THE SECOND PENANG BRIDGE: SUSTAINABLE DESIGN, CONSTRUCTION AND OPERATION

Presented by : Dr. Ismail Mohamed Taib,
Managing Director, Jambatan Kedua Sdn Bhd

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Content

Abstract

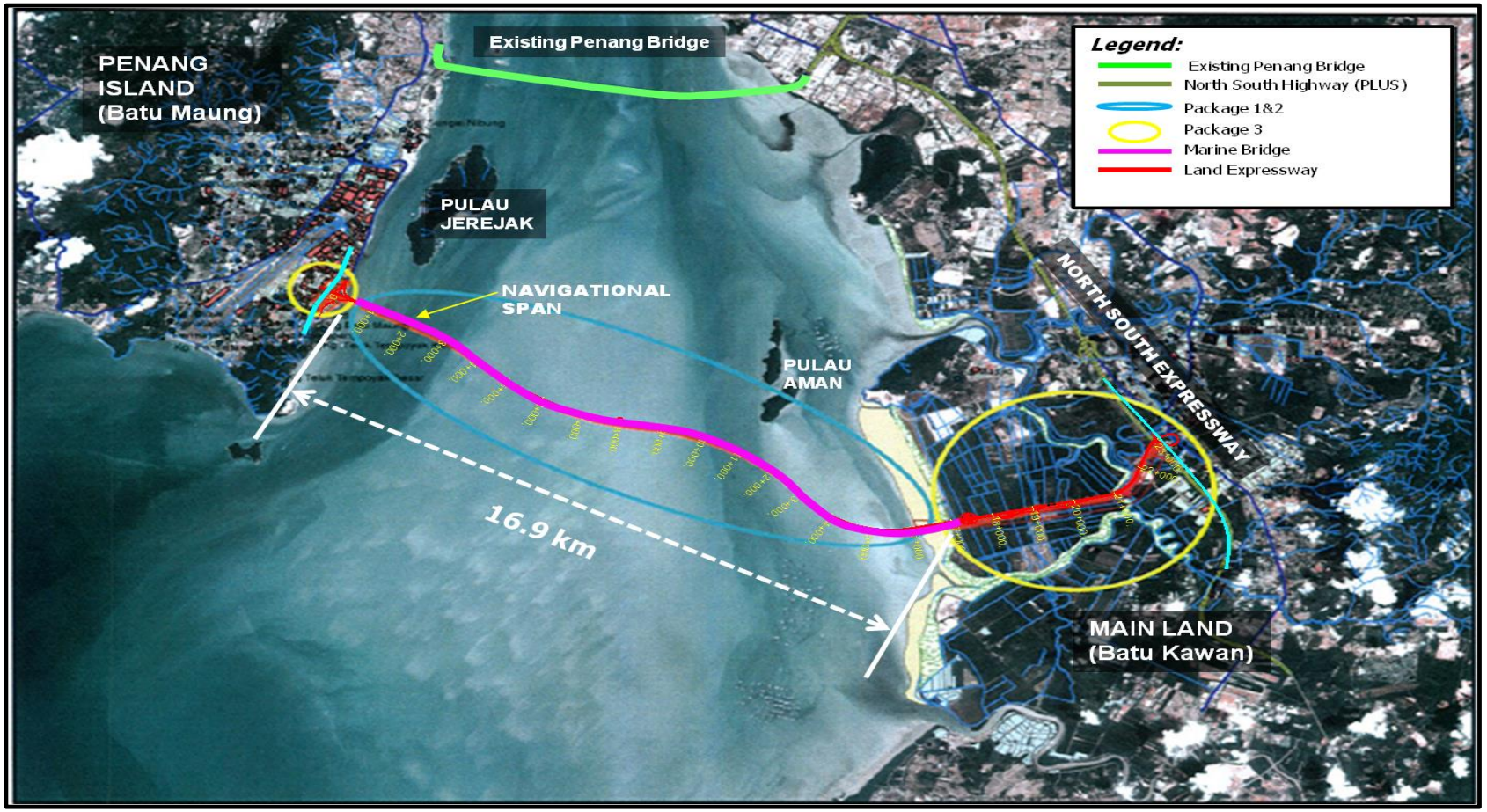
- Jambatan Kedua Sdn Bhd (JKSB), a wholly-owned company of the Malaysia Minister of Finance (MoF Inc.) is the concessionaire for the Second Penang Bridge Project (PB2X).
- The bridge with the cost of RM4.5 billion was crowned as longest in South-East Asia with a total length of 16.9 km over water.
- The construction of PB2X commenced in November, 2008 was open to traffic on 1st March 2014.
- The Project faces various challenges in applying sustainability to both design, construction, operation and maintenance.
- It is also pioneering in Malaysia to be fully designed for seismic load for a 475 year return period earthquake and a 2500 year return period earthquake with "no collapse" criteria.

Project Introduction

- The Second Penang Bridge when completed, will improve trade efficiency and enhance logistics systems by providing better connectivity and accessibility to Penang International Airport.
- The bridge will alleviate the current overloaded traffic at the existing bridge and to meet the future traffic demand, apart from being one of the key elements in the development of Penang as logistics and transportation hub for the northern region of Malaysia under the Northern Corridor Economic Region (NCER) programme.
- Feasibility Study on the Project started under the 8th Malaysia Plan and completed in 2002.
- The preliminary Environment Impact Assessment study was undertaken for the project and approved by the Department of Environment in 2007.

