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Technical Measures to Ensure Safety in Operating Load Combination

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Abstract
Technical measures to ensure safety in operating two port cranes together might be applied in cargo handling in seaport, river port, and warehouse. The article has investigated two technical measures: proper load balance between cranes before lifting, and optimal weight allocation to ensure the compliance of the crane's maximum lifting capacity regulation. These two cranes work alternately, one working, one-stop. In this case, it is also necessary to appropriately arrange the distance between the two planes and the cargo lifting steps. The distance between the two planes and loading should be based on the slant angle of the cargo slings of the cranes and never exceed the allowed limit. Under this condition, the distance between the two planes should be lower than the difference of the yoke length and the horizontal projection of the cable. The movement distance of the cargos (moving step) is determined according to the allowable angle of the cable. At that time, the movement distance of the cargos is the distance between the two positions when a crane changes the reach and the second crane does not work provided that the yoke is parallel to the ground. The article has investigated about the determination and selection of crane yoke along with the lifting and moving cargo; it will be a solution to ensure safety when using crane two-port crane to lift cargos that are heavier than lifting capacity of the cranes.

Keywords: *load combination, lifting, port crane, lifting capacity*

1. INTRODUCTION

Freight transport has a vital role to play in logistics. Thanks to an efficient logistics industry, the cargo is widely transported from one place to another. In the current economic development situation, in ports in particular and companies, warehouses, and transport hubs in general, the application of scientific and technical achievements in the mechanization of cargo handling is significant and necessary[1]. All factors in the handling process should be specified and defined - that is, the process of cargos handling. This process was developed based on the study of specific mechanized diagrams, ensuring the rationality and feasibility to achieve the requirements such as optimally operating handling equipment; maximum labor productivity of each handling plan; and the safety of handling equipment. Therefore, the process of cargos handling must be carefully planned for every kind of goods and handling equipment so that all activities of cargo handling should be based on the technological process[2]. Optimally and safety operating handling equipment also depends on the working plan. One of the super-weight cargo handling measures is to use a combination of two cranes working together.

The "load combination" method using two cranes are working together to handle the cargos that exceed one crane's lift capacity at a definite reach[3]. This method has a significant economic role to play in optimizing crane productivity in seaport and river port when heavy lifting equipment is not available [4][5]. It may help to cut the cost of renting fees, transportation fees, and other opportunity costs. Sometimes, the jetty surface in the port cannot withstand the pressure of large lifting equipment; the "load combination" method is a highly effective technological measure. Improperly using load combination measures may cause work-related accidents to people and equipment or reduce the effectiveness of this technology.

The measure of proper load port between cranes is the use of lifting yoke[6]. This is a kind of bulk material handling equipment with a simple structure, affordable price, and user-friendly[3]. On the lifting yoke, we may arrange the crane hook points and hang the bulk cargos on flowing the rule: the distance between the crane hook points and the crane hook points of the crane should be inversely proportional to the crane's lifting capacity.

To avoid overloading the cranes when lifting and moving the cargo. It is necessary to plan and control of cargo handling operations by the characteristics and technical features of the crane. For the port-crane, thanks to the ability to change the reach when carrying the cargo and the lifting capacity does not depend on the reach, it is possible to apply various ways of lifting such as lifting in the same plane of the two cranes, combining both rotate and change the reach[7], moving cargo by changing the reach in 2 different planes (2 vertical planes containing cranes parallel to each other), then a crane shortens the reach, the other crane extends the reach with the same step of moving.

There are issues that may happen when applying the load combination method:

- Flip the crane because of overload results in steel structures and crane damage[8].
- Only allowing lifting weight is much lower than the lifting capacity of the crane, thus reducing crane efficiency.
- Only using two cranes with the same technical features that limited the efficiency of other available port cranes[9].

The above technical problems have limited economic-technical roles when implementing the load combination. The root cause is that the technical measures may have taken in the wrong way. Therefore, to ensure safety, take advantage of the crane's lifting capacity and satisfy technical requirements, technical measures are a matter of concern[10].

However, because of the diversity and sophisticated technical features of lifting equipment, technical solutions need to be explicitly studied for each type of crane. The article does not go into the theoretical issues but only refers to technical measures to meet safety requirements when combining two cranes working together to lift the cargos that have higher weight than the lifting capacity of the cranes.

