Study on Connecting Method of Box Pontoons

Young-Jun You, Youn-Ju Jeong, Min-Su Park, Du-Ho Lee

Abstract—Due to a lot of limited conditions, a large box type floating structure is inevitably constructed by connecting many pontoons. When a floating structure is made with concrete, concrete shear key with saw-teeth shape is often used to carry shear force. Match casting for the shear key and precise construction on a sea are very important for making separated two pontoons as one body but those are not easy work and may increase construction time and cost. To solve this problem, one-way shear key is studied in this paper for a connected part where there is some difference between upward and downward shear force. It has only one inclined plane and can resist shear force in one direction. Big shear force is resisted by concrete which forms an inclined plane and small shear force is resisted by steel bar. This system can reduce manufacturing cost of individual pontoon and construction time and cost for constructing a floating structure on a sea. In this paper, the feasibility study about one-way shear key system is performed by comparing with design example.

Keywords—Connection, floating container terminal, pontoon, pre-stressing, shear key.

I. INTRODUCTION

SINCE the creation of ship, sea has been just a passage way to move people or goods for a long time. In recent decades, unceasing efforts to exploit ocean has been tried, for example, natural resource development. Structures to exploit ocean were small and fixed type such as cargo ship and offshore wind power in the past but nowadays they become large and floating type. FPSOs (Floating Production and Storage Offloading), and floating airport in Figs. 1 and 2 are clear examples.

While the structure like Fig. 1 is made like ship-shape for performing special purpose such as mining, processing, storing and loading and so on, the structure like Fig. 2 is constructed for securing workable area or storage space which has working conditions like earth. The latter type is useful to construct the infrastructure on it such as floating container terminal, floating harbor, floating island, and floating city. However, to make a vast area on a rough sea, many precast members like pontoon have to be made on land, moved to install place, and connected to form a structure.

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Fig. 1 Example of floating structure: FPSO [1]

Fig. 2 Example of floating structure: Airport [2]

This paper is for study on a connecting method of concrete pontoons for constructing a floating structure like Fig. 2, especially in respect of shear key. The applied shear forces along the longitudinal direction of a structure may have different values according to the configuration of the applied loads. From this reason, one-way shear key which has only one connected plane is considered in this study. Concrete member of the one-way shear key resists to the big shear force and so does steel bar to the small shear force. This system is similar to that reinforced concrete beam in flexure which is optimized in respect to material characteristics and economy. In other words, concrete resists only compression and so does steel bar to tension. The effectiveness of this system is check with a finite element analysis result and a calculation example.

II. SIGNIFICANCE OF THIS STUDY

A huge structure is needed to make a vast working or storage area on a sea. It is almost impossible to make the structure like on land. From this reason, the structure is constructed by connecting modules like pontoon. Connecting method is important because it is related with the safety of the structure. The technology has already been widely applied to the construction on land and this can be applied similarly to the offshore construction. General connecting sequence of box type

