Design Concept Long Span Bridge with Floating Foundation

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Abstract. Indonesia is a maritime country where the sea area is larger than the land area and consists of a group of islands stretching from west to east. Inter-territorial accessibility can become faster and smoother by structure long span bridges. In the deep sea and tidy ground conditions allow use of pile foundation, however the floating foundation is an option that can be taken. The purpose of this paper is to propose the concept of a long-span bridge floating foundation that is capable and stable to support the load or forces that work.

1. Introduction

Indonesia is an archipelago country that consists of a group of islands stretching from west to east. Inter-territorial accessibility can become faster and smoother by structure long span bridges. In the deep sea and water where the bottom is too soft for pillars, the floating foundations is an option that can be taken.

Floating bridge has been known for 4000 years, generally used for temporary military purposes and materials made of wood. Now the floating bridge can be built by used of concrete, steel or a combination of concrete and steel. Floating bridge has been used in many countries such as; USA, Canada, Norway, England, Japan, Maldives. Built-in bridges are dominated by short span.

Long bridge spans such as arch bridge, cable stayed, suspension and extradosed relatively rare. The use of long spans floating foundation that has a high clearance will facilitate the movement of marine or river transportation. The first long-span buoy bridge is the Yemenai Japanese bridge that was completed in 2000 [1]. Now a study and analysis of long span bridge floating foundation is being developed in European and Norwegian.

2. Floating foundation bridges concept

The basic concept of floating bridges is simple: the piers or foundations are replaced with floating elements floating freely or with mooring lines (Figure 1). The foundation bridge floating bridge is inspired by the natural law of the lifting force of water (buoyancy force). Vertical loads, (live and dead loads) are held by a pontoon system consisting of single columns or multiple column combinations. Horizontal loads are retained by the mooring system. The effectiveness of the work and the function of floating bridge is influenced by the interaction of several aspects namely: 1) environment and loading, 2) stability, 3) station keeping, 4) motion response, 5) structural integrity.

3. The Elements of long span floating foundation bridges

The main element of the bridge floating foundation is the pontoon and mooring system. The pontoon consists of two forms: a continuous pontoon and a separate pontoon. On a suitable long span bridge of pontoons is a separate pontoon that directly supports the upper structure. A separate pontoon can be a single pontoon or some cells arranged horizontally or vertically. A single cell pontoon section
can be; a) circle, (b) base case (D < W < 2D), (c) oblong (W > 2D), (d) oval (D > W). Horizontal combined pontoons are composed of two cells where the lower cell has a larger diameter. Vertically combined cells can be made with a unified arrangement without a gap or with horizontal connecting rods.

![Figure 1. Floating foundation long span bridges, (a) Cable stayed, (b) Suspension bridge](image)

![Figure 2. Shapes of one cell pontoon, (a) Circular, (b) base case, (c) oblong, (d) oval](image)

![Figure 3. The shapes of unified cell pontoon, (a) horizontal unified cell, (b) vertical unified cell, (c) vertical unified cell with rod connection](image)

Mooring system is used to reduce the movement of the bridge. There are several methods or mooring systems used is; 1) The dolphin-guide frame, 2) Pier/quay wall, 3) Sliding piles, 4) Cable(chain and anchor (catenary), 5) Tension leg method (taut and vertical tension leg).

On long floating bridge, mooring type that can be used is cable type, chain with anchor, and tension leg. Chain provides greater stiffness than cable / wire. More vertical tension legs can produce better stability than leg or catenary links, but will require a larger cost of anchoring.

4. Load and load combination

Floating foundation must be able to support the loads and combinations of the load, to the ultimate, service, fatigue, accidental and postdamage conditions. By their feature the load acting on floating foundations is classified as in Table 1.

The combination of loads on the floating structure according to [2] and [3] summarized by Chandrasekaran, 2015[4] is shown in Table 2.
| Load Type                  | Description                                                                                                                                                                                                 |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Permanent (load) loads (PL)| Weight of structure bridge and any permanent equipment that does not change during the life of the structure. (structural weight, dry equipment, ballast, and hydrostatic pressure) |
| Live loads (LL)            | Loads that can be changed, moved or removed during the life of the structure. (vessel, personnel, and liquid)                                                                                                 |
| Environmental loads (EL)   | Loads on the structure due to the action of wind, wave, current, tide, earthquake, tsunami, or ice                                                                                                           |
| Deformations loads (DL)    | Loads on the structure due to out-of-level supports and subsidence                                                                                                                                          |
| Accidental load (AL)       | Loads on the structure due to dropped object, ship impact, blast, and fire.                                                                                                                                  |

| Load Type                  | Description                                                                                                                                                                                                 |
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| Accidental load (AL)       | Loads on the structure due to dropped object, ship impact, blast, and fire.                                                                                                                                  |

| Limit State | Load categories |
|-------------|-----------------|
|             | PL | LL | DL | EL | AL |
| ULS (normal)| 1.3 |1.3 |1.0 |0.7 |0.0 |
| ULS (extreme)| 1.0 |1.0 |1.0 |1.3 |0.0 |
| SLS         | 1.0 |1.0 |1.0 |1.0 |0.0 |
| FLS         | 0.0 |0.0 |0.0 |1.0 |0.0 |
| PLS (accidental)| 1.0 |1.0 |1.0 |1.0 |1.0 |
| PLS (post-damage)| 1.0 |1.0 |1.0 |1.0 |0.0 |

5. Movement

5.1 Stability

The stability of a floating foundation is related to the rotational movement of a floating. The floating is stable if the rotational motion can return to its initial equilibrium position. The inverting force in the buoyant structure can be generated by: floating moment, ballast and mooring.