Project Alignment

- **JKSB was appointed as concessionaire for PB2X in August 2008 for period of 45 years. It is responsible for the project management, design, construction, operation and maintenance.**



Overall Project Organization

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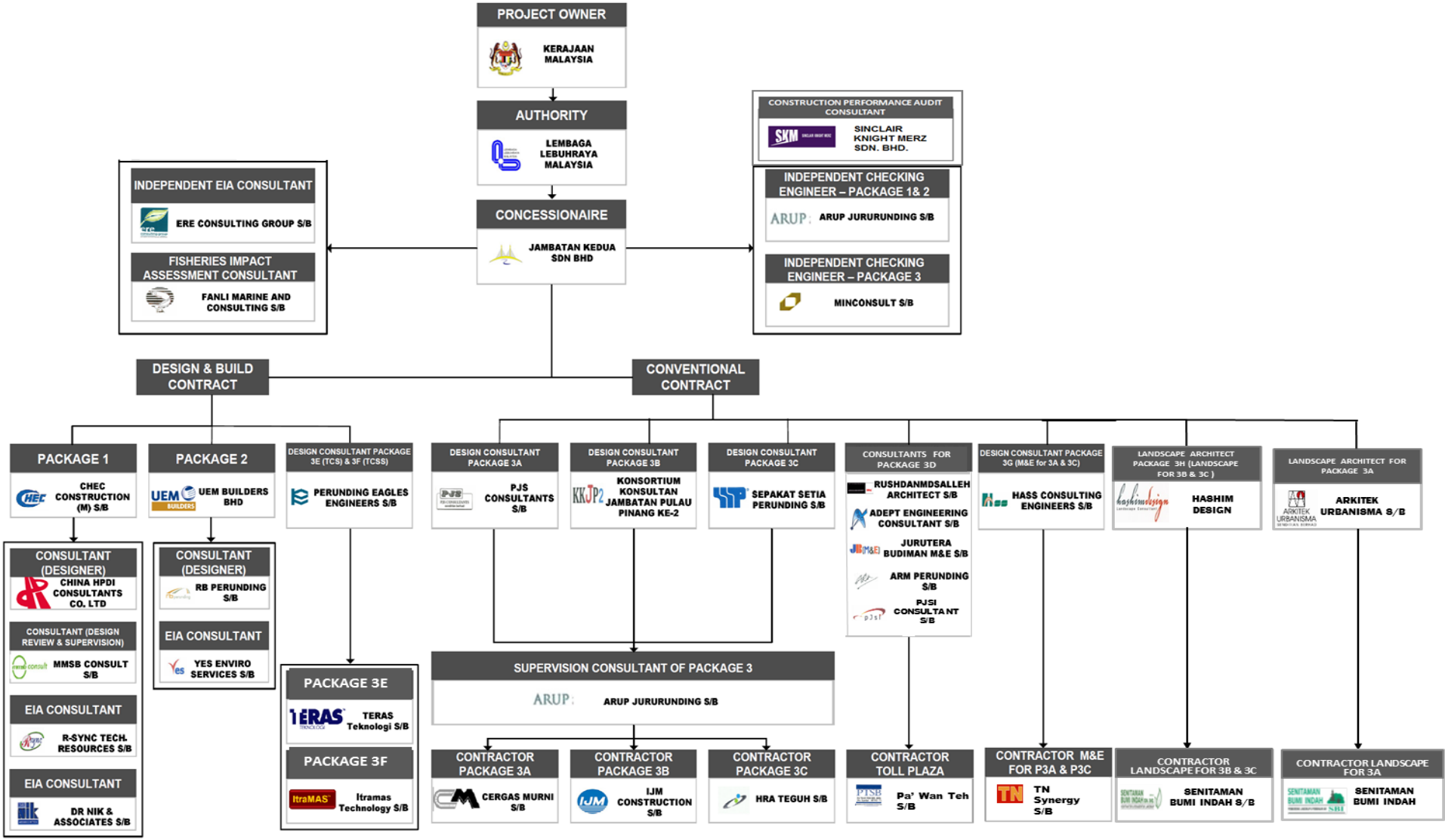
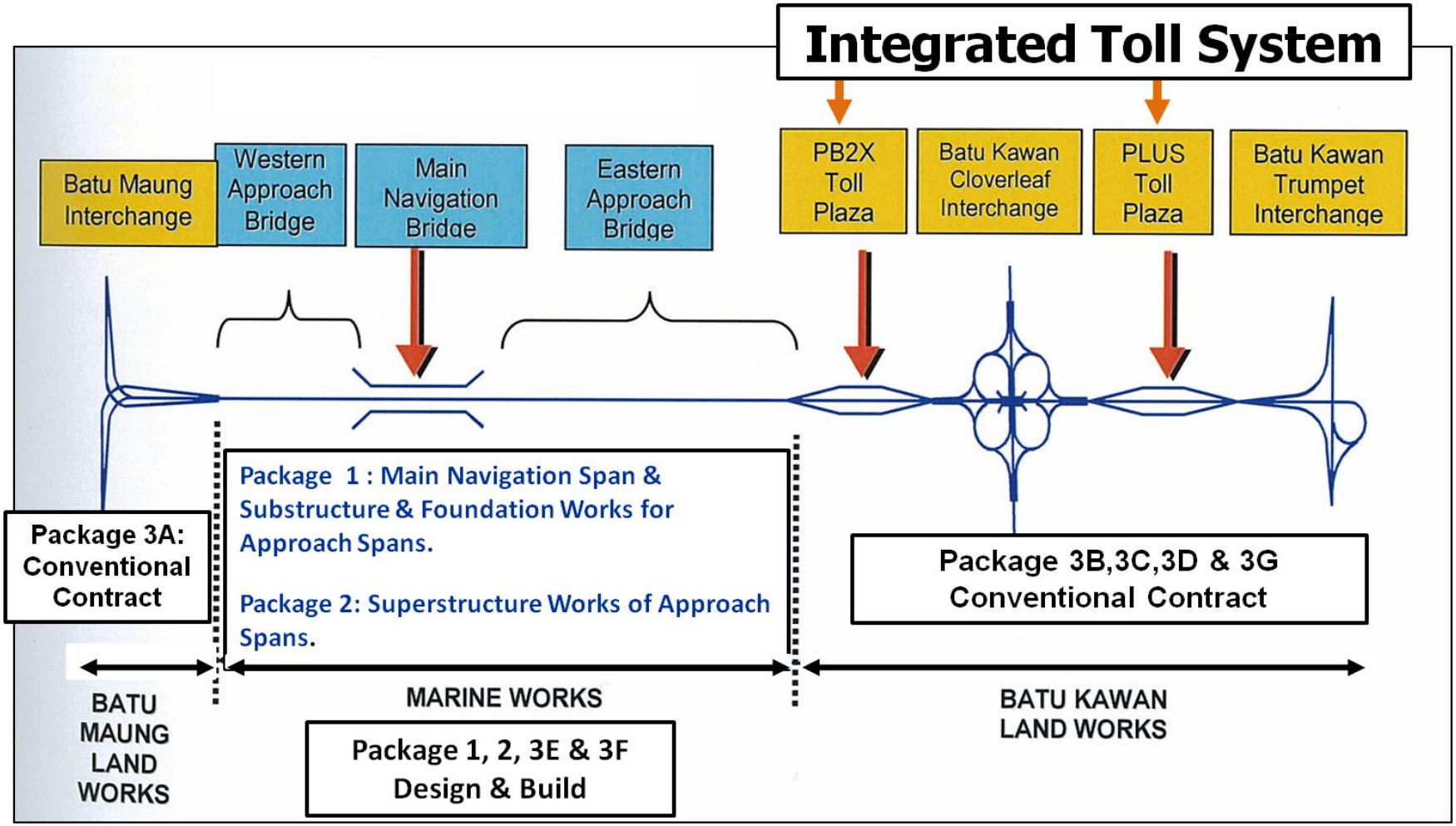


