deck is required.


**Figure 20:** Kampung Linsum Bridge, Rantau, Negeri Sembilan.

Initially the engineers who were engaged to design the bridge had proposed using two steel structural welded beams (see Figure 22a). Later on, the consultants chose to go with the UHPFRC girder design due to convincing argument and benefit of adopting an UHPFRC composite bridge design solution. Such benefits include no piers at the waterway of the river, much lower maintenance, more eco-friendly, better aesthetically and, most importantly, it was cheaper!

Figure 22b summaries the comparison of the EIC results between the UHPRFC and steel composite bridges. In terms of material consumption, the UHPFRC solution consumed 14% more material (in terms of weight) than the steel-composite girder solution. In terms of environmental impact, however, the UHPFRC solution had 66% less embodied energy and 57% less $CO_2$ emissions. In terms of the 100-year GWP, the UHPFRC solution gives a reduction of 52% over the steel-composite girder design. In addition to the environmental cost savings, the UHPFRC composite bridge superstructure resulted in a projected cost saving of 27%. Thus, the UHPFRC solution was not just better for the environment, it was a more economical solution based on initial costs. When maintenance costs are considered, the UHPFRC solution is vastly more economical!

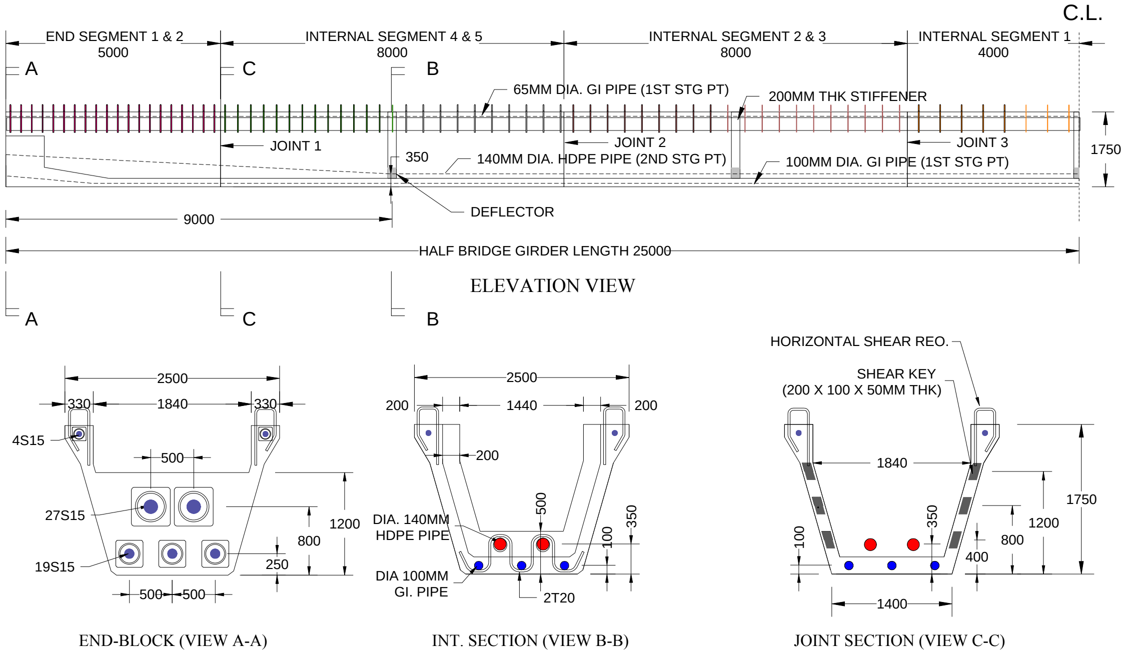
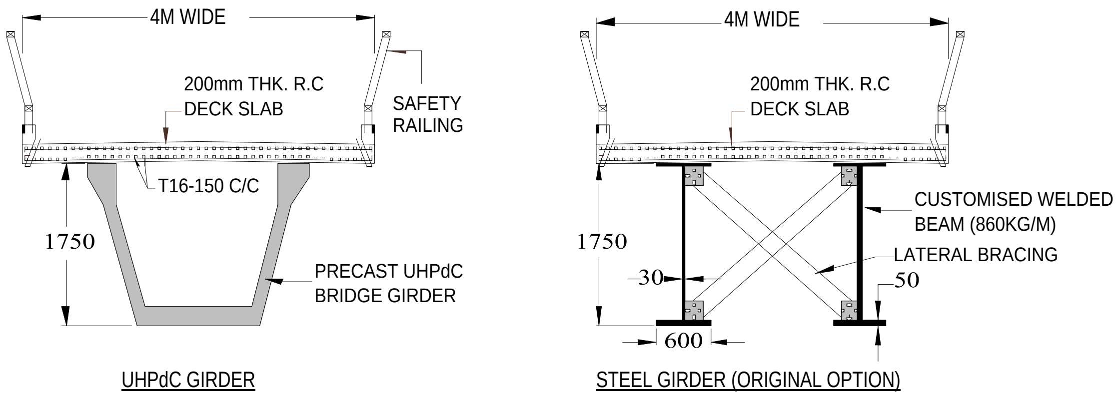