The stability of a floating system consists of static equilibrium and dynamic equilibrium. If the floating structure shakes with a fixed angle of rotation then two possible moments are the reversal moment (P.b) and the falling moment (P'.b'). The relation moment and the failing moment are denoted by Figure 4. Figure 4 (a) shows that the floating structure will be stable if the height of the Meta center is positive or greater than the gravity center (G). The greater the value of meta center (M) then the degree of stability is higher. The dynamic stability of the floating structure can be evaluated by figure 5[1]. According to [1] dynamic stability will occur if the area area (BCD + OBDE) > 1.4 x area (OBDE + OAB) or righting moment is greater than 1.4 times heeling moment.

![Figure 4](image1.png)  ![Figure 5](image2.png)

**Figure 4.** Floating structure stability, (a) stable, (b) unstable

**Figure 5.** Dynamic stability evaluation [1]
5.2 Deflection and displacement

Floating bridge is very sensitive to movement. Floating bridges should be designed to meet the criteria of deflection and movement boundaries to provide the comfort and safety of bridge users. The bridge must be safe under normal conditions (1-year storm) and strong enough/not to collapse under extreme conditions (100-year storm).

| Loading condition | Type of deflection or motion | Maximum deflection | Maximum motion |
|-------------------|-----------------------------|--------------------|----------------|
| Traffic load      | Vertical (vertical)         | L/800              | ± 1,0°         |
|                   | Rotation (roll)             |                    |                |
| Environmental load| Vertical (heave)            | ± 0,3 m            | 0,5 m/s²       |
|                   | Lateral (sway)              | ± 0,3 m            | 0,5 m/s²       |
|                   | Rotation (roll)             | ± 1,5°             | 0,05 rad/s²    |

5.3 Dynamic movement response of floating foundation

The floating structure movements consist of six degrees of freedom, three translational movements and three rotational movements. The determinant factor in the analysis of floating structural movement is period, damping and stiffness. The general equation of the floating structure movement is expressed by;

\[ [M + A]\ddot{X} + [B_1 + B_2]\dot{X} + [C + c]X = F(t) \]  

where

\(X, \dot{X}, \ddot{X}\) are generalized displacement, velocity and acceleration at each degree of freedom, \(M\) is mass–inertia matrix of the structure, \(B_1\) is structural damping coefficient, \(B_2\) is hydrodynamic damping coefficient, \(C\) is structural stiffness matrix \(c\) is hydrostatic stiffness (hydrostatic restoring forces), \(F(t)\) is forces acting on the structure.

The structural damping is the damping related to the internal friction in the material of the structure. In the analysis, the damping structural can be expressed by classical Rayleigh proportional to a coupling between the velocity, and the strain velocity at each node-point.

Hydrodynamical damping is due to the waters interaction with the submerged pontoons, which is combined from geometrical damping and drag damping. The geometrical damping is also called wave or diffraction damping is caused by structural vibrations that generate waves in the fluid around the structure. The drag damping or viscous damping is due to viscous effects and vortex shedding in the water around the structure.

According to [9], [10] there are two analytical methods used in the dynamic analysis of floating structures:

1. Frequency domain analysis (Probabilistic analysis)
2. Time domain analysis (Deterministic analysis)

Frequency domain analysis is a simulated event at a certain time with a predetermined frequency interval. Frequency domain can be used to estimate the random wave response including movement and acceleration of floating structure. The advantage of this method is more saving time calculation. Disadvantages in this method ie for transient response and nonlinear response require non-linear equations to be changed in linear or nonliner form eigenmodes the integration over a wide range of frequencies [11] and [12].

With the Fourier transform, the equations of motion can be expressed in the frequency terms so;

\[ \{-\omega^2(M + A) + i\omega(B_1 + B_2) + (C + c)\} = \{F(\omega)\} \]  

For systems without attenuation the above equations can be simplified in the eigenvalue problem.
The floating structure response can be analyzed using the Operator Amplitude Response (RAO) function which converts the external load in the form of a wave in response to a structure. The relationship between RAO and spectral structural response for unit amplitude units is;

\[ S_u(\omega) = (RAO(\omega))^2 S(\omega) \]  

where

\[ RAO = \frac{F(\omega)}{-\omega^2(M + A) + i\omega(B_1 + B_2) + (C + c)} \]  

Time domain analysis is the completion of dynamic movement of structures based on time function. The approach adopted in this method uses time integration procedure and will result in time history response based on time function x (t). Quite accurate to analyze wind sensitive bridges and nonlinear behavior such as long span bridges [13] and [14]. The dominant time gain is that all nonliner models (system matrix and external load) can be modeled correctly but take longer time.

6. Modeling floating foundation
The finite element model of a floating foundation consists of blocks, springs, additional masses and damping. Ponton is modeled as a very rigid fictitious beam. Linear or non linear springs are used to model the horizontal and vertical stiffness of the mooring or the tether. Hydrodynamic Properties consist of hydrodynamic added damping and hydrodynamic added mass. Hydrodynamic added damping can be liner or nonliner.

7. Design procedures long spans briges with floating foundation.
Procedure design of long span floating foundation can be described as the flowchart in Figure 6.

Figure 6. Steps and procedural of design the long span floating bridges
8. Discussion

Floating foundation and mooring system must be designed to be able to carry the load and its combination without losing its stability and without experiencing shaking and displacement beyond the tolerable limits. Modeling floating foundation structures are carried out to simulate and evaluate the global behavior of structures.

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