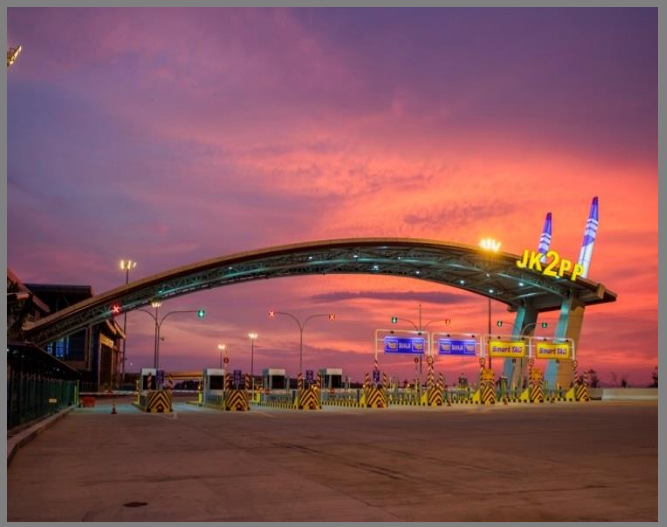

MALAYSIA GOVERNMENT

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MALAYSIAN HIGHWAY AUTHORITY

JAMBATAN KEDUA SDN. BHD.

THE SECOND PENANG BRIDGE:

Unraveling The Link Between Aesthetics and Technical Resilience in Designing Mega Bridges

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

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Abstract

- Jambatan Kedua Sdn Bhd (JKSB), a wholly-owned company of the Minister of Finance (MoF Inc.) is the concessionaire for the Second Penang Bridge Project (PB2X).
- The bridge with cost of RM4.5 billion was crowned as the longest in South-East Asia with a total length of 16.9 km over water.
- The construction of The Second Penang Bridge commenced in November, 2008 and 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.