2. TECHNICAL REQUIREMENTS OF THE LOAD COMBINATION METHOD

Article 1.5.7 of Vietnamese Standard 4244-2005 stipulates that: "Only two or more lifting equipment can be used to lift a load in special cases. Users ought to implement safety measures approved. The load distribution on each equipment should not exceed the lifting capacity of each lifting equipment. In the safety measure, there must be a loading diagram, load moving diagram, and specify the sequence of operation ..."[11]

Thus, specifying these provisions when implementing the crane method should satisfy the following technical requirements:

1. Ensure that the load distribution on each equipment should not exceed the lifting capacity of each lifting equipment at the corresponding reach[12].
2. When lifting and moving goods, we have to make sure that each crane lifting capacity is under control.
3. Make sure that the lifting cable is not overly skewed vertically[13].
4. When moving goods, it is necessary to set up the moving map and specify the order to perform the operation and carefully move the cargos one by one[14].

3. MEASURES TO AVOID OVERLOAD OF THE CRANES WHEN LOAD COMBINING

To ensure the lifting weight acting on each crane does not exceed the permitted lifting capacity of the crane, we may use a crane yokes to distribute the load[15].

Consider the case of using two cranes with lifting capacity Q_1, Q_2 to lift the weight of $Q \leq Q_1 + Q_2$ and $Q > Q_1$, $Q > Q_2$.

When the hook is attached to the cargo, under the effect of load Q, the tension of the hanging cable in each crane must be less than or equal to the lifting capacity of Q_1, Q_2 (Fig 1).

Call:

The distance between the two cables is L.

The distance from center O to Q_1 is L_1

The distance from center O to Q_2 is L_2

Considering the port of the item code we have:

$$Q = Q_1 + Q_2 \tag{1}$$

$$Q_1.L_1 = Q_2 L_2$$

Then

$$Q.L_1 = Q_1.L$$

$$Q.L_2 = Q_2 L \tag{2}$$

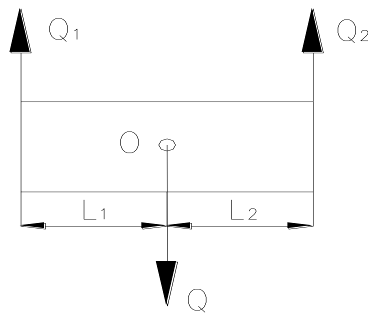

Figure 1. Diagram of force

If the Centre of the cargos is in the middle of two cables, then $L_1 = L_2$ and $Q_1 = Q_2 = Q / 2$. In other words, we may use two cranes with equal lifting capacity.

If the center is not on the middle of two cables (this case is similar to the two cranes with different lifting capacities Q_1, Q_2 and lifting Q) then $L_1 \neq L_2$. Therefore, in order to ensure safety for cranes, it is necessary to select an appropriate cable hanging point that satisfies formula (2). This is very difficult to implement.

Therefore, in order to avoid overloading, it is necessary to arrange the crane yoke with the moment arm in proportion to a load of each crane (Fig 2) to satisfy the condition (2).

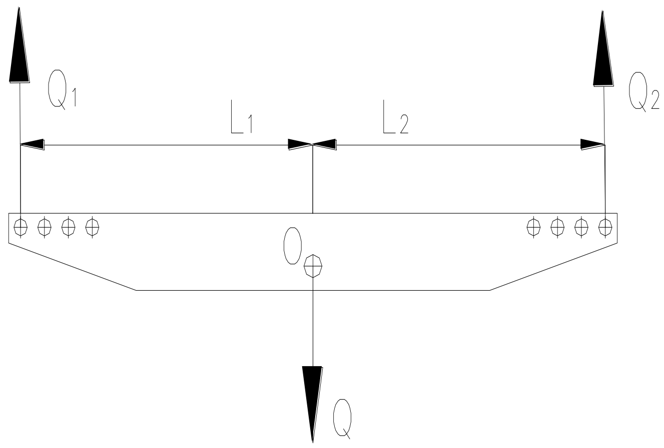

Figure 2. Force diagram in Crane yoke

From formula (2), in the crane yoke:

$$L_1 = \frac{Q_1 L}{Q} \quad (3)$$

$$L_2 = \frac{Q_2 L}{Q} \quad (4)$$

$$\frac{L_1}{L_2} = \frac{Q_1}{Q_2} \quad (5)$$

Formula (5) shows that the cable tension force in each crane is inversely proportional to the distance from that force to the center of the cargos. Therefore, to distribute the load by the lifting capacity of each crane when the cranes are working together, it is necessary to calculate and chose a yoke with the dimensions satisfying the formula (3), (4). Diagram of using crane yokes shown in Figure 3.