Distribution of Contract Packages

- **PB2X is divided into the following packages :-**



Sustainable Development

- **JKSB has undertaken the lifecycle management of PB2X where sustainable development and green technology are the key to building the future.**
- **Sustainable development is an enduring balanced approach to social progress, economic activity and environmental responsibility.**
- **The emphasis to a lowest whole life cost is to promote the concept of design for durability. Durability is influenced by the following factors:**
  - **Design and detailing**
  - **Specification of materials used in construction**
  - **Quality of construction**
- **In effort to conserve natural resources and protect the environment, high standards of environment protection were incorporated.**
- **Marine fauna were closely monitored to avoid changes to the sensitive marine environment.**

Design Stage

- **Most of the bridge sections utilized IBS and prefabricated on land to reduce the amount of time spent at sea and the risks of damaging or polluting the marine environment.**
- **The segmental box girders (SBG) were optimally design for minimum weight and lesser embodied energy by adopting higher reinforcement ratios and less but higher strength concrete .**
- **The use of hybrid pre-stressing encompassing both external and internal pre-stressing increases design economy.**
- **All concrete use of high performance concrete with RCPT < 800 coulombs in 56 days, concrete cover and crack width conforming to latest Eurocode requirement.**

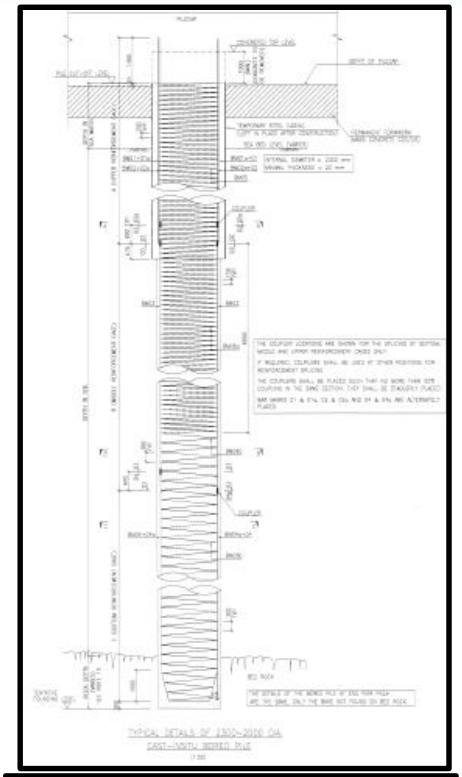
Construction Stage

- **Stringent quality control in accordance to project specification were enforced to ensure minimal maintenance.**
- **The best practice was adopted for the bridge construction including equipment selection and working method statements.**
- **Every 2 months, periodic site audit are done by the Independent Checking Engineer.**
- **The dredging of the 270m wide construction channel involving 14 million cubic metres of the Great Kra Flats seabed.**
- **The sludge was disposed off Pulau Kendi by barges installed with satellite tracking, trap door and depth sensor devices.**
- **PB2X construction use repetitive steel formwork and machineries for casting of 291 nos. pile caps, piers, pylons and 8092 nos. of SBG.**
- **A monthly environmental monitoring audit is done by and independent EIA consultant. Quarterly fisheries impact assessment for marine and fisheries resources including aquatic environment and aquaculture are also done.**

Foundation And Substructure Design

MAIN NAVIGATION SPAN

- For the marine portion, Soil Investigation (SI) works were carried out with 205 nos. of boreholes drilled of which 50% were technical boreholes and 50% were common geological boreholes.