**Figure 21:** Detail of UHPFRC UBG1750 girder.

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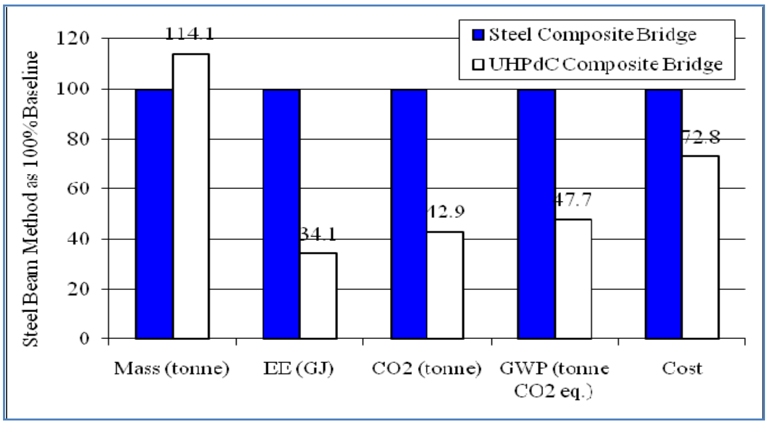



(b)

**Figure 22**: (a) Comparison of steel composite bridge against UHPFRC composite bridge, (b) EIC assessment (details in Voo et al. [3]).

## 2.6 25 M KAMPUNG ULU GEROH BRIDGE (MEDIUM TRAFFIC BRIDGE), COMPLETED

The JKR Perak (Kinta Daerah) was the first to use UHPFRC in Perak state in the construction of a short span motorway bridge at a small village called Kampung Ulu Geroh crossing a river call Sungai Itik (refer to

Figure **23**). To-date, this bridge is Malaysia first full UHPFRC bridge/deck system where the superstructure of the bridge is constructed without conventional RC deck. This bridge was designed to withstand 30 units HB loading and HA + KEL loading as per BD37/01. Construction of the bridge commenced at mid November 2011, and the bridge work was completed in mid January 2012 (which gives a construction period of 2 months). This bridge has a single span length of 25m and was constructed using two precast UHPFRC T-girders 1.375 m deep, 1.5 m wide at the top flange (refer to

Figure **23**).

The major obstacle in this project was the poor existing access road to the job site. The largest vehicles able to access to the site were the 20 tonnes capacity mobile crane and those ten wheels trucks which come with a tray length not exceeding 8 m. Given such constraint, the conventional precast RC beams was immediately ruled out in the design due to the self-weight of the 25 m long conventional precast RC beams which exceed the maximum possible carrying capacity of the two mobile cranes. The other possible option is using steel bridge where weight is not a major issue. However, the authority rule out this option too because maintenance is something they wanted to avoid. Besides, no centre pier is allowed in the waterway of the river. With these limitations, the UHPFRC bridge system proved to be the best solution as a single UHPFRC T-beam weighted only 25 tonnes and in addition the girder has remarkable durability. The UHPFRC girder ends were encased in normal strength concrete abutments and made integral with the abutment seating. Unlike any conventional concrete beam, the UHPFRC girders were built without any conventional shear reinforcement as the UHPFRC had considerable shear capacity.

