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IMPROVED CROSSING OPTION FOR THE STRAIT OF GEORGIA

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Problem Definition

- The **Lower Mainland** and **Vancouver Island** are separated by the **Strait of Georgia** (240 km long and 18.5 to 55 km wide)
- Current crossing methods (ferry or plane) are **not sustainable** as affordable and efficient options for daily commuters, tourists and visitors

(Source: Super Teacher Worksheets, 2017).

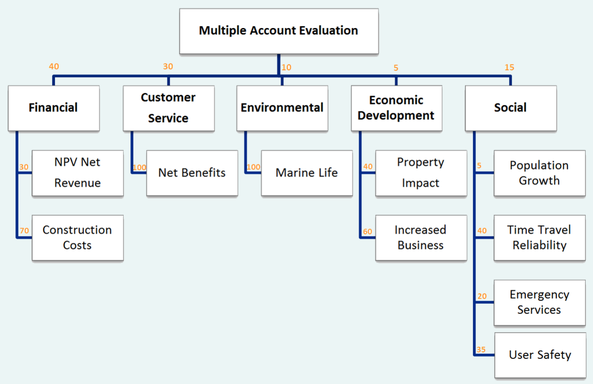
(Source: BC Government, n.d.).

- The **main objective** is to design an optimal crossing alternative based on geotechnical, structural, financial, social, and environmental considerations
- **Major challenges** include length of crossing, large depths to seabed, presence of a major shipping route, and environmental impacts

Phase I: Preliminary Design

- Preliminary designs for a **cable-stayed bridge** and **submerged floating tunnel (SFT)** were conceptualized and compared against the base case of the existing **ferry system**

(Source: Nair, 2015).



- A **multiple account evaluation** was implemented based on the factors listed above, identifying the SFT as the **optimal crossing option**

Phase II: Design of a Submerged Floating Tunnel Module

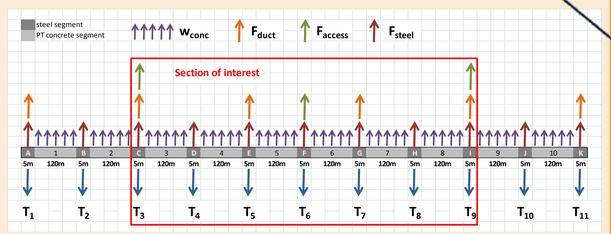
1) Railway Tunnels

- The **railway tunnels** are the two outer SFT tunnels that house the passenger trains
- 120 m match-cast, post-tensioned concrete segments span between 5 m steel segments that act as tie-down points for the **anchor system**
- The steel segments double as periodic connection points for the **access tunnel** and the **piston relief duct**
- Modeled as a continuous beam with tie-down anchors considered as jack-knife supports
- SAP2000 analysis uses the following **adapted limit states design**:

$$\alpha_B B + \alpha_D D + \alpha_{SDL} SDL + \alpha_L L$$

where α_B=1.0; α_D=0.95;
α_{SDL}=0.9; α_L=1.35

- Considers three critical load cases:
  (1) Permanent loads
  (2) Live load with two center spans unloaded
  (3) Live load with one center span unloaded
- The SFT exploits the natural buoyancy forces of water to keep a net upward force on the system

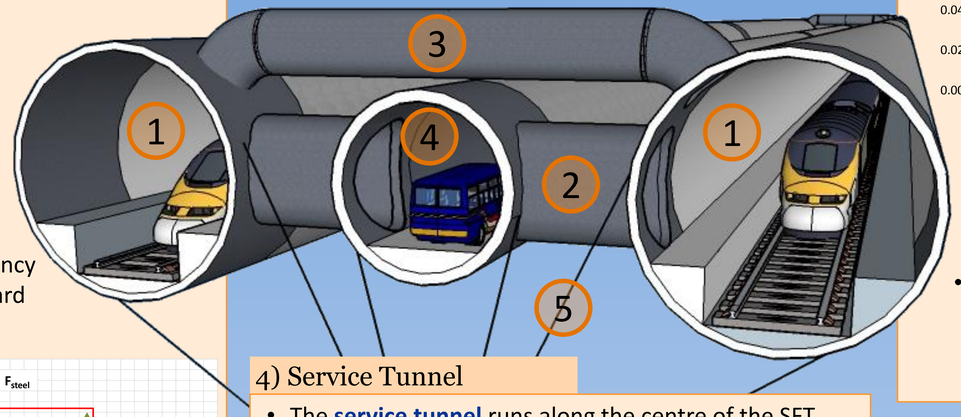


2) Access Tunnels

- Steel **access tunnels** provide a connection between the railway tunnels and service tunnel every 375 m
- Used in case of emergency evacuation and maintenance
- Can also house machinery, electrical rooms, and equipment necessary for tunnel operation