BORED PILES

- 2.0m diameter with average of 120m were adopted for Cable-Stayed Bridge.
- have achieved a capacity of 25 MN at 120m depth with 8m socketed in bedrock.
- Reversed Circulation Drilling (RCD) method was adopted and the total time taken is 2 weeks to complete one point for each RCD.

- The platform constructed for the bored piling works which after the piling works are lowered down together with the Steel Fender to be reused as a pilecap soffit and side formwork for the Cable- Stayed Bridge pile caps.

APPROACH SPAN

For Approach spans, different types of piling are adopted as stated below:-

Spun Piles

- **1.0 m diameter with prefabrication length of 65m with no joints were used over 85% of the entire approach spans substructure.**

Steel tubular piles

- **1.6 m diameter steel tubular piles with average driven length of 80 m were used in deep water area (adjacent to the Main Navigation Span).**

Bored piles

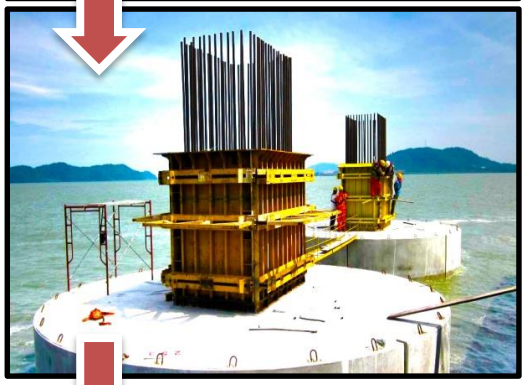
- **1.5 m bored of average length 80 m were used at mudflats near to mainland due to difficulty in dredging.**

APPROACH SPAN

Pilecap

Two stages construction of pilecap are adopted:

- **To minimize temporary works and in situ works, precast RC shells were used for the pilecaps.**
- **The pilecap were designed to have two stages of casting.**
- **The 1st layer is cast to act as a base for the installation of precast concrete shell and to act as permanent formwork for the 2nd layer.**



APPROACH SPAN

Sub Structure

Steel formwork

- **518 nos. of low piers (maximum height 6m) were constructed in a single cast using continuous set of pre fabricated steel formwork from pier to crosshead.**
- **60 nos. of high piers (>6m to 21.6m) were constructed using layers of prefabricated steel formwork.**

Superstructure Design

Superstructure at the Approach Span – Segmental Box Girder (SBG)

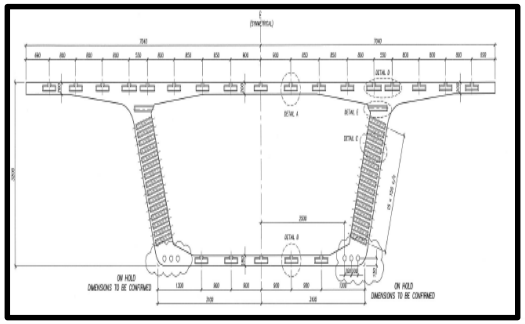
- **The superstructure of approach spans adopts SBG 14.08m width, 4.0m length and 3.20m depth. Short line casting was selected because it does not require extensive casting facilities, special heavy lifting equipment and storage.**

- **The specific data SBG casting requirements as below:-**

  - *Weight of each SBG – 65 - 100 tonnes*
  - *Early strength – 12 N/mm² (after 12 hours is required for internal, side, and cantilever formwork to stripped)*
  - *Daily output – 15 nos/day (at peak)*
  - *Total moulds – 21 moulds*

- **The segments are launched to the sea via barges and erected on a span-by-span using overhead self launching girder.**

- **40 nos. complete spans of 14 segments are easily able to be completed within one month period.**



Main Span Stay Cables

- The cable stayed bridge utilizes post tensioned concrete beam-and-slab decks. The concrete cross girders are cast in-situ with a 250mm deck slab. At the pylon the deck is built-in into the legs to provide fixed support.
- The semi fan layout stay cables system is designed based on parallel strand system with associated anchorages and deviation saddles of low relaxing high strength steel strands of diameter 15.7mm are arranged symmetrically in 2 planes of 18nos. of cables.
- The typical spacing of the cables at the edge beam and pylon is 6m and 2.525m respectively.
- The cables are symmetrically tensioned and anchored both at the edge beams and at the pylons with cable saddles at the pylon.