pontoons is seen in Fig. 4. As seen in Fig. 4, this work has many phases and needs careful construction process, consequently takes long construction time.
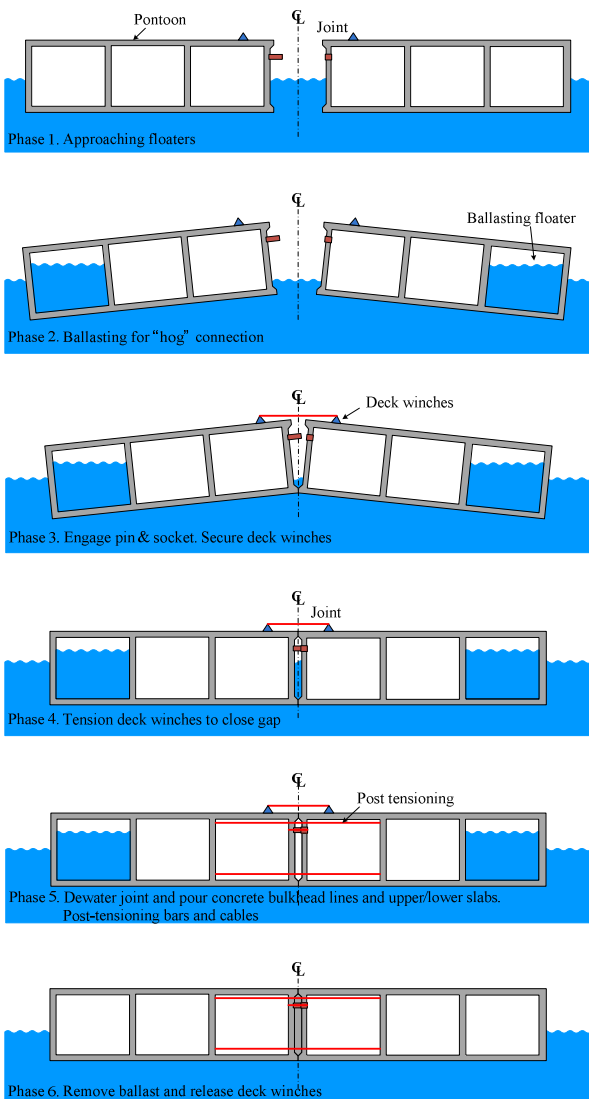

Fig. 3 Towing of pontoon modules [3]

Fig. 4 Phases of connecting two pontoons

To construct a structure on a sea, special equipment may be required and the rental fee of it is more expensive than that used on land, even though both have same function. Moreover, working days on a sea is much shorter than that on land. For example, in breakwater construction where working environment is relatively more stable over on a rough sea, available working days were just a third [4]. Therefore fast construction is the one of governing factors which affect total construction cost.

In aspect of cost and stability, pontoons can be made with concrete. When two concrete blocks are connected, shear key is often used between those and this does a role of resisting shear force. There are widely used two types of shear key as seen in Fig. 5. Female-female type has empty space for interlocking and shear key is formed after filling the empty space with epoxy material. Therefore, it needs form work and curing time. This type is preferred because it gives the designer more construction tolerance. Male-female type has an advantage of speediness over the female-female type but it is not easy to make precise connecting plane between two blocks, so called, match-casting [5].

A shear key of male-female type would be preferable rather than female-female type due to the construction time, the cost of equipment, and coarse working environment. However the difficulty in adequately matching two precast concrete blocks still has a bad influence on workability as well as construction cost. Therefore, there needs a solution to solve this problem by modifying the shape or connecting method of shear key.

III. BASIC CONCEPT OF CONNECTING SYSTEM

A. Assembly of Pontoons

To make wide marine working space like a floating container terminal, it is inevitable that small pontoons are connected on a sea because those are often constructed on land having spatial limitation. The basic geometry of unit pontoon may depend on the size of dry dock and it is recommended to make it big as much as possible because connecting work on a rough sea affects total construction time and cost.

There could be a lot of configurations to make many pontoons connected as seen in Fig. 6. This study considers a row in the left configuration in Fig. 6.
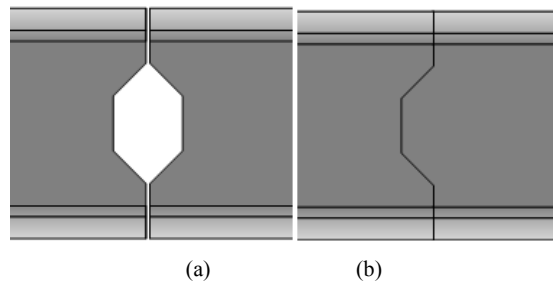

(a)   (b)

Fig. 5 General types of shear key: (a) female-female (b) male-female
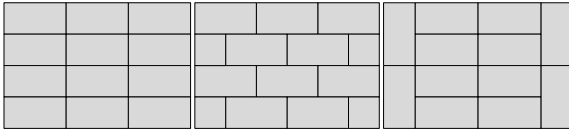
Fig. 6 Assembly examples of pontoons

B. Shear Force Diagram

When a floating container terminal is considered, two main forces (cranes and containers) apply on it. It is clear that containers will be loaded after that cranes are installed on the structure.