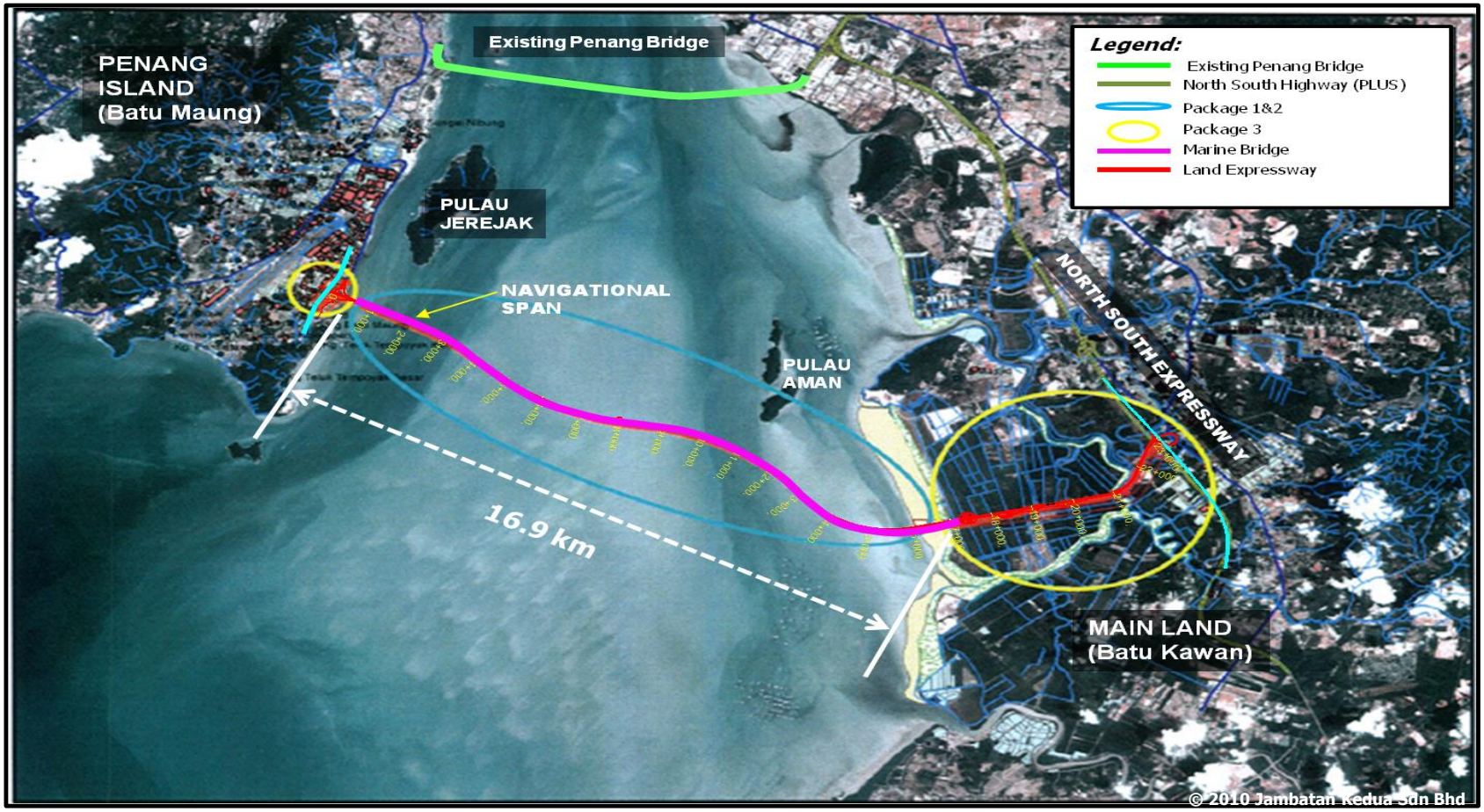
Project Introduction

- 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.