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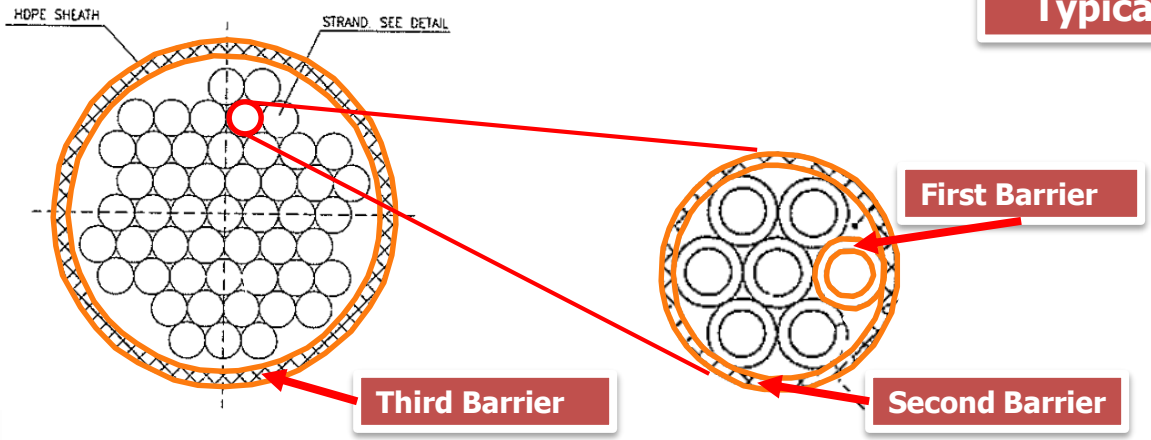
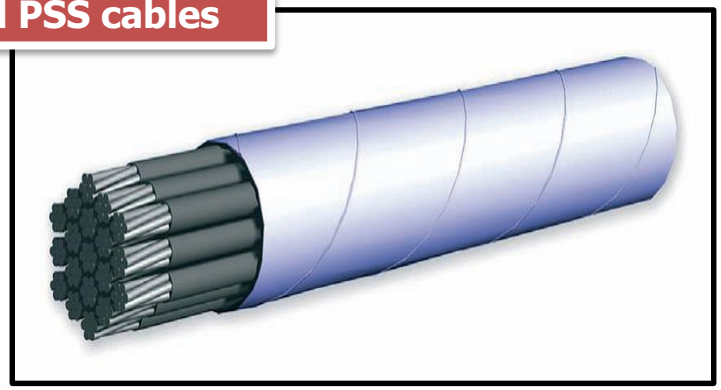
Main Span Stay Cables (con't)



Typical PSS cables



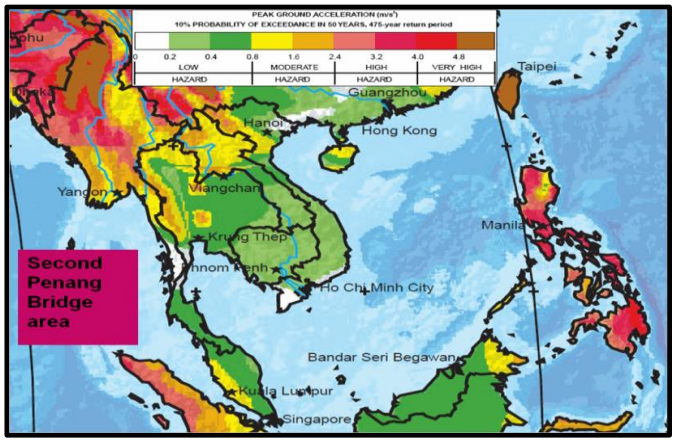
- Corrosion protection is provided for the main tension elements by using at least 3 complete nested barriers.
- The strands are galvanized and individually sheath inside a grease filled HDPE duct and additionally surrounded by external HDPE duct.
- The construction cycle for each segment is typically 13 days.

Design Consideration

Seismic Design Consideration

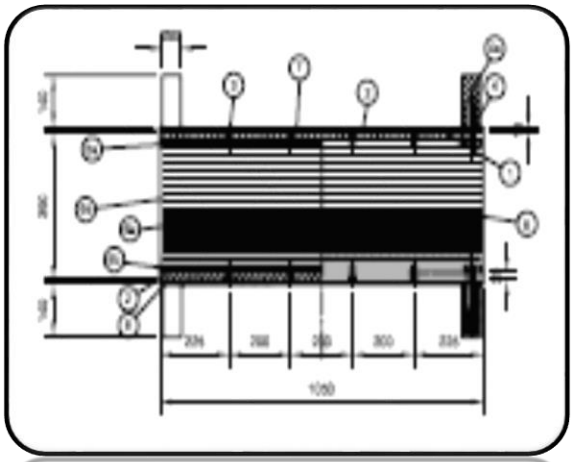
- Second Penang Bridge area is located within the stable Sunda tectonic plate with low seismic activity level. However, this low seismic region is situated about 300-600 km from Sumatran faults which have produced earthquakes with ground motions that are felt in buildings in Kuala Lumpur and Singapore.
- In line with the current design requirement, the Second Penang Bridge is pioneering in Malaysia to be fully designed for seismic load for a 475 year return period earthquake and a 2500 year return period earthquake with 'no collapse' criteria.
- The seismic design was based on the Design Response Spectrum obtained from a Seismic Hazard Assessment Study carried out for the Project.
- The seismic design criteria as below: -

Return Period (Years)	Peak Bedrock Acceleration (PBA)	Peak Response Acceleration (PRA)	Damage Performance Level		
			Marine Bridge	Land Expressway	
				Critical Bridge	Other Bridges
475	0.0555g	0.1773g	Minimal damage	Minimal damage	Repairable damage
2500	0.11g	0.3261g	No collapse		



High Damping Rubber Bearing (HDRB)

- During the design review process, the Independent Checking Engineer (ICE) had highlighted that the spun piles at the approach marine bridge by Package 1 Contractor could only safely cater for the 475 year earthquake and found to be overstressed under the 2500 year earthquake event and the piles would experience section failure due to brittleness.
- A resolution between JKSB, ICE and Package 1 designer was reached by changing the bridge articulation via introducing seismic bearing as construction was already at an advanced stage.
- HDRB has the ability to withstand large displacement in bilateral and rotational direction, durable with minimal maintenance as well as utilizing natural rubber available locally
- Package 2 Contractor was instructed to adopt High Damping Rubber Bearings (HDRB) to replace the conventional mechanical pot bearings.
- HDRB was designed by Tun Abdul Razak Research Centre (TARRC) at Brickendonbury, United Kingdom, a laboratory of the Malaysian Rubber Board (MRB).