If a structure with a weight of q_{Struc} and a length of L is constructed according to the construction sequence in Fig. 4 and floated in still water, the buoyance of q_{B1} which has an equilibrated force with a total weight of the structure occurs as seen in Fig. 7 (a) and there are no section forces. When a concentrated force by a crane (P) is applied on this structure, section forces occur and so does a new buoyance of q_{B2} or q_{B3} for equilibrium as seen in Figs. 7 (b) or (c). Fig. 7 (d) shows an operating case and containers are fully loaded.


(a)

(b)

(c)

(d)
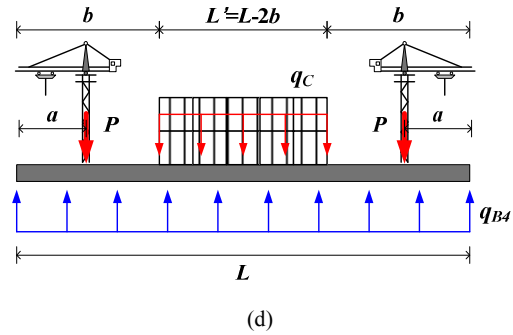
Fig. 7 Applying forces for conditions: (a) still water, (b) point loading, (c) symmetry of point loads, and (d) full loading

Fig. 8 shows shear force diagrams for each case except for no loading state. The direction of shear force changes at any point where a force is loaded. In case (d) in Fig. 7, the convention of the shear force by uniform load could have plus or minus according to the loading point and value but it is not of significance over the matter to be dealt with in this paper. The significant consideration in this paper is that the direction of shear force in any range does not change. For example, the direction of shear force has plus sign in a range from the left end to a and has minus sign in a range from a to the center in Fig. 8. This phenomenon results in that shear keys to carry shear force between two concrete blocks just need to resist the shear force only in one direction.
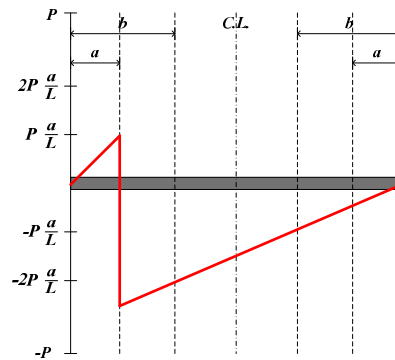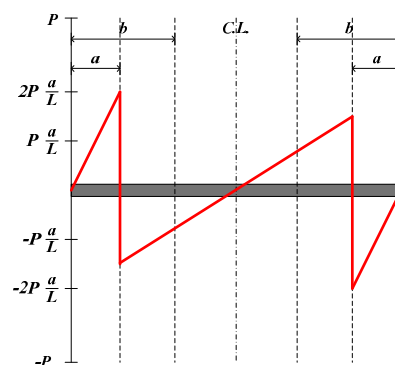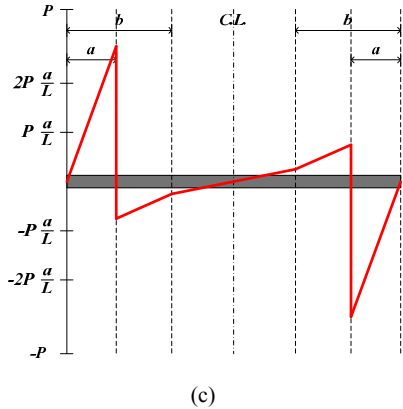

(a)

(b)