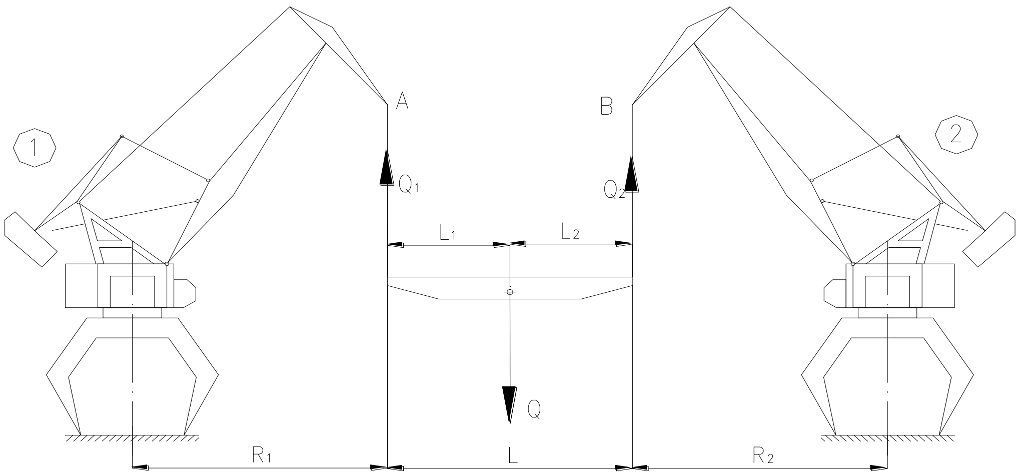

Fig 3. Force diagram with a yoke and two cranes

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To use crane yokes for cranes with different lifting capacities, it is necessary to calculate and arrange various hook positions to accommodate the different cranes (Fig. 2). Another thing to consider is that if the selected crane yoke is too heavy, it will negatively affect the lifting ability of the crane, limiting the economic role of the method.

4. MEASURES TO AVOID OVERLOADING OF EACH CRANE WHEN LIFTING AND MOVING CARGOS DURING WORKING TOGETHER

Lifting:

With the load distribution yoke as above, when the cargo hangs on the cable, the cable tension force at each crane will be distributed by the lifting capacity of the respective crane. However, when working if the lifting or moving of the cargo is not reasonable, it will also lead to overload, the cargo cable may also be tilted too much.[16]

When starting the lifting mechanism of Q from the ground, the cable tension force will be: ψ.Q with

$$\psi = 1 + \frac{\tau}{\pi\tau}\left|\sin\frac{\pi\tau}{\tau}\right|$$

I am being a dynamic coefficient.

If the starting time is concise, the cable tension force may reach to 2 times of Q [17].

In the case of a crane, if two cranes have equal lifting speed, the same starting time, the cable tension force of the two cranes also increases with equal proportions when starting, $\psi .Q_1$, $\psi.Q_2$.

If two cranes have different speeds (Fig. 4), V_2 speed is more significant than V_1, then the cable of the first crane will be too tight, while the cable of the second crane is not stretched. This means that the crane with higher speed may be overloaded[18]. Therefore, when lifting cargo, it is necessary to ensure that the speed and performance of the two cranes must be equal, the lifting speed must not be too high, especially when lifting cargo from the hard ground.

Moving

For the port-crane, it is allowed to carry cargos when changing the range[19]. Therefore, to move the cargo from one location to another, it is possible to move the cargos by coordinating the change of reach, and rotating the 2 cranes when they work together.

Usually, to prevent the cable being overly skewed and to limit the transmission force between the two cranes, it is necessary to arrange two cranes in different planes when rotating, changing the reach, rotating and changing[20] (Fig. 5) simultaneously.

Then, depending on the cargo location and the way to move the cargos, it is possible to move the cargos in the following ways:

- The two cranes are placed in two planes in parallel and opposite direction, alternately changing the reach in the plane of each crane. One work, one stops (Figure 5)

- The two cranes are placed in two planes in parallel and opposite direction, performed simultaneously to change the reach in the plane, 1 crane to increase and 1 crane to reduce simultaneously.
- The two cranes are located on the same plane, varying the reach in the same plane, the first increases, and the second reduces simultaneously.
- The two cranes are placed in two planes in parallel and the same direction, changing the reach to increase or decrease simultaneously.