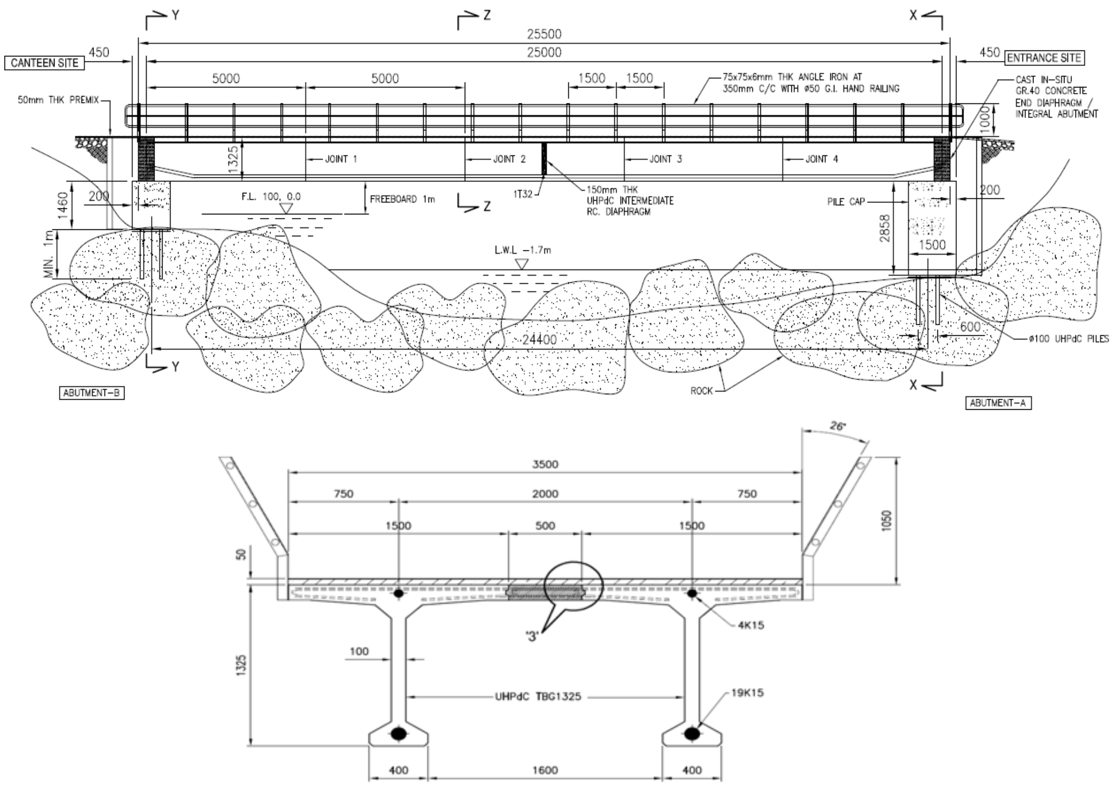



**Figure 23:** Typical sectional details of UHPFRC bridge at Kampung Ulu Geroh, Gopeng, Perak.

Figure 24a shows two units 20 tonnes capacity of mobile cranes were used to launch the girder. According to the beam launcher, they claimed this is the lightest concrete beam ever launched given the length of the girder is 25 m compared to the other beams. Figure 24b shows the bottom view of the two girders parked adjacent to each other with the joint ready to be stitched. UHPFRC bridge system is unique compare to other bridge system as the major part of the bridge deck was integrally casted together with the beam during manufacturing. Therefore, only small portion site required stitching work is required using the same grade of UHPFRC, after the beams have securely seated on the abutments. Figure 24c shows the in-situ UHPFRC was poured at the jointing area without any external compacting tools. After 1 day, the formwork was removed and the in-situ UHPFRC has attained an average cube compressive strength of 70 MPa (refer to Figure 24d). After 14 days, the cube sample of the in-situ stitch where tested to have an average cube compressive strength of 145 MPa.


(a)

(b)

(c)


(d)

(e)

**Figure 24:** (a) Beams launching using two units 20 tonnes capacity mobile crane, (b) in-situ bridge joint ready for stitching, (c) placing of in-situ UHPFRC for the bridge joints, (d) view from bottom of the bridge after stitching of the bridge joint and (e) the completed Kampung Ulu Geroh Bridge.

## 2.7 18 M KAMPUNG ULU KAMPAR BRIDGE (MEDIUM TRAFFIC BRIDGE), COMPLETED

Figure **25** shows another example on a short span bridge crossing a river with a total span length of 18 m was constructed by JKR Perak (Kinta Daerah). The bridge is located at a small village call Kampung Ulu Kampar, which is approximately 30 km from the capital city of Perak, Ipoh. Similar to the Kampung Ulu Geroh Bridge (refer to Section 2.6), this bridge also uses the full UHPFRC bridge/deck system. This bridge was designed to withstand 30 units HB loading and HA + KEL loading as per BD37/01. Construction of the bridge commenced at mid January 2012, and the bridge work was complete at end of February.

Similarly, the major challenge of the project is the poor access road to the job site. No long trailer is able to access to the job site. Although UHPFRC girder system has weight advantage over conventional system, the bridge designer or contractors still have bridge length issue to consider. The bridge designer eventually comes up with an idea to break the 18 m girder into three segments, thus having each segment measured 6 m long and weighted merely 6 tonnes. Thus a simple ten wheels truck can be used to transport the bridge segment (one at a time) and later on aligned off-site, then post-tensioned to form a single girder (see Figure 26).

**Figure 25**: The new UHPFRC bridge at Kampung Ulu Kampar, Gopeng, Perak.


(a) (b)

**Figure 26**: (a) A 10 wheels truck transporting one 6 m long UHPFRC girder segment and (b) bridge segments aligned off-site ready for post-tensioning work.

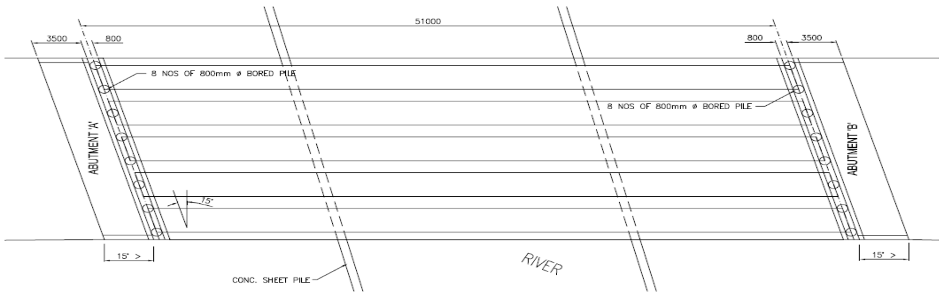
## 2.8 51 M RANTAU-SILIAU BRIDGE (RANTAU, NEGERI SEMBILAN), ON-GOING

After the construction of Kampung Linsum bridge (refer to Section 2.5), the JKR Negeri Sembilan has decided to replace a multi-span old concrete bridge which span approximately 50 m. Figure 27a shows a recent photo of the existing bridge which has four rows of central RC columns (i.e. 5 columns per row) located at the waterway of the river. Figure 27b shows during the monsoon season, very often, large amount of debris trapped at the piers, which may not be an ideal practice due to large timber or logs may flow from the upstream and collide with the columns, thus eventually reduce or damage the structural integrity and safety of the bridge. JKR Negeri Sembilan took the full advantage of the UHPFRC technology and putting up a new single span 51 m long motorway bridge which comes with four carriageway lanes using five pieces of the same UHPFRC U-trough girder as presented in

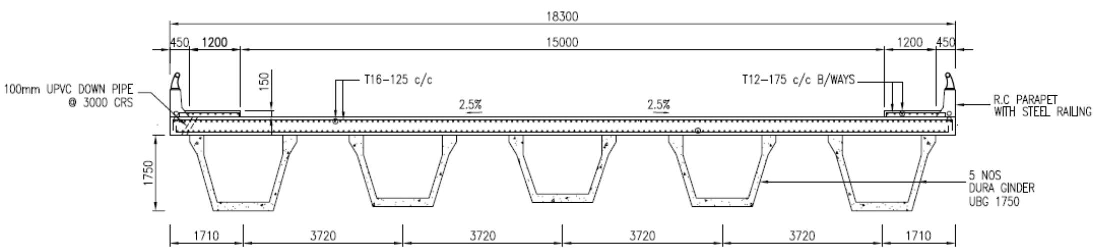
Figure 21. The UHPFRC girder ends were encased in normal strength concrete abutments at the bridge site and made integral with the abutment seating. The bridge will be constructed without any central columns thus leaving the entire waterway of the river clear from obstruction. Detail of the new bridge is given in Figure 28. The bridge was designed to withstand full highway loading as per BD37/01.