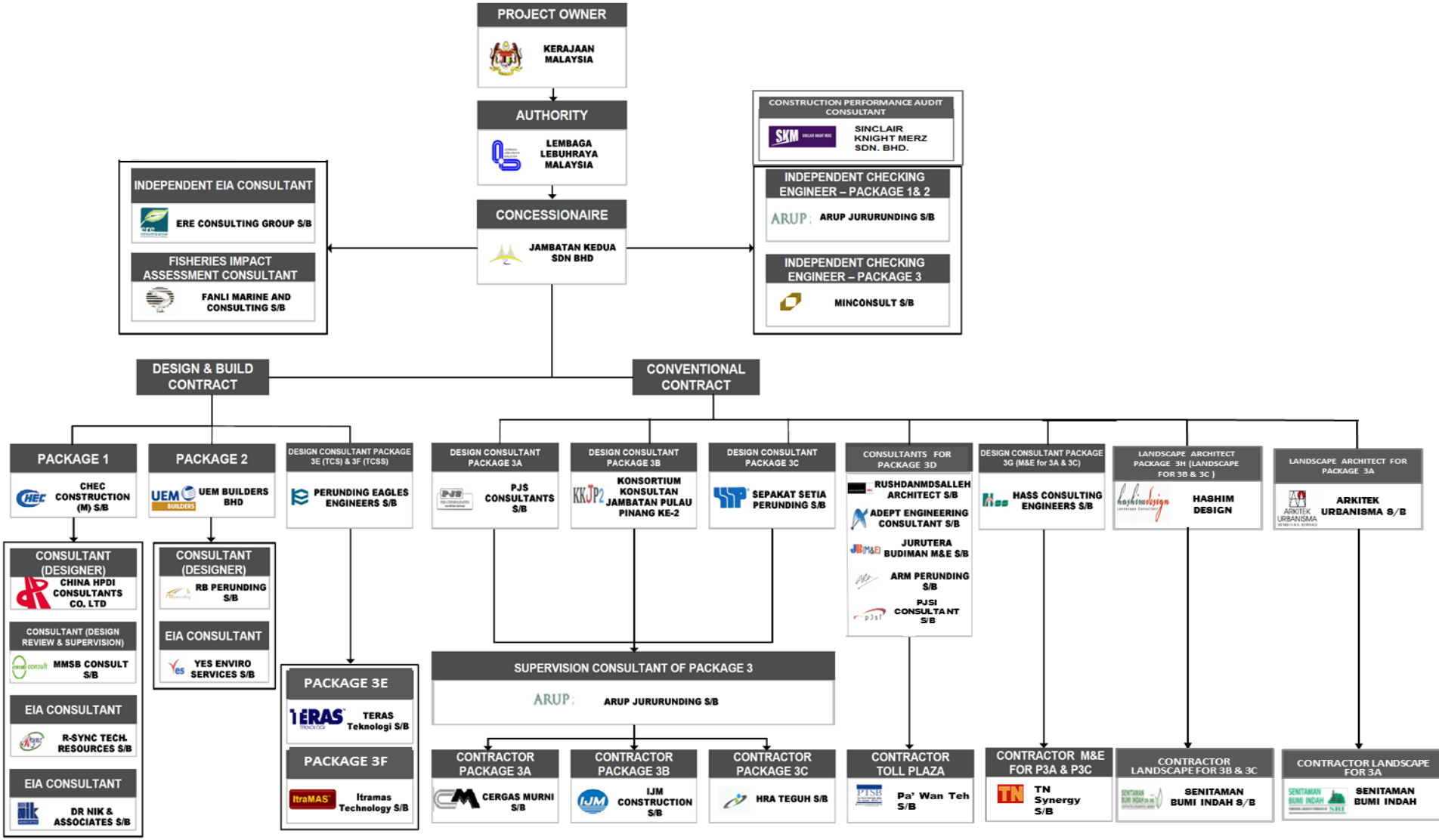
- Project Alignment

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



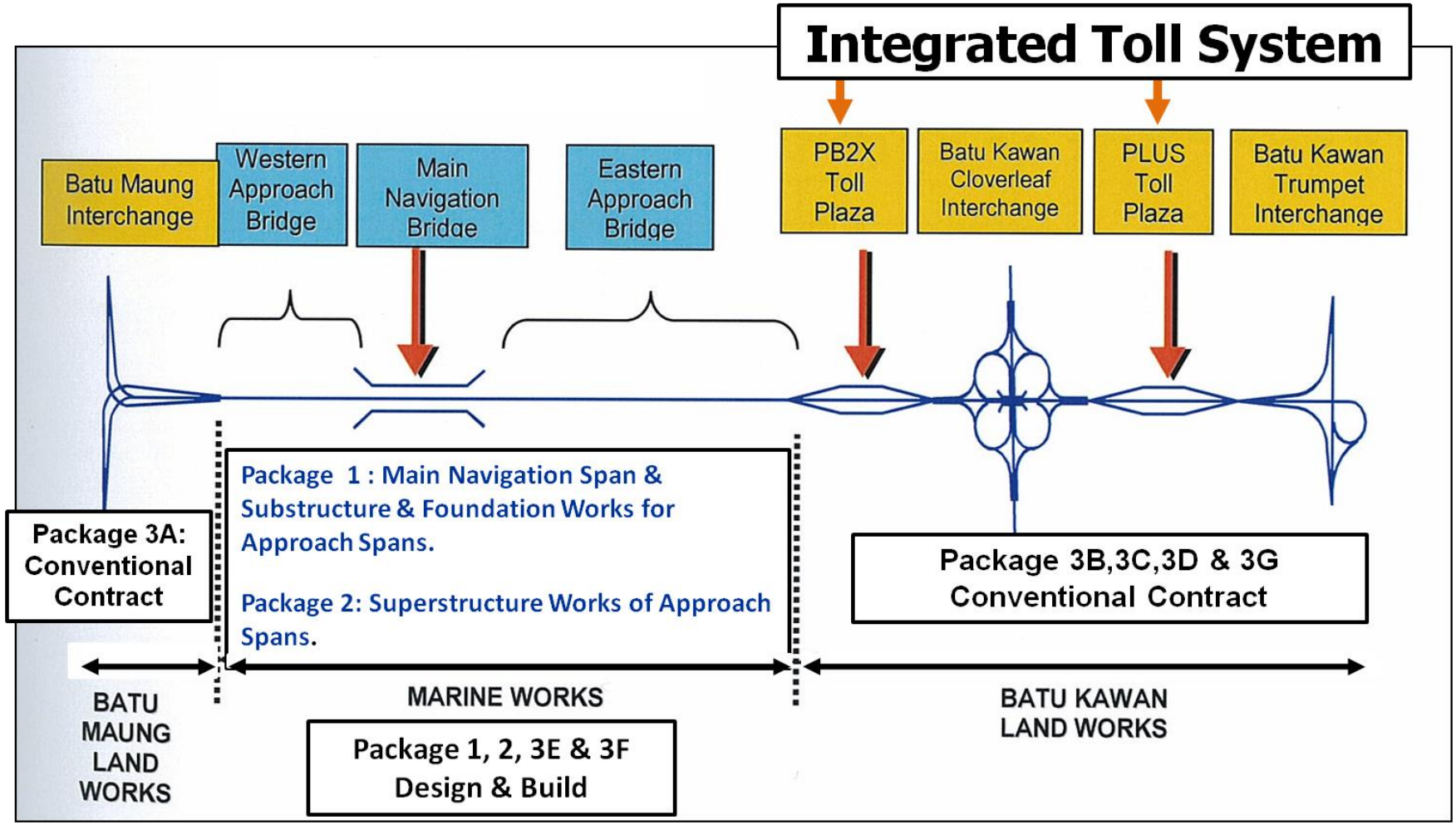
- Overall Project Organization

JAMBATAN KEDUA SDN. BHD. (824573-U)
Wholly owned by Minister of Finance, Incorporated



- Distribution of Contract Packages

- **The Second Penang Bridge is divided into the following packages :-**



Photographs

Photo by Ooi Bee Siang

Photo by Lim Kien Hock

Second Penang Bridge Unraveling The Link Between Aesthetics and Technical Resilience in Designing Mega Projects

Second Penang Bridge Unraveling The Link Between Aesthetics and Technical Resilience in Designing Mega Projects

Photo by Leong Cheon Khan

Second Penang Bridge Unraveling The Link Between Aesthetics and Technical Resilience in Designing Mega Projects

Photo by Jaafar Abdul Razak

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Aesthetic Design Concepts

Bridge – Place Integration

- A bridge should be built to complement and exist in harmony with its surroundings.
- Design of the bridge should then be approved by identifying and studying all as at least the most important aspects of a bridge – such as architectural history, environmental, topographical, structural, geological, geometrical, social, cultural and archeological.