(c)
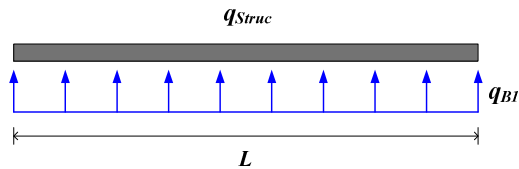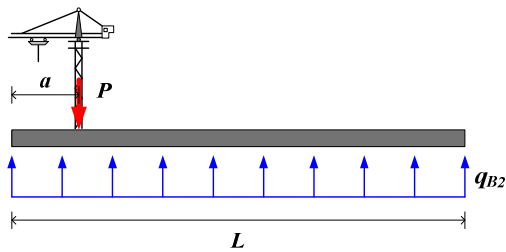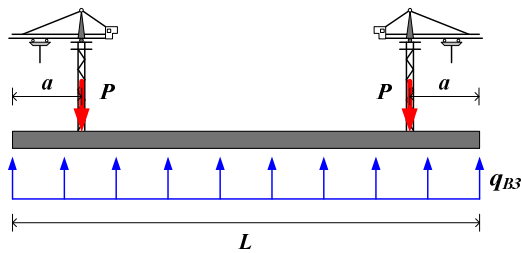
Fig. 8 Shear force diagram for conditions: (a)point loading, (b) symmetry of point loads, (c) full loading
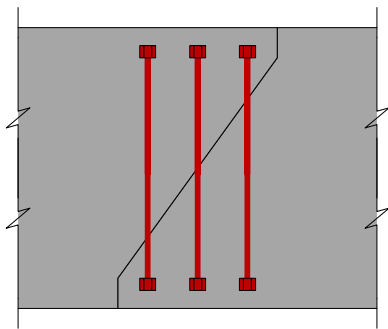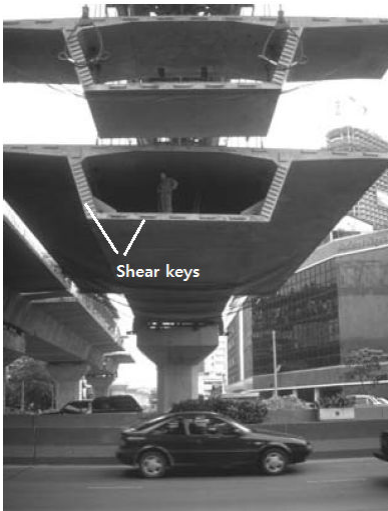

Fig. 9 One-way shear key

Fig. 10 Photo of conventional shear key [6]

C. One-way Shear Key

The shape of widely used shear key is like Fig. 5 and this resists upward and downward shear force. If there is no significant load change on a floating structure, shear key could be designed to resist the shear force in one direction, upward or downward. Therefore, a modified shape of shear key instead of the conventional shape in Fig. 5 can be considered as seen in Fig. 9.

If a structure is small and shear force is not significant, only one shear key like Fig. 5 could be used and it has five connecting planes. However, many shear keys are needed and the connecting planes increases when a structure is big and shear force is significant as seen in Fig. 10.

The shear key in Fig. 9 has only three connecting planes irrespectively of the size of structure. This simple connecting plane can decrease construction time and cost. This shear key is limited to the case that the difference of upward and downward shear forces is big because this can resist force in one direction and concrete has excellent capacity for compression. Small force of the opposite direction can be resisted by steel bars with good capacity for tension.

### IV. FEASIBILITY STUDY ON CONNECTING SYSTEM

A. Basic Capacity of One-Way Shear Key

To check simply the effect of the one-way shear key, an analysis by finite element method (FEM) was performed.