(a) (b)

**Figure 27**: (a) Existing old RC bridge with four rows of RC piers at the waterway of the river and (b) debris collected at the piers.




(a)

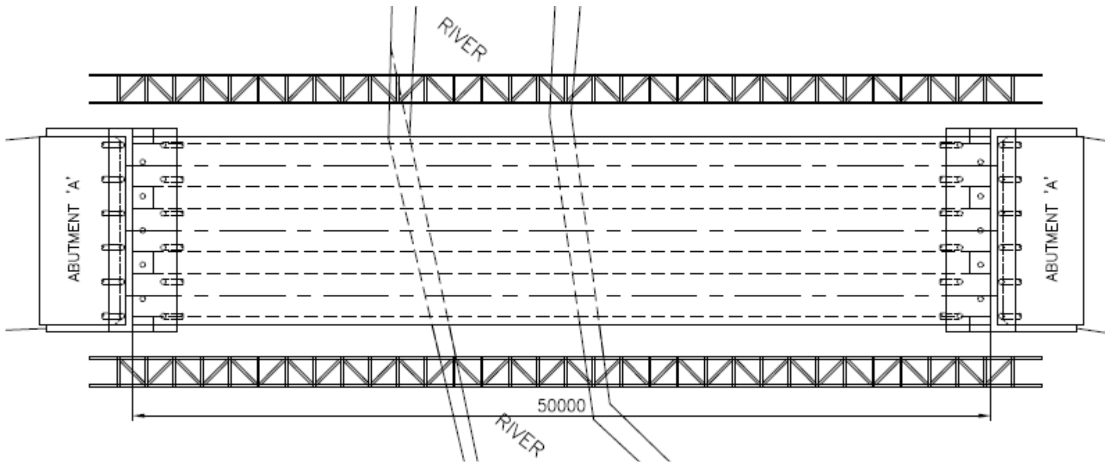



(b)

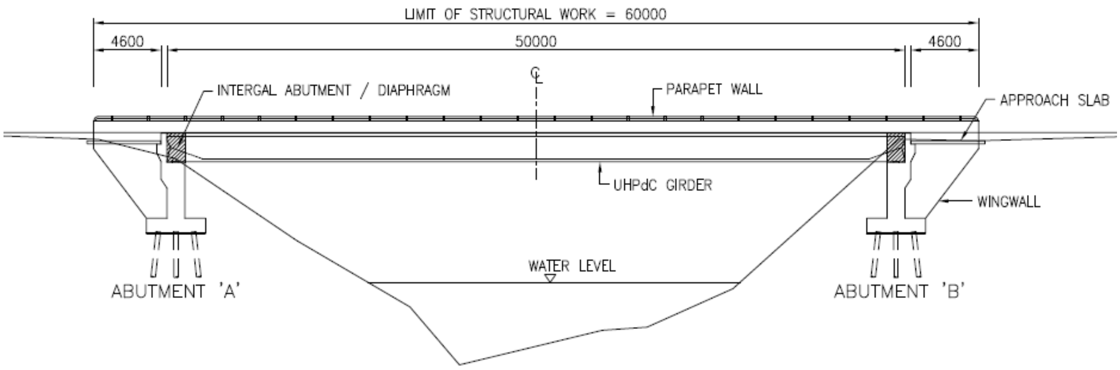
**Figure 28**: (a) Plan View and (b) Typical Bridge Section of new Rantau-Siliau Bridge.

## 2.9 50 M TITI BRIDGE (JELEBU, NEGERI SEMBILAN), ON-GOING

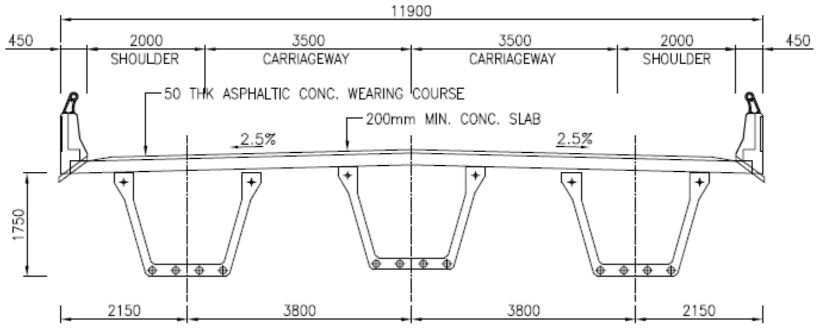
Figure 29 presents the general detail of a new dual carriageway motorway bridge that is currently under construction by JKR Negeri Sembilan. The composite bridge has a clear span of 50 m (leaving the entire waterway of the river clear from obstruction), and total bridge deck width of 11.9 m. The bridge was designed to withstand full highway loading as per BD37/01. Figure 29 shows the typical section of the bridge, whilst the bridge were constructed using three UHPFRC U-trough girders 1.75 m deep, 2.5 m wide at the top, topped with a 200 mm thick cast in-situ reinforced concrete. The UHPFRC girder ends was encased in normal strength concrete abutments at the bridge site and made integral with the abutment seating. The UHPFRC girder was built without any conventional shear reinforcements. Construction of the bridge was expected to complete by early 2013.