HDRB –Section

Ship Collision Impact Load

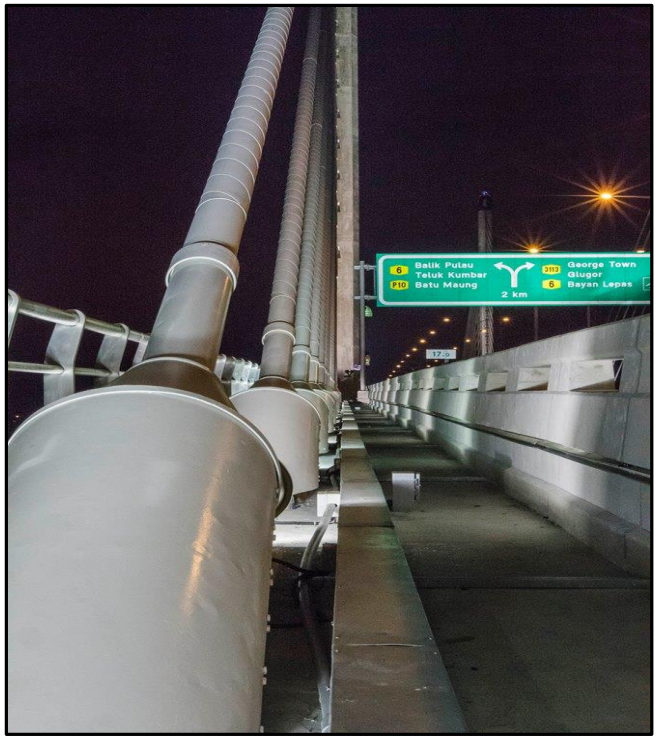
- **The following Ship Collision Impact Loads are adopted in the design following the guidelines in "AASHTO LRFD Bridge Design Specifications 2004". A risk assessment was conducted to verify the following ship collision impact loads to meet with the Government Requirements.**

No.	Location	Design Criteria
1.	Main Navigation Bridge pylons	• Design loads are 27.6 MN • The resistance will be sufficient to withstand impacts from 4,500DWT ship at a speed of 6.7 knots at pylons.
2.	Transition Piers adjacent to the Main Navigation Bridge	• Design loads are 13 MN • The resistance will be sufficient to withstand impacts 4,500DWT ship at speed 3.3knots, and 1,540DWT barge at speed 2 knots.
3.	Approach span piers adjacent to the Transition Piers	• Design loads of 6MN • This resistance will be sufficient to withstand impacts from 4500DWT ship at an impact speed of 1.7 knots, and 1,540DWT hopper barges at a drifting speed of 2 knots.
4.	All other Approach Span piers	• Design loads of 1 MN • This resistance is sufficient to withstand impacts from 1,540DWT empty barges with 200 ton displacement at drifting speeds of 1.5 knots, and impacts from 200 ton displacement small boats at drifting speed of 1.5 knots. • Approach Span pier design resistance is examined in terms of safety level against impact due to 1,540DWT fully laden barge drifting at a speed of 2 knots (1m/s).

Risk Assessment On Fire Hazard

- **The design approach is to allow for the loss of any individual stay cable and not to provide specific fire protection to the cables. It could allow any two cables being removed simultaneously in combination of 10% life loading at ultimate limit state. The Second Penang Bridge is design for the dynamics affect of a sudden cable rupture.**

- **The stay cables are located outside the external parapets of the deck structure. The possibility of impact, vandalism or fire on the stay cables is indeed very low. Emergency response capability for a fire hazard was incorporated in operational management to ensure lower residual risk.**



Green Building Technology

Toll Plaza & Administrative Building Complex

- **The design is based on requirements of :-**
  - ✓ **80% of IBS**
  - ✓ **88% (Platinum) for PB2X Toll Plaza Green Building Index (GBI).**
  - ✓ **80% (Gold) for PLUS Toll Plaza GBI.**