Structurally Expressive Forms

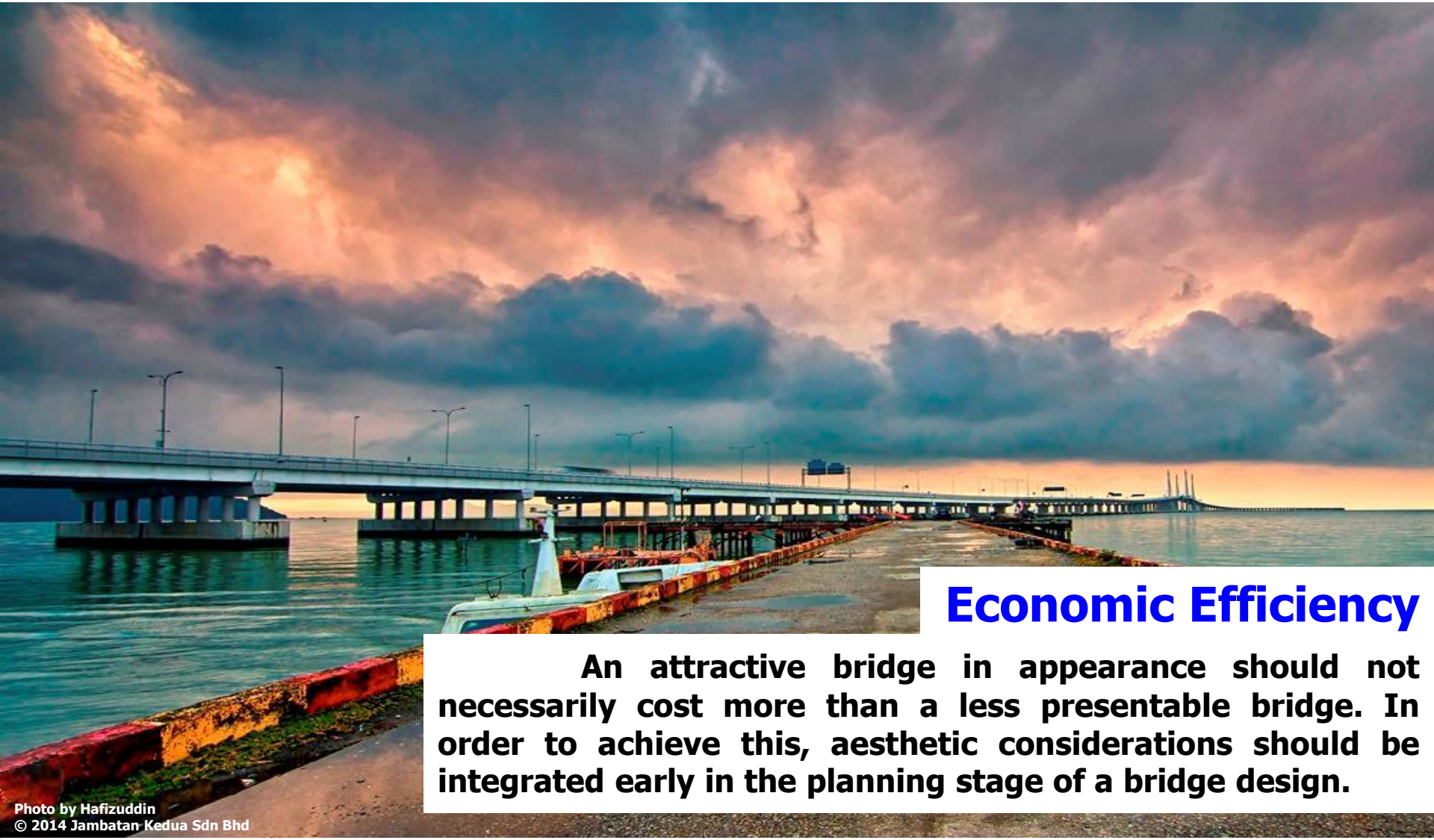
The form should be shaped to support its loads in the most appealing manner so that the emphasis on the structural efficiency shall not be at the expense of its visual appearance.

Method of Construction

A proper method of construction should have a balance between aesthetic consideration and ease of construction, disturbance to traffic flow or to the environment.