(a)




(b)




(c)

**Figure 29**: (a) Plan View, (b) Elevation View and (c) Typical Bridge Section of new Titi Bridge.

## 2.10 90 M SUNGAI NEROK BRIDGE (LENGGONG, PERAK), ON-GOING

To-date, the JKR Perak is *possibly* the world's first organization to use UHPFRC bridge girder in the construction of a multi-spans motorway bridge. Figure 30 shows the schematic detail of a newly awarded dual carriageway motorway bridge, which is currently under construction at Jalan Lenggong, crossing a river call Sungai Nerok (Kota Tampan Air). The bridge consists of three equal spans where each span has a span length of 30m c/c.

Similar to Kampung Ulu Geroh Bridge (refer to Section 2.6) and Kampung Ulu Kampar Bridge (refer to Section 2.7), this bridge is using the UHFRC bridge/deck system where the superstructure of the bridge is constructed without conventional RC deck. Figure 30 shows a total of 30 m UHPFRC Tee-girders used to construct the bridge. All the UHPFRC girders will be encased with normal concrete at the abutments/piers making the whole bridge as a full integral bridge without any expansion joint. This bridge was designed to withstand 45 units HB loading and HA + KEL loading as per BD37/01. Construction of the bridge is expected to commence at March 2012, and the bridge work is expected to complete before 2013.

According to the bridge designer, the superstructure of this bridge is approximately half the weight of the conventional design, which leads to significant saving in term of foundation. Besides that, the highly durable nature of UHPFRC promises to offer much longer design life and offers almost negligible maintenance during the service life of the bridge.

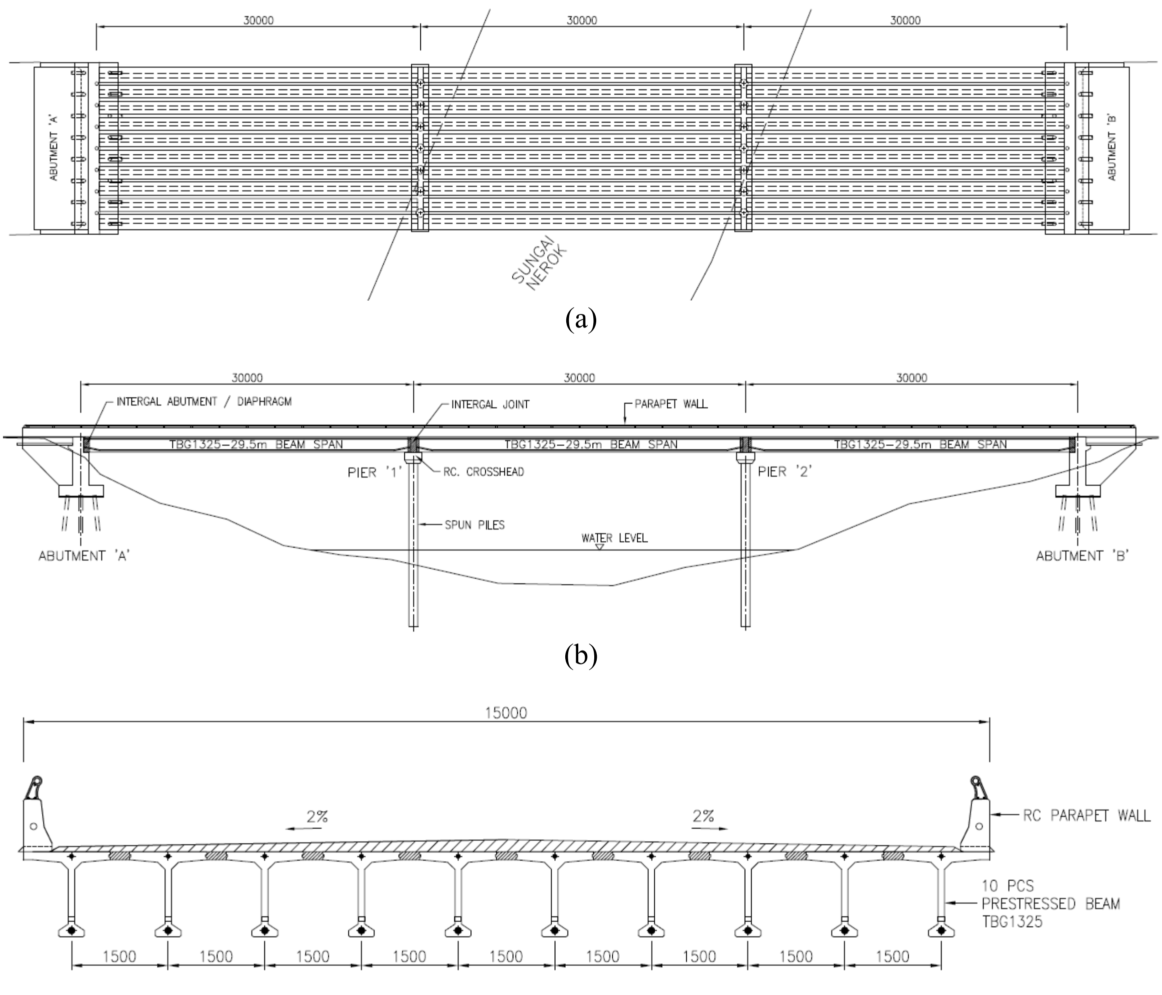



**Figure 30**: (a) Plan View, (b) Elevation View and (c) Typical Bridge Section of new Sungai Nerok Bridge, Lenggong, Perak.