Both conventional and proposed models have same connecting length and inclination of shear key as seen in Figs. 11 (a) and (b). Pre-stressing force to connecting two blocks in longitudinal direction was considered as a uniform load at both end sides. Material of model was steel because the aim of this analysis is just to check the behavior and relative capacity of the one-way shear key, not for real design. Interface element with no friction was used to allow the separation of two block. Therefore, there is just mechanical interlocking between blocks.
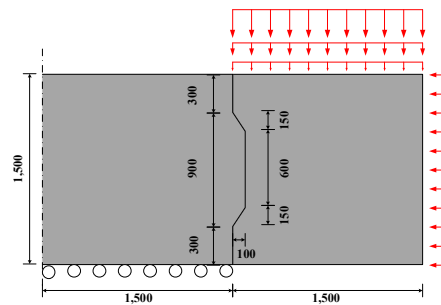
(a)
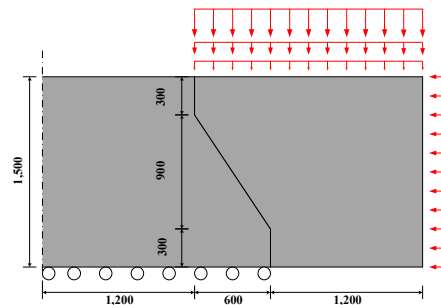
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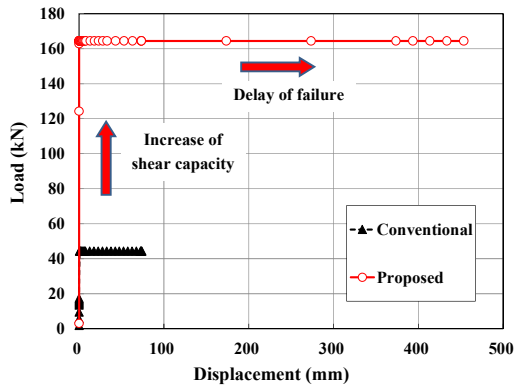
(c)

Fig. 11 FEM analysis: (a) conventional type, (b) one-way shear key, (c) analysis results

Fig. 11 (c) shows the analysis results. There is no material failure in these models. The resisting capacity for shear depends on the inclination and the connected length of the connected plane. Even though two shear keys have same inclination at the connected plane, the connected length of the one-way shear key is bigger approximately six folds than the conventional type. The increase of the connected length contributes the delay of failure when there is no material failure.

B. Wave-Induced Shear Force

If a structure floats under wave condition like Fig. 12, section forces occur by wave. The motion of the structure in wave causes dynamic forces due to the accelerations involved. Despite the dynamic nature of the interaction between structure and wave, the traditional design practice was to reduce this dynamic problem to a quasi-static one [7]. In this quasi-static design process, the maximum wave length is usually assumed to be equal to the length of the structure and the wave is of cosine form.

When a wave with the height of H_w and the length of L_w goes through a floating structure with the width of B, the wave height at any point x can be considered by (1), then buoyancy per meter of the structure under wave condition can be calculated by (2) using the density of seawater (ρ_w), and finally wave shearing force is like (3).
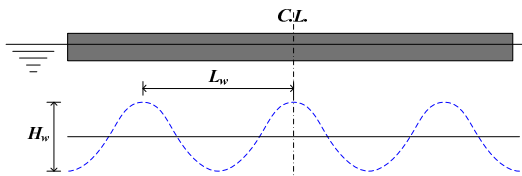

Fig. 12 Wave shape

$$h_w = \frac{H_w}{2} \cdot \cos\frac{2\pi}{L_w} x \tag{1}$$

$$b_x = \rho_w \cdot B \cdot h_w \tag{2}$$

$$Q_w = \int b_x \, dx \tag{3}$$

C. Calculation Example

A lot of loads including ballast, storage, traffic and equipment, crane, fender, and so on [8] are to be considered when a floating structure is designed. However, simple conditions will be considered in this paper. A floating container terminal is 240 m long and 16 m high. The width of it will be considered just as 10 m for simplicity. The structure is like a long box and it will be constructed as reinforced concrete member. Two container gantry cranes at the both ends will be installed and twenty feet dry cargo container [9] will be stacked up as seen in Fig. 13. This structure is located 35 m below sea level and the wave height and length for design are 5.4 m and 40 m, respectively.
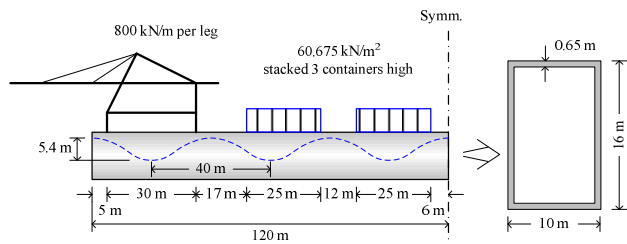

Fig. 13 Geometry for calculation example

Considering that the precast unit length for a pontoon is 60 m, this structure can be constructed with four pontoons with the length of 60 m or two of them and a 120 m pontoon. The latter will be better because it is important to reduce the number of connecting times.