Ease of Maintenance

- Eventually all bridges will require maintenance and repair. Maintenance details should be properly considered and planned so do not impact the appearance of the bridge.
- A continuous girder design enables shallower depths to be achieved and avoids numerous expansion joints. These joints are the source of maintenance problems.



Economic Efficiency

An attractive bridge in appearance should not necessarily cost more than a less presentable bridge. In order to achieve this, aesthetic considerations should be integrated early in the planning stage of a bridge design.

Guidelines for Aesthetic Design

Aesthetic qualities of design are intangible, perceived qualities arising from the relationship of design elements. The properties of aesthetic qualities are proportion, rhythm, order, harmony, balance, contrast, scale and unity. These properties are the basic elements of creative design compositions common to all fine arts as well as bridges architectural. The aesthetic considerations associated with these factors:

1) **Bridge Integration with Environment**
2) **Primary Bridge Elements**
3) **Secondary Bridge Elements**
4) **Architectural Embellishment**

1) Bridge Integration with Environment

Landmark Structures

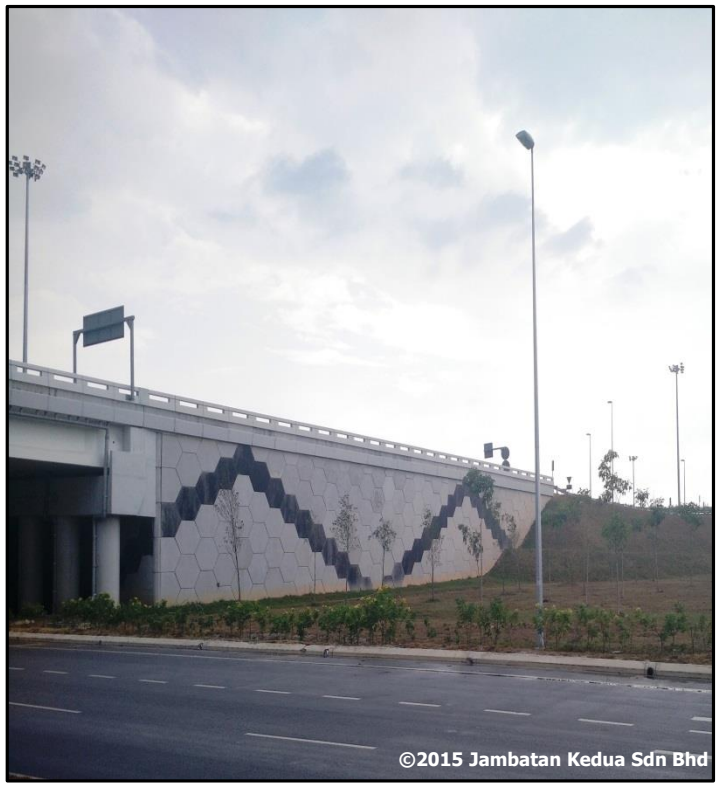
The approach road alignment to a landmark or major bridge can be slightly curved to create an awareness to the bridge users upon approaching the structure and enable them to appreciate the aesthetic qualities of the structure.

Landscaping

Considerations for landscaping should include the following:

- **The natural landscaping in the area should be maintained. The same species of trees or shrubs should be planted around the bridge.**
- **The vegetation at both ends of the bridge should be in visual balance.**
- **A proper landscaping can reduce the visual mass of large and plain abutment or wall.**
- **The type of plant that can grow to obscure the essential elements of the structural form or function should be avoided.**

Earth Retaining Structures.



- The top of a retaining wall should be developed into graceful profile.
- Abrupt termination to the retaining wall should be avoided.
- Weep holes should be not placed on the exposed face of the retaining wall as they may cause staining. Drainage system should be designed to filter, collect and drain water away from the wall.
- Where a retaining wall and sloped grade are combined to provide a grade separation, the wall should be placed at the top of the slope. This could provide more open space at the roadway level.

Relationship Between Geometry and Environment

Considerations for horizontal and vertical alignment should include the following:

- **The horizontal alignment of a long and sloping bridge should be done with a smooth and elegant curve.**
- **Horizontal alignment should not have irregular curves as it interrupts the flow of the structure, disturbing its order and harmony.**
- **Vertical profile of a bridge should coincide with the approach road gradient.**
- **Road vertical profile should preferably have a crest at the center of the bridge to create an impression of efficiency and safety.**
- **A vertical curve on a bridge allows users to feel the sensation of entering and leaving the bridge.**

2) Primary Bridge Elements

Superstructure

Generally a long span bridge with the smallest possible girder depth is preferable to a short multiple span bridge. The primary aesthetic goal is to achieve a slander superstructure while maintaining continuity and proportion. However, if a multiple span bridge is avoidable, it should be designed for balance, visual continuity and harmony.