## 2.11 29 M KAMPUNG BANIR BRIDGE (BATANG PADANG, PERAK), ON-GOING

Recently, the JKR Perak has called for tender on a dual carriageway bridge. Figure 31 shows the schematic detail of a newly tendered motorway bridge, which is located at Kampung Banir at Batang Padang. The bridge consists of single span crossing of 29 m. Similar to Kg. Ulu Geroh Bridge (refer to Section 2.6), Kg. Ulu Kampar Bridge (refer to Section 2.7) and Sungai Nerok Bridge (refer to Section 2.10), this bridge will be constructed using the UHFRC bridge/deck system where the superstructure of the bridge is constructed without conventional RC deck. All the UHPFRC girders will be encased with normal concrete at the abutments making the whole bridge as a full integral bridge without any expansion joint. This bridge was designed to withstand 45 units HB loading and HA + KEL loading as per BD37/01. Construction of the bridge is expected to commence at June 2012, and the bridge work is expected to complete before 2013.

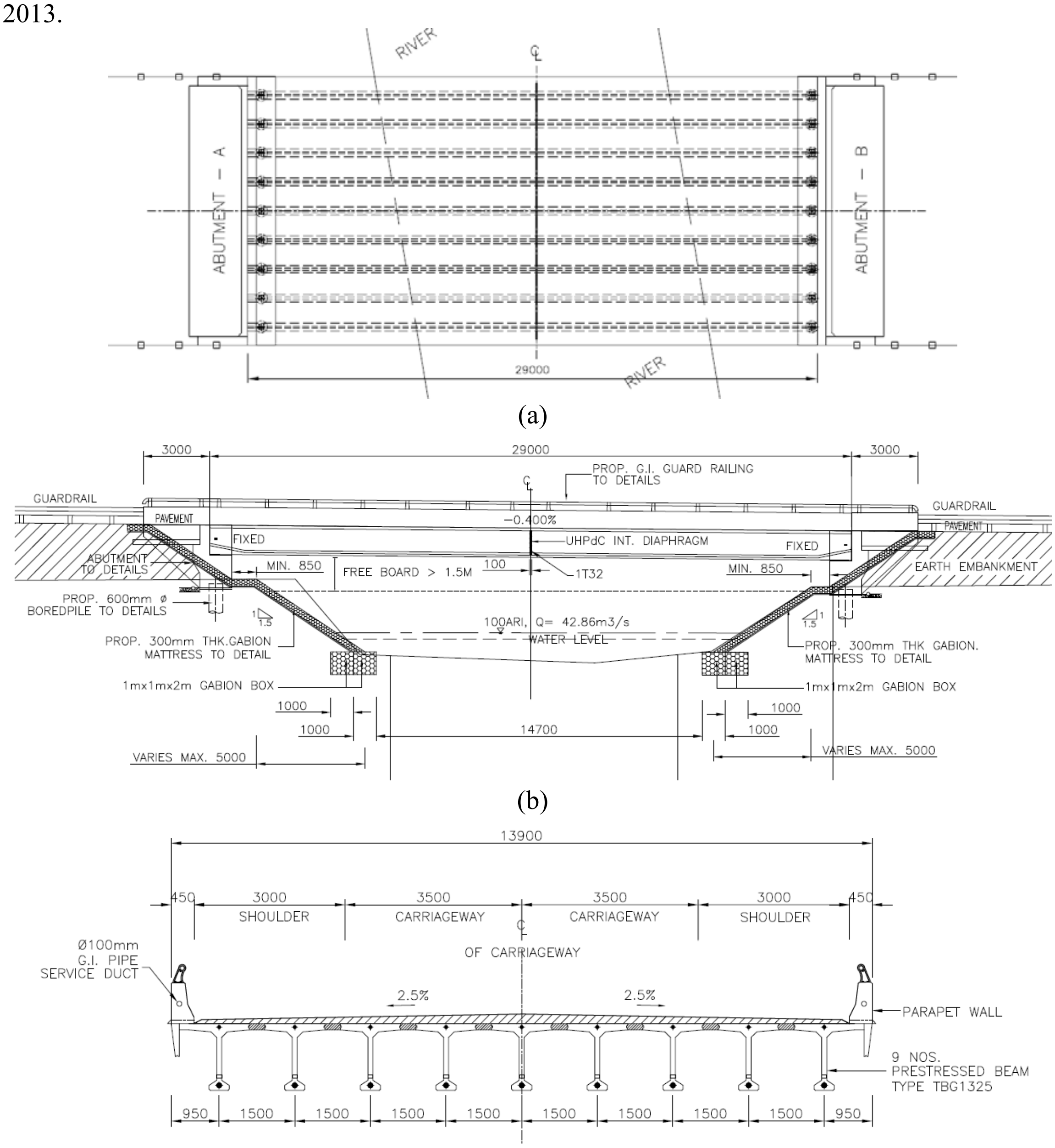



**Figure 31**: (a) Plan View, (b) Elevation View and (c) Typical Bridge Section of new bridge at Kampung Banir, Badang Padang, Perak.

## 2.12 173 M ARCHES FOR TOLL CANOPY (PULAI PENANG), ON-GOING

Recently, RMS Architect has designed a 150 m long by 30 m wide elliptical shape toll canopy at the Plus toll plaza of the Second Penang Bridge. The roof canopy is designed to be over-hanged by a pair of structural arches, come with arch length of 186 m, arch horizontal length of 173m and vertical height of 30 m (see

Figure **32**). In this project, the project owner and concessionaries are the Lembaga Lebuhraya Malaysia (LLM) and Jambatan Kedua S/B, respectively. Initially the structural members of the arches were proposed to be built using conventional steel truss structure. However, it was later proposed with an alternative design where UHPFRC arch-like pipe structures were used because the owners have foreseen the benefit of using UHPFRC arch which includes mainly the elimination of maintenance as the arch structure is built close to the sea-side. In addition it gives immediate cost saving and improved aesthetics.