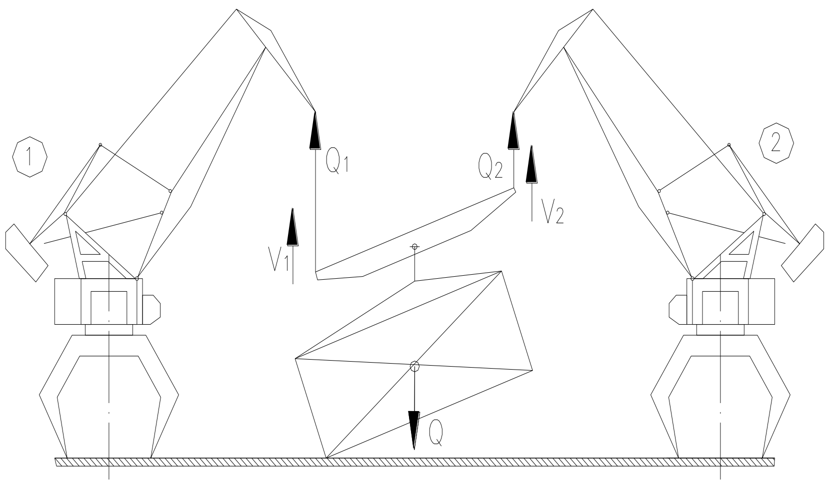


Figure 4. Uneven lifting

- The two cranes are placed in two planes in parallel and the same direction, changing the reach and turning, increasing or decreasing the reach simultaneously.
- Two cranes are placed in two planes in parallel and opposite direction; both cranes work together while changing the reach and rotation.
- Two cranes are placed in two planes in parallel and opposite direction. Two cranes work alternately. Both change the reach and spin; one works, the other stops and vice versa

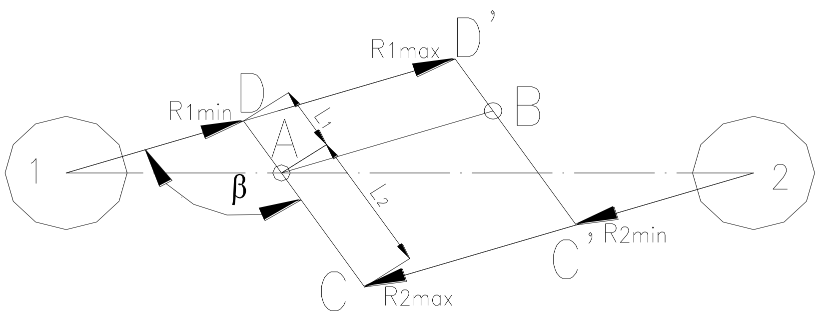


Figure 5. Force diagram of balance crane position

1- Port Crane 1 2- Port Crane 2

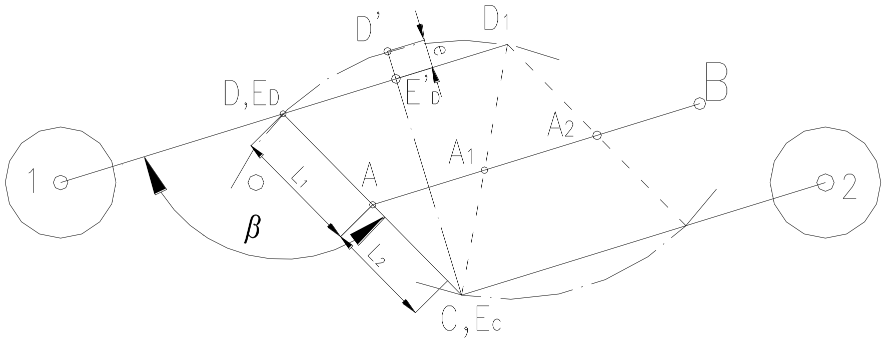
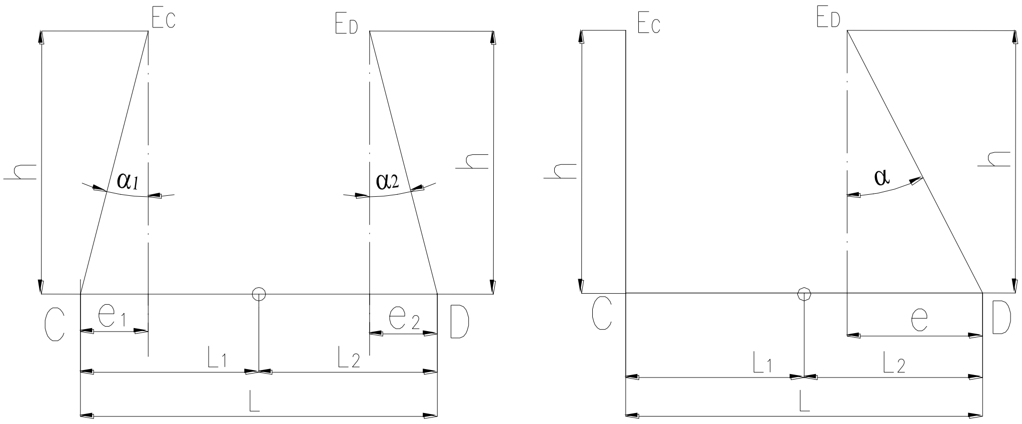