Box Girder Bridges

Considerations for box girder structures should include the following:

a) The apparent depth of the superstructure could be reduced by:-

- **Using narrow main beam, large cantilever and shallow parapet height**
- **Slanting the girder fascia to vary the relative brightness of the surface.**

Cable-stayed Bridge

Considerations for cable-stayed bridge structures should include the following:

a) To produce aesthetically appealing bridges, the pattern of the cables should have clarity and unity. For clarity of cable arrangement:-

- **The best solution is the use of single plane cables.**
- **For two or more planes, adopt the harp configuration so that all cables on one side of the tower are parallel from the oblique view and crossing are avoided.**

b) The deck fascia should run undisturbed through the outside of the cable anchors. The cable anchors should not be attached to the outside of the beam.

c) Anchorage should not interrupt the visual line flows of the deck fascia and the pier tower.

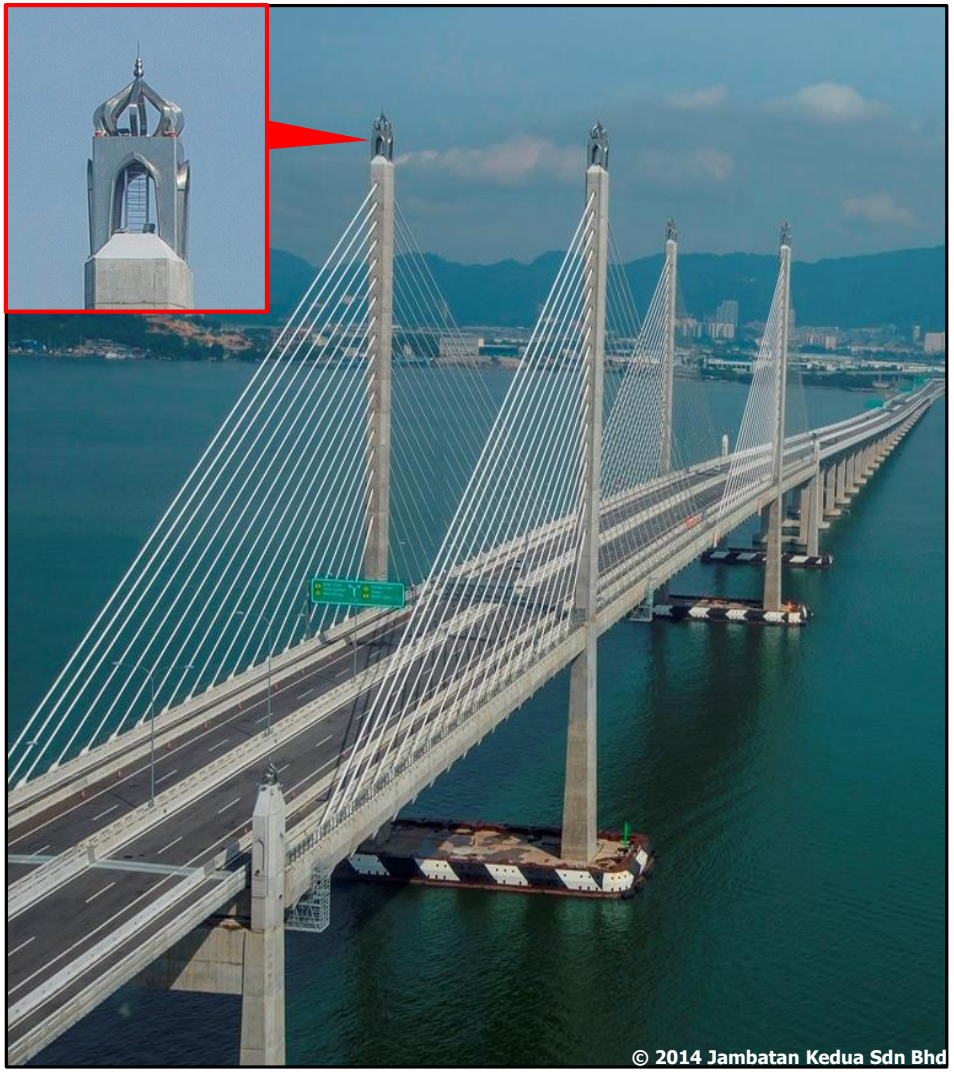
d) Anchorages should express their function of transferring loads and not to appear dominant or made invisible.