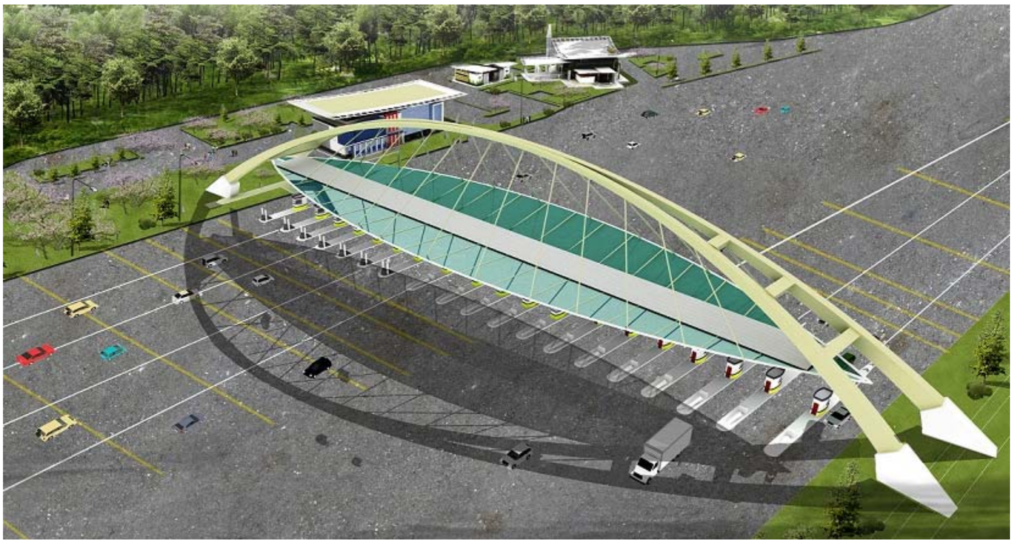
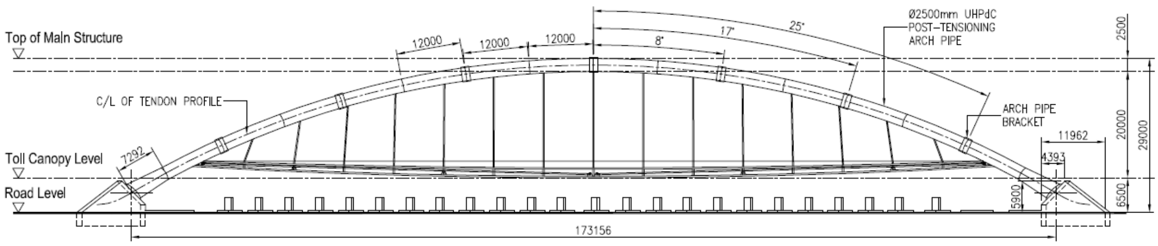
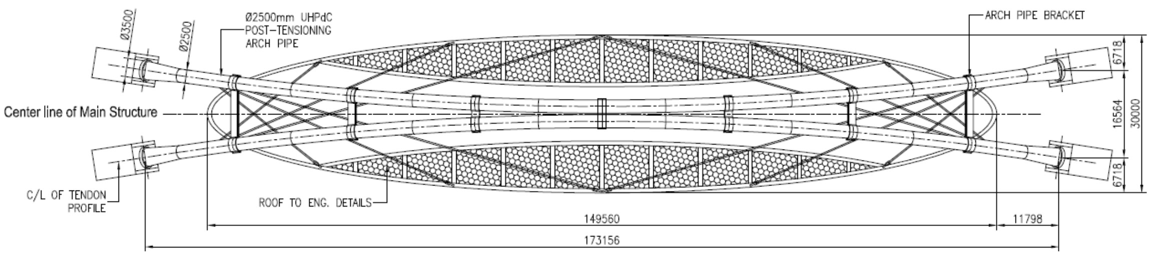


**Figure 32**: Artist impression of the proposed toll canopy and the arches.




(a)




(b)

**Figure 33**: (a) Elevation View and (b) Plan View of proposed toll canopy.

## 3.0 CONCLUSION

This paper briefly presents some of the successful and on-going applications of UHPFRC technology in Malaysia. Some of the examples presented were the portal frame building, retaining wall, motorway bridges, security wall panel and arch structures. Throughout the examples presented herein, the technology of UHPFRC has proven to be an alternative sustainable construction material that embraced the uniqueness of both concrete and steel. Besides, the environmental impact assessment shows that UHPFRC structures are able to give immediate savings in terms of primary material consumption, embodied energy, $CO_2$ emissions and global warming potential. The UHPFRC technology is proved to be a greener construction material as it supports the vision of a sustainable construction in future. The authors are of the opinion that in the future, UHPFRC technology will contribute significantly to the realization of sustainable development. The technology carries an equation that sums up 'sustainable construction' in that it provides for a minimum impact on the environment, maximizes structural performance and provides a minimum total life-cycle cost solution. The benefits are:

- immediate reduction in overall consumption of non-renewable raw material;
- encourage the use of recycle materials (such as silica fume and GGBS);
- better quality and finishes of finishing products;
- prolong the service and design life of structures;
- minimized maintenance due to the its superior durability;
- support the visionary of green economy.

## REFERENCES

[1] BS1881-Part 114, 1983. Testing concrete. Methods for determination of density of hardened concrete. *British Standard*, British Standards Institution, ISBN. 0-580-12948-9, 8 pp.

[2] AS 1012.9, 1999. Determination of the compressive strength of concrete specimens. *Australian Standard*, Standards Australia, 12 pp.