Figure 6. Moving steps diagram

Within the scope of the article, we will focus on the first way (Fig 5). This way it is more comfortable to implement high safety. Besides that, based on the calculation of this case, we might be applied to other cases.

Considering the two-port cranes using the CD yoke length L, the distance from the hang point to the crane 1 and 2 is L_1 and L_2 respectively, to lift and move the goods from A to B by changing the range from Rmin - Rmax in 2 parallel planes (Fig 5).

Suppose, at the beginning, the yokes CD created with the cranes an angle $\beta > 90^0$, the distance between the two planes of the K crane at that time will be less than L, the distance of the 2 hanging point $E_C E_D = L$. Crane 1 changes the range from point D to D_1, while the crane 2 is not working (Fig. 6). The moving step from D to D_1 is considered the moving step of the crane 1 within its reach. Then, the CD yoke will rotate and $E_C E_D < L$, the slings of the cranes will tilt the angle α_1, α_2 outward. When the angle is perpendicular to crane 1, E_C E_D has the smallest value E_C E'_D, the angle of the α_1, α_2 cable has the most significant value**.** To be more secure, suppose that the E_C coincides with C, and the yoke revolves around the E_C point. Then point D will draw a circle of radius L; this circle intersects the crane plane 1 at point D. The tilt of the cable will focus on the D point of the yoke with the α angle (Fig.7b)



a, **b,**

Figure 7. The diagram of the cable is tilted when the yoke rotates

According to safety regulations, α tilt angle does not exceed 5^0, from which, if the hanging height is h, we have:

$$e = h.tg_{\alpha_1} \le h.tg5^0 = 0,087.h \quad (6)$$

The moving step DD_1 by L and e is:

$$DD_1 = 2.DE'_D = 2.\sqrt{L^2-(L-e)^2} = 2.\sqrt{0,087.h.(2L-0,087h}$$

$$DD_1 = 0,59.\sqrt{h.(2L-0,087h)} \quad (7)$$

The distance between the two planes of cranes is:

$$K = CE'_D = L - e = L - 0,087h \quad (8)$$

From Figure 6, the initial tilt angle β can be determined by the formula:

$$\sin\beta = \sin(180^0-\beta) = \frac{L-e}{L} \qquad \beta = ar\sin(\frac{L-e}{L}) \quad (9)$$

Corresponding to the moving step, the crane 1 from position D to D_1, the moving step of cargo AA_1 will be:

$$AA_1 = \frac{L_1 DD_1}{L} = \frac{0,59.L_1.\sqrt{h.(2L-0,087h)}}{L} \quad (10)$$

If two cranes have the same lift capacity and choose $L_1 = L_2 = L/2$ then $AA_1 = DD_1/2$.

When crane 1 stops working, crane 2 changes the reach in its plane, similar to the above, the crane 2 moving step is also defined according to (7), and the movement of the cargo will be:

$$A_1A_2 = \frac{L_2 DD_1}{L} = \frac{0,59.L_2.\sqrt{h.(2L-0,087h)}}{L} \quad (11)$$

The total length of cargo movement after 2 cranes working will be:

$$AA_2 = AA_1 + A_1A_2 = \frac{0,59.(L_1+L_2).\sqrt{h.(2L-0,087h)}}{L} \quad (12)$$