Piers

- **The pier shape should be integrated with the form and shape of superstructure. The pier shape should be integrated with the form and shape of superstructure.**
- **Piers should not be the visual focal point of a bridge composition. However, they could be considered as a focal point for aesthetics. Piers that appear larger than necessary are undesirable because attention is directed away from the superstructure.**

- **Piers should be of sufficient size to perform their function. Too slander a pier gives an impression of instability whereas a short or large pier is unsightly.**
- **In the design multiple piers, the should be visual continuity between the adjacent pier shapes. When viewed from the oblique angle, this continuity as well as the stacking effect should be checked.**

- **A pylon tower should be seen rising from the ground or water to the top as a single element, unless the bridge is an opening type, which can be visually broken at the pivot point.**
- **Aesthetic treatment to the top of the pylon should be given careful consideration as it is a prominent features. The designer should refrain from adopting non-functional adornments, as these will appear odd and out of place.**



3) Secondary Bridge Elements

Bridge Accessories

Bridge accessories such as crash barriers, signages and lightings can impair the visual appearance of a bridge. Due attention should be given to the placement, size and detail of the fixtures, not only to minimize the diminishing impact or visual intrusion but also to enhance the overall appearance.

a) Signages

Consideration for signages should include the followings:-

- **Signages should be placed off the bridge whenever possible.**
- **Signages be attached to bridges should not extend beyond the bridge structure and they should be consistent height.**

- **Internally lit signages should be used where elimination of the external light sources and associated grating and support is beneficial.**

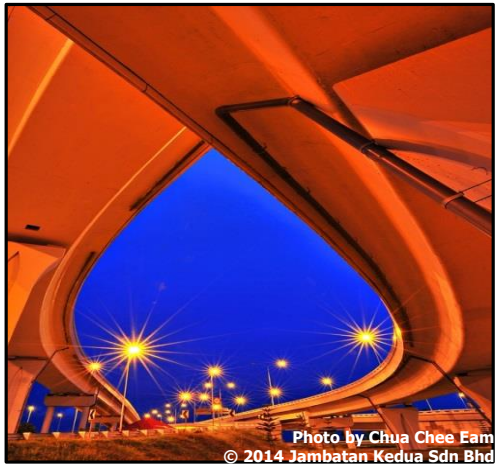
b) Lightings

Consideration for lightings should include the followings:-

- When locating lights, the designer should recognize the inherent symmetries or other major characteristics of the overall structure.
- Lights should be mounted under the structure in some consistent relationship to the structural elements.
- Floodlights can be utilized to accentuate the forms of the structure, e.g. the tower pylons of a suspension bridge.
- Light poles and fixtures should be integrated with the structure type and the rail system.
- Light poles should be placed in some logical relationship to the structure, e.g. symmetrical to a superstructure or over a pier in sequence with railing posts.

c) Drainage and Conduit Systems

Consideration for drainage and conduit system should include the followings:-



- **Free-fall drainage system outlets should be concealed and their placement should not cause staining to the bridge.**
- **Drainage pipes should be placed on the least visible side of piers. A configuration that is consistent with the pier shape should be used.**
- **Pipe and conduit systems should be kept simple with minimal fittings.**
- **Placement of the systems on the outside of the fascia girder or along the barrier system should be avoided.**
- **Conduits and pipes also should be concealed. Installation should only take place in locations such special grooves or in-between beams.**

Bridge Detailing

Bad details, small as they may seem, draw attention to themselves and end up detracting and negating all other efforts. Corners, joints, edges and other minor items contribute a great deal to the overall appearance and, if done badly, can create an eyesore. Details such as color should be used to develop harmony within the structure and between the structure and its setting.