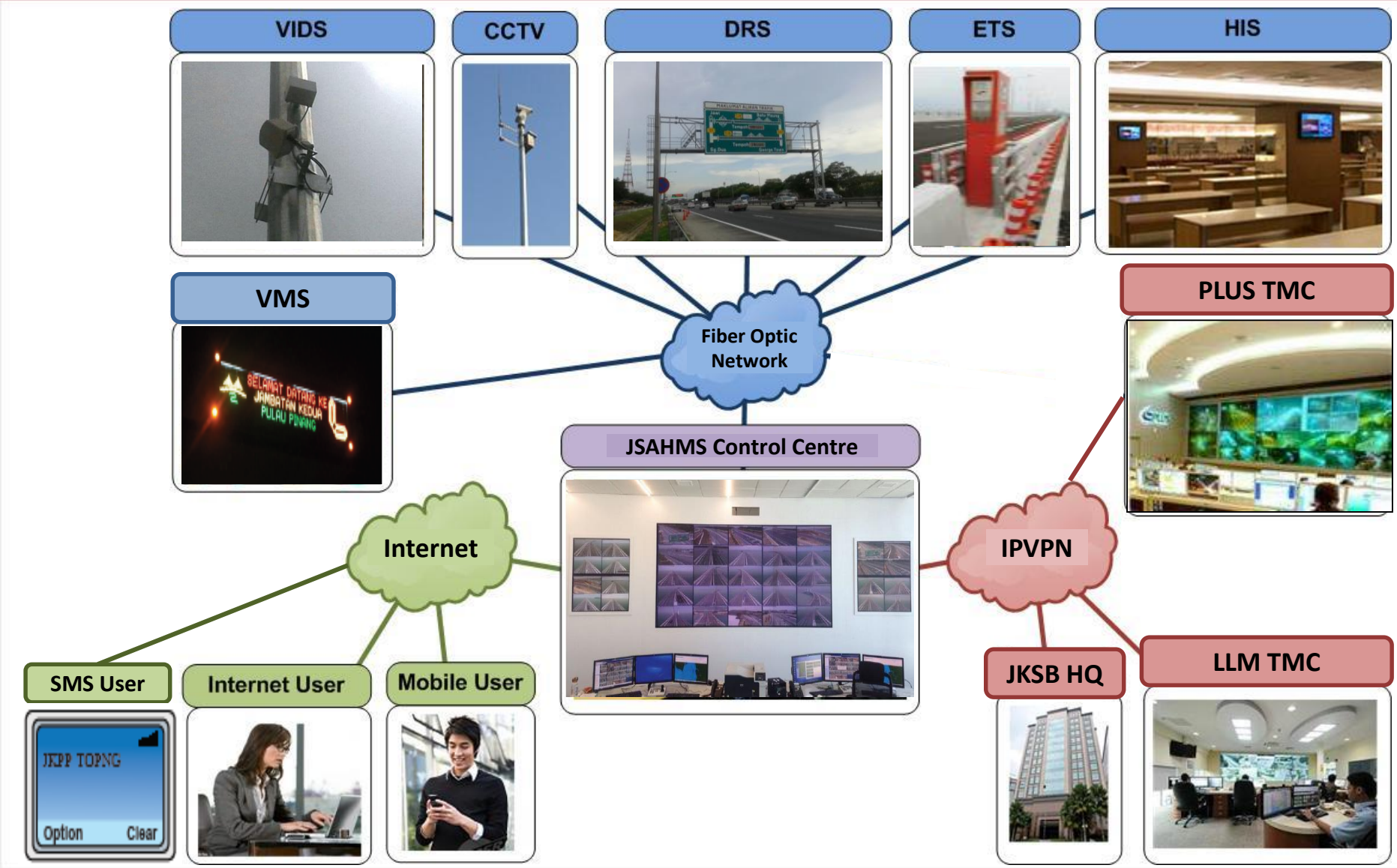
- **The details of the target score as follows :-**

ITEM	MAXIMUM POINTS	TARGETED SCORE
Energy Efficient (EE)	35	32
Indoor Environment Quality (EQ)	21	20
Sustainable Site Planning & Management (SM)	16	11
Materials & Resources (MR)	11	8
Water Efficiency (WE)	10	10
Innovations (IN)	7	7
Total Score	100	88 (PLATINUM)