In the case of the CD yoke created with the boom of the cranes an angle of $\beta = 90^0$, the distance of the two crane plane K = ECED = L, when the reach is changed, the cargo cable of the cranes will tilt into the inside of angles α_1, α_2. Similar to the above, in order not to exceed the allowable tilt angle, the maximum 2 points of hanging point E_C E_D will be:

$$E_C E_{D(\max)} = L + e = L + 0,087h \quad (13)$$

Then, the cargo movement step DD_1 will be:

$$DD_1 = \sqrt{(L+e)^2 - L^2} = \sqrt{e(2L+e_1)}$$

$$= \sqrt{0,087h.(2L+0,087h)}$$

$$DD_1 = 0,295.\sqrt{h.(2L+0,087h)} \quad (14)$$

Compared to the above case, DD_1 is a half. If $\beta < 90^o$, DD1 is smaller. Therefore, the distance between two planes should be lower than L. The distance between the two cranes can be chosen in the range of:

$$L - 0,087h \le K \le L \quad (15)$$

The cargo movement step DD_1 will be at the maximum when

$$K = L - 0,087h$$

5. PRACTICE

Two port-cranes lifting capacity Q_1 = 12T and Q_2 = 8T, hanging point height h = 10m, yoke length L = 10m, cargo Q = 20T from A to B (AB = 16.29m) (H5). Determine the hanging point Q on the yoke, the crane's moving step and the number of times to carry out the cargo of the cranes.

Selecting the moving option by placing two parallel cranes, alternately changing the range:

Determine the hanging point on the yoke:

We have Q= Q_1+ Q_2, then, according to formula (4), (5) we have:

$$L_1 = \frac{Q_1 L}{Q} = \frac{12.10}{20} = 6(m)$$

$$L_2 = \frac{Q_1 L}{Q} = \frac{8.10}{20} = 4(m)$$

So the hanging point is 6m from the plane of 12T crane, and 4m from the plane of 8T crane.

Determine the distance of 2 cranes and moving step:

Select the movement with the most significant moving step, crane 1 works, crane 2 stops working, according to (8), the distance between the two cranes is:

$$K = L - e_1 = L - 0,087h = 10 - 0,087.10 = 9,13(m)$$

Determine the moving step:

According to (7), the moving step of the crane will be:

$$DD_1 = 0,59.\sqrt{h.(2L - 0,087h)} = 0,59.\sqrt{10.(2.10 - 0,087.10)} = 8,146(m)$$

The moving distance of cargo: corresponds to the moving step of two cranes:

According to (10), the moving step of the crane 1 will be:

$$AA_1 = \frac{L_1.DD_1}{L} = \frac{6.8,146}{10} = 4,887(m)$$

According to (11), the moving step of the crane 2 will be:

$$A_1A_2 = \frac{L_2.DD_1}{L} = \frac{4.8,146}{10} = 3,258(m)$$

Crane 2 works, the crane 1 stops working, the crane's moving step 2 will be:

$$A_1A_2 = \frac{L_2.DD_1}{L} = \frac{4.8,146}{10} = 3,258(m)$$

The total length of movement after 2 cranes working will be:

$$AA_2 = AA_1 + A_1A_2 = 4,887 + 3,258 = 8,145(m)$$

The number of movement times to move the cargo through a section AB = 16.29m are:

n=16.29 / 8.145=2 (lần)

In conclusion, to move the cargo through section AB = 16.29m, by alternately changing the range, it is necessary to place parallel cranes together, about 9.13m apart from each other. The moving step does not exceed 8,146m; then the cargo will move 8,145m. The number of movement times to move the cargo through a section AB = 16.29m are two times.

6. CONCLUSION

Through the above analysis and calculations, in order to ensure safety when two port-cranes work together to lift cargo with a heavier weight than their lifting capacity, it is necessary to select yoke to divide the load rightly. At the same time, calculate and choose the most suitable lifting method and need to operate the crane in a particular order with appropriate speed.

The calculation results when the two cranes work together to lift the cargo by changing the reach shown that if we choose the right yoke and the method of placing the crane, move and lift cargo properly with proper moving step and take every step carefully, it will satisfy the safety requirements for cranes when working together.

However, the above calculation only mentions a case of lifting cargo when two cranes work together. In addition to this case, depending on the position of the cargo, crane position, movement direction, characteristics of the crane, we may use other moving-lifting options. Therefore, in specific cases, it is necessary to calculate possible options, from which choose the most effective, easy to implement, and safest option. The above calculation results can be applied to calculate the remaining cases.

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