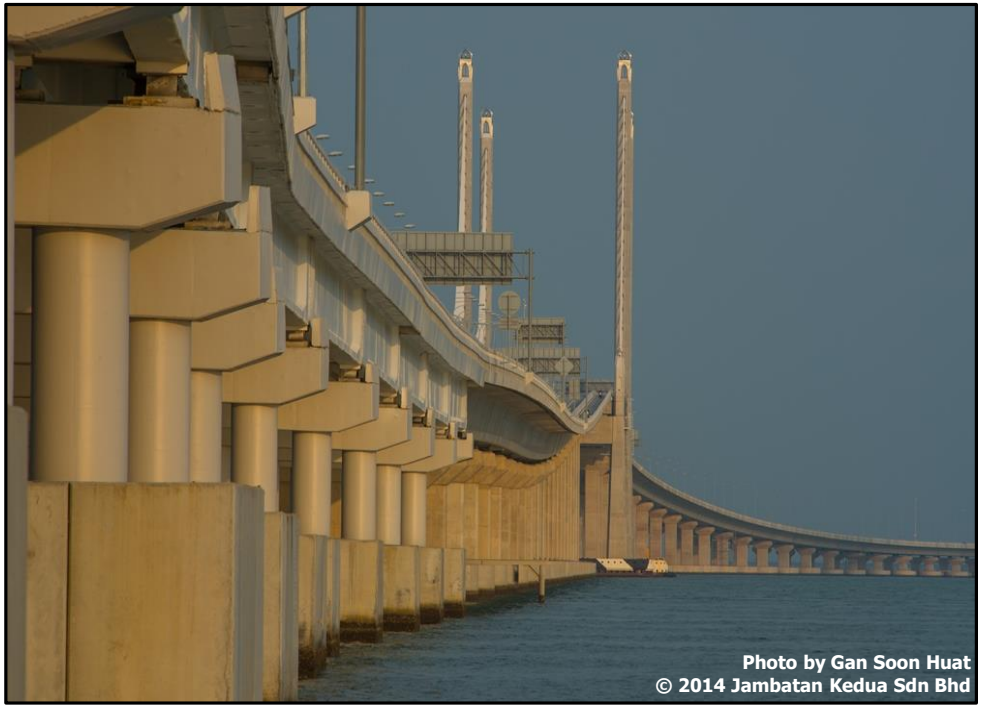


Photo by Gan Soon Huat

a) Shadow Effects

- **An adequate deck cantilever should be provided to maximize the shadows cast on the fascia girder, thus reducing the apparent depth of the girder and the harshness of a bright fascia.**
- **The relative brightness of bridge surface could be varied by changing their inclination to catch more, less or no light at all.**

- **Appropriate detailing to pier shapes and textures to create shadows on them could enhance their slenderness.**
- **The basic form of a bridge can be portrayed by outlining features with illumination or light to create a silhouette, eg. stringing lights along the cables of a suspension bridge.**

b) Surface colors

Consideration for surface colors should include the followings:-

- **Bridge features could be emphasized or diminished by colors. Light colors tend to emphasize while dark colors diminish the features.**
- **Full-hued colors are not harmonious with the naturally occurring environment, therefore the use of these colors should be limited to built-up settings.**
- **Bright and intense colors should be used with discretion.**
- **The color of fixtures such as signages, railings and posts should complement each other and blend with the structure.**
- **The color of the drainage pipes and conduits should be the same as the structure element on which they are mounted.**
- **The color on the fascia girder should be of a darker shade than on the parapet. The darker color will tend to make the fascia girder less dominant than its brighter counterpart.**

c) Surface Textures

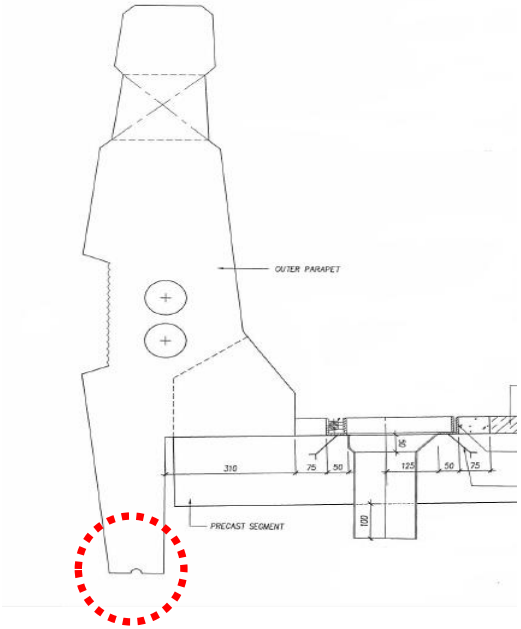
Consideration for surface textures should include the followings:-

- **The designer should recognize and plan for the pattern created by the construction joints, tie holes and weep holes.**
- **The appearance of a solid wall parapet could be enhanced by creating patterns and texture to its surface.**
- **Distance and driving speed alter the viewer's perception of surface patterns and textures. Hence, their sizes should correspond to dominant users. Large pattern elements should be used for higher speed traffic. Finer and more complicated elements should be adopted for pedestrians and slow-moving vehicles.**
- **Concrete stain should be used to improve the appearance of structures. The stains could also hide blotchy surfaces as well as seal and protect the concrete.**

d) Drip Grooves

Consideration for drip grooves should include the followings:-

- **Drip grooves should be provided on the underside of the bridge to avoid staining.**
- **The grooves should be deep, wide and continuous for effective flow. Ensure no grout bridge across the grooves during construction.**



4. Architectural Establishments

A design features is considered architectural when it influences appearance without structural necessity. The best use of architectural features incorporate structural requirements in the solution, thereby combining both structural and architectural considerations to enhance the overall solution.

The architectural establishments should include the following:

- **Architectural features should not be superfluous and unnecessary.**
- **Architectural should be sensibly applied to disguise unsightly component such as cable anchorage and discontinuity.**
- **Art features should be considered from the start as an integral part of the design and not as an afterthought.**
- **Structures and sculptures can be incorporated at the bridge ends to signify its entry and exit points.**
- **Sculptures and decorations enhancing a bridge should not cause maintenance problems.**
- **Architectural recommendations should establish aesthetic and visual compatibility with the highway corridor.**

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