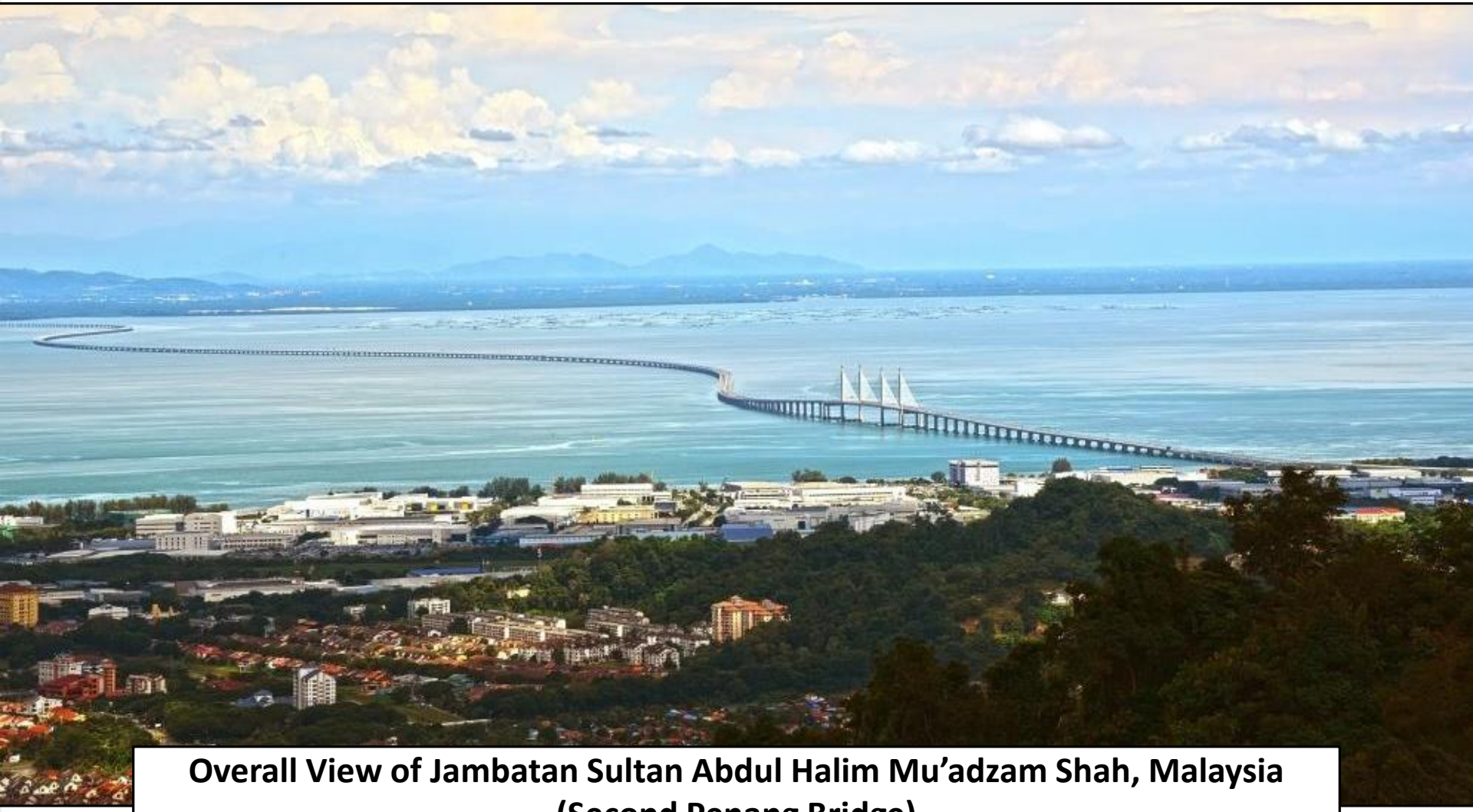
PB2X Toll Plaza

PLUS Toll Plaza

Overall TCSS Architecture



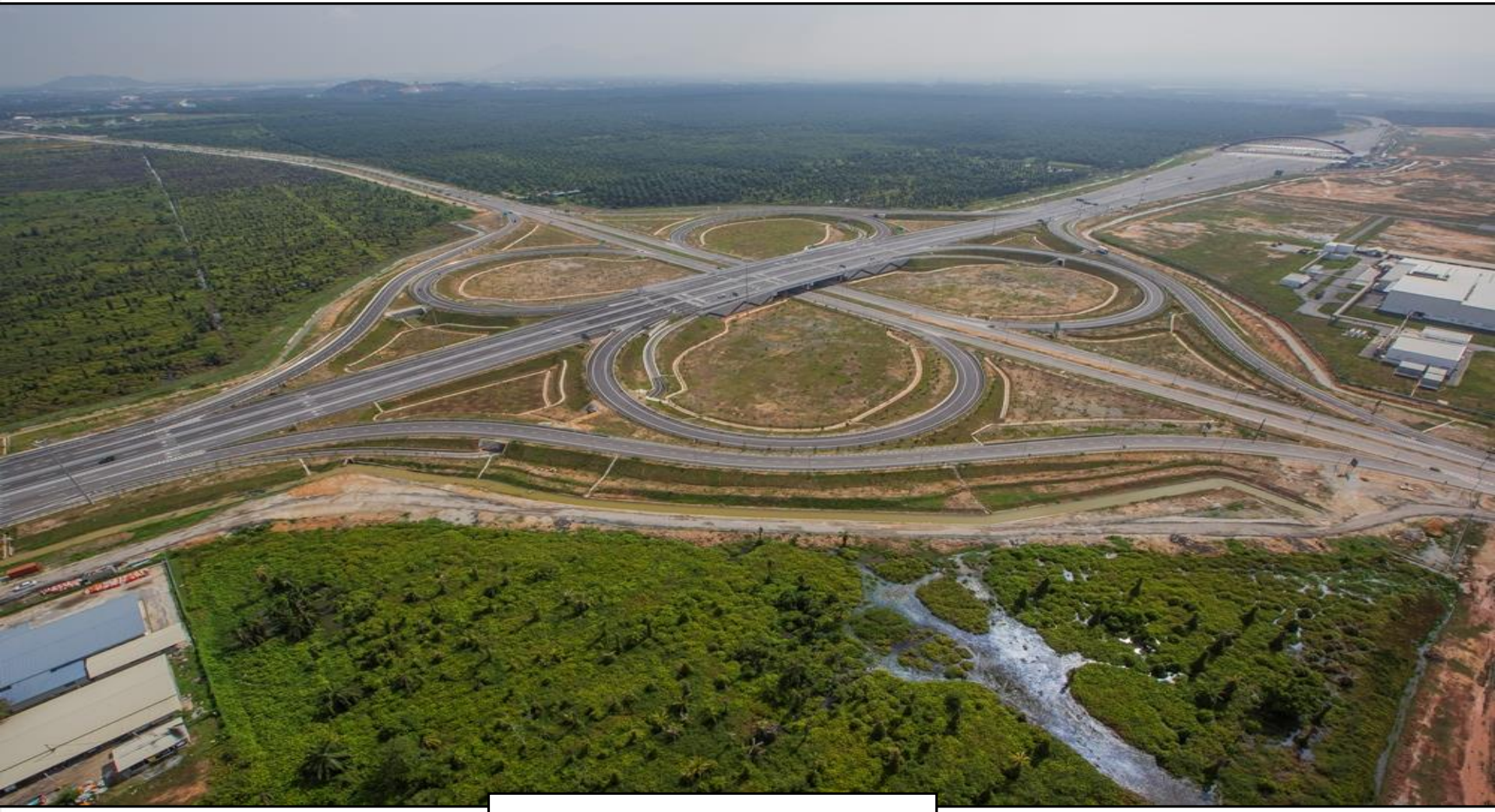
Latest Photographs



Overall View of Jambatan Sultan Abdul Halim Mu'adzam Shah, Malaysia (Second Penang Bridge)

View of Main Navigation Span at Night

Batu Maung Interchange



Cloverleaf Interchange

Trumpet Interchange

PB2X Toll Plaza

Bandar Cassia Toll Plaza

Conclusion

- **The implementation of this fast-track project particularly on its construction techniques are to be exemplary and reference to other upcoming bridge constructions of its kind.**

- **The execution of Design & Build concept for the major portion of the project is anticipated to produce impressive results and lead to many innovations as well as promoting a cost-effective bridge engineering and maintenance practice in Malaysia.**

- **JKSB completed the Second Penang Bridge with the highest quality, timely delivery and within the budgeted cost to contribute towards sustainable development.**

Thank You
For Your Kind Attention