[3] BS6319-2, 1983. Testing of resin and polymer/cement compositions for use in construction. Method for measurement of compressive strength. *British Standard*, British Standards Institution, 4 pp.

[4] AS1012.16, 1996. Determination of creep of concrete cylinders in compression. *Australian Standard*, Standards Australia, 8 pp.

[5] BS1881-Part 121, 1983. Testing concrete. Methods for determination of static modulus of elasticity in compression. *British Standard*, British Standards Institution, 7 pp.

[6] BS EN 12390-6, 2000. Testing hardened concrete. Tensile splitting strength of test specimens. *British Standard*, British Standards Institution, ISBN: 0-580-36606-5, 14pp .

[7] ASTM C496, 2004. Standard test method for splitting tensile strength of cylindrical concrete specimens. *ASTM Standards*, ASTM International, United States, 5 pp.

[8] ASTM-C1018, 1997. Standard test method for flexural toughness and first crack strength of fiber reinforced concrete (using beam with third point loading). *ASTM Standards*, ASTM International, United States, 8 pp.

[9] ASTM C1202, 2005. Standard test method for electrical indication of concrete's ability to resist chloride ion penetration. *ASTM Standards*, ASTM International, West Conshohocken, PA, 6 pp.

[10] ASTM C1556, 2004. Standard test method for determining the apparent chloride diffusion coefficient of cementitious mixtures by bulk diffusion. *ASTM Standards*, ASTM International, United States, 7 pp.

[11] BS EN 14630, 2006. Products and systems for the protection and repair of concrete structures. Test methods. Determination of carbonation depth in hardened concrete by the phenolphthalein method. *British Standard*, British Standards Institution, ISBN: 0-580-49622-8, 12 pp.

[12] ASTM C944-99, 2005. Standard test method for abrasion resistance of concrete or mortar surfaces by the rotating-cutter method. *ASTM Standards*, ASTM International, United States, 4 pp.
[13] BS1881-Part 122, 1983. Testing concrete. Method for determination of water absorption. *British Standard*, British Standards Institution, ISBN: 0-580-12959-4, 4 pp.
[14] Adeline, R., lachemi, M., & Blais, P. (1998). Design and behavior of the Sherbrooke Footbridge. Paper presented at the the International Symposium on High-Performance and Reactive Powder Concretes, Sherbrooke, Canada.
[15] Deem, S. (2001). Concrete Attraction-Something New on the French Menu-Concrete. Retrieved 10 June 2009, from http://www.popularmechanics.com/science/research/2002/6/concrete/print
[16] Cavill, B., & Chirgwin, G. (2003). The world's First RPC Road Bridge at Shepherds Gully Creek, NSW. Paper presented at the 21st Biennial Conference of the Concrete Institute of Australia (CIA), NSW, Australia.
[17] Graybeal, B. A. (2011). FHWA TECHNOTE: Ultra High Performance Concrete, FHWA Publication No: FHWA-HRT-11-038: Federal Highway Administration.
[18] Voort, T. L. V., Suleiman, M. T., Sritharan, S., Iowa Highway Research Board, & Iowa Dept. of Transportation. (2008). Design and Performance Verification of UHPC Piles for Deep Foundations: Center for Transportation Research and Education, Iowa State University.
[19] Massicotte, B., & Boucher-Proulx, G. (2010). Seismic Retrofitting of Bridge Piers with UHPFRC Jackets Designing and Building with UHPFRC: State of the Art and Development (pp. 531-540). London: Wiley-ISTE.
[20] Brühwiler, E., & Denarié, E. (2008). Rehabiltation of Concrete Structures Using Ultra- High Performance Fiber-Reinforced Concrete Proceedings of the Second International Symposium on Ultra-High Performance Concrete. Kassel, Germany.
[21] Schmidt, C., Riedl, S., Geisenhanslüke, C., & Schmidt, M. (2008). Strengthening and Rehabilitation of Pavements Applying Thin Layers of Reinforced Ultra-High Performance Concrete (UHPC-White Topping) Proceedings of the Second International Symposium on Ultra-High Performance Concrete. Kassel, Germany.
[22] Green, B. (2010). An Investigation of UHPC/RPC Materials for Enhanced Penetration Resistance Paper presented at the the American Concrete Institute Fall Convention.
[23] Rebentrost, M., & and Wight, G. (2009). Investigation of UHPFRC Slabs Under Blast Loads. Paper presented at the Proceedings, Ultra-High Performance Fiber Reinforced Concrete Marseille, France.
[24] Voo, Y. L., & Foster, S. J. (2009). Reactive powder concrete: analysis and design of RPC girders. Germany: Lambert Academic Publishing.
[25] Voo, Y. L., and Poon, W.K., (2008), "The World First Portal Frame Building (Wilson Hall) Constructed Using Ultra-High Performance Concrete", 33rd Conference on "Our World in Concrete & Structures: Sustainability", 25 -27 August 2008, Singapore, pages: 493 –500.
[26] Poon, W.K., Voo, Y.L., and Yap, S.K, (2009), "Thin Protective Wall Panel Made From 150 MPa Ultra-High Performance Ductile Concrete (UHPdC-DURA)" Proceedings of the 10th International Conference on Concrete Engineering and Technology 2009 (CONCET 2009), 02-04 March, Shah Alam, Kuala Lumpur, Malaysia. (in CD-format).
[27] Voo, Y.L., Augustin, P.C., and Thamboe, T.A.J., (2011), "Construction and Design of a 50 m Single Span UHP Ductile Concrete Composite Road Bridge", The Structural Engineer, Vol 89(15), 2nd August, The Institution of Structural Engineers, UK, pages: 24–31