3) Piston Relief Ducts

- Steel **piston relief ducts** allow air pressurized by high train velocities to disperse between the two railway tunnels
- Spaced at 250 m intervals



4) Service Tunnel

- The **service tunnel** runs along the centre of the SFT
- Acts as a roadway for specialized service vehicles, allowing for quick access during maintenance or in case of emergency
- Tube system and resulting analysis is identical to that of the railway tunnels

5) Anchor System

- Two types of anchors, VLAs and SCAs, are employed to transfer SFT buoyancy forces to the seabed

1) Vertical Loaded Anchors (VLAs) *125 m intervals*

- Analyzed through design standards provided by the manufacturer:

(Source: Vryhof Anchors, 2010).

$$\boldsymbol{D} = 1.5 \times k^{0.6} \times d^{0.7} \times \boldsymbol{A}^{0.3} \times tan^{1.7}(\alpha)$$

Where: D –Penetration depth [m]
A – VLA area [m^2]

$$\textbf{UPC} = N_C \times S_U \times \boldsymbol{A}$$

Where: UPC – Ultimate Pull-Out Capacity [kN]
A – VLA area [m^2]

2) Suction Caisson Anchors (SCAs) *750 m intervals*

- Analyzed through two methods in accordance with DNV standards:

(Source: Cranemaster, 2017).

Plastic Limit Analysis: equates external work done by inclined load to the energy dissipation through the SCA

$$\boldsymbol{H} = \frac{\int \left(F_{ls}\left|1-\frac{z}{L_o}\right|+F_{as}\xi\right)dz+\frac{M_b}{L_o}+V_b\xi}{\xi\tan(\psi)+\left|1-\frac{L_i}{L_o}\right|} \; ; \; \boldsymbol{V} = H\tan(\psi)$$

Simplified Analysis: uses fitting parameters (*a* through *e*) to simulate results from 3D FEA analyses

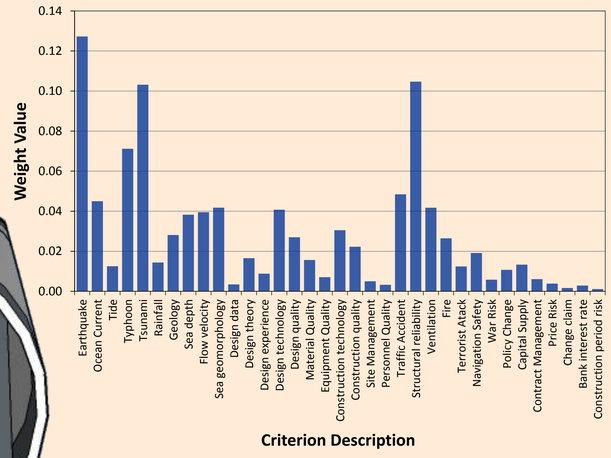
$$\frac{\boldsymbol{V_0}}{s_{u0}D^2} = \left(a_1\frac{s_{u1}D}{s_{u0}}+b_1\right)\left(\frac{L}{D}\right)^{C_1}+\left(d_1\frac{s_{u1}D}{s_{u0}}+e_1\right)\left(\frac{L}{D}\right)$$

$$\frac{\boldsymbol{H_0}}{s_{u0}D^2} = \left(a_2\frac{s_{u1}D}{s_{u0}}+b_2\right)\left(\frac{L}{D}\right)^{C_2}+\left(d_2\frac{s_{u1}D}{s_{u0}}+e_2\right)\left(\frac{L}{D}\right)$$

Where: H *and* V – Horizontal and vertical load capacities [kN]

Risk Analysis

- The risks associated with the SFT are assessed based on natural environment, design, construction, operation, and economics
- An **Analytic Hierarchy Process** is completed in MATLAB to evaluate the weight of the criteria shown below



- The resulting top three risks are:
  1) Earthquake (weight = 0.127)
  2) Structural Reliability (weight = 0.105)
  3) Tsunami (weight = 0.103)

Construction and Materials

- **Off-site modular construction** will be employed to:
  a) improve quality, critical for the durability of concrete in seawater (Perkins, 1986)
  b) improve construction schedule
- Techniques used for immersed tunnels may be implemented, such as towing segments out to water
- VLAs may be deployed into position before the tunnel
- Materials selected to **mitigate future maintenance problems**

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