Using (1), (2), and (3), wave-induced shear force is acquired as:

$$Q_w = 1726.6 \cdot \sin\frac{\pi}{20} x \tag{4}$$

Equation (4) indicates hogging state and this value will be minus at sagging state. This paper considers only hogging state for simplicity because there is little difference of shear force between hogging and sagging states. Fig. 14 shows that shear force by wave and loads along the length for each state in Fig. 7.
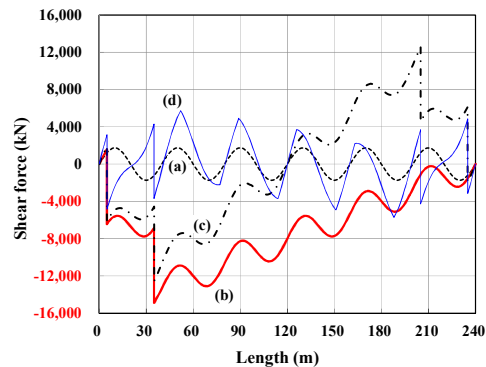

Fig. 14 Shear force diagram of example under wave

As seen in this shear force diagram, maximum shear force occurs in the section when a gantry crane is installed at one side of the structure. Symmetric installing of the crane and stacking containers cause the reduction of section shear force. Connecting section located at 60 m from the left end has to successfully resist the shear force with -12000 kN when a gantry crane is installed at one side and +2500 kN in operating condition.

The load carrying capacity of one-way shear key is good for one direction but it can't resist shear force in the opposite direction. However, the quantity of shear force in one direction is relatively not so big over that in opposite direction, in this case +2500 kN, because the floating structure will be in a similar condition like Fig. 7 (d).

This shear force with plus direction can be resisted by using steel bars in vertical direction. Table I shows the characteristic properties of pre-stressing steel bars. Selection three bars with the diameter of 36 mm gives a capacity of 2550 kN and the section force of 2500 kN is overcome. Finally, two steel bars at each side wall of the connected plane are used for design and connecting lay-out is like Fig. 15.

TABLE I
CHARACTERISTIC PROPERTIES [10]

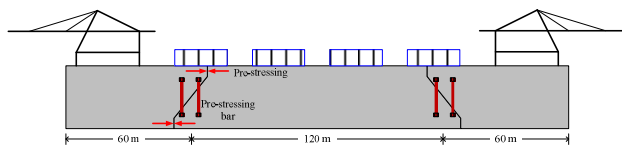| Nominal dia. (mm)	Nominal area (mm^2)	Nominal tensile strength (MPa)	Characteristic strength (kN)	
			Max. Force	0.1% Proof
32	804	1080	870	750
36	1018	1030	1050	850
40	1257	1030	1295	1050
56	2463	1000	2460	1995
75	4418	1000	4418	3580

Fig. 15 Completion of connecting pontoons

V. CONCLUSION

In this paper, a modified connecting shear key was studied. Connecting technology for concrete blocks has already been widely used in bridge engineering. However, this would not be the best solution on a rough sea where construction condition is quite coarse. For easy and fast construction of a floating structure, a modified connecting system was proposed in respect of only shear behavior because flexural behavior can be dealt with easily by exiting technology. One-way shear key was adapted considering that there is a big difference between upward and downward shear forces for a structure like floating container terminal. Basic concept and layout for this system was explained and the feasibility was check by FEM. Calculation and design for a realistic structure were performed.

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