Deduction and prevention of container overboard accident during loading and unloading

Zhibiao Chen¹.*, Xianling Zhu² and Jingzhou Zhang¹

¹ CCS Wuhan Rules & Research Institute, Wuhan China, 430022
² Wuhan Institute of Shipbuilding Technology, Wuhan China, 430050

*E-mail: zbchen@ccs.org.cn

Abstract. To prevent the recurrence of containers overboard accident during loading and unloading, taking the accident at Yueyang Chenglingji Terminal as the study object, the mechanical deduction is carried out. A kind of method to determine whether a container will overturn is put forward, including the criterion and the quantitative algorithm of the corresponding indicators, i.e. the allowable heel angles. By verifying, the estimated results according to the algorithm described in this article, are basically consistent with the Yueyang accident. Therefore, a set of measures to prevent such accidents are provided, including adding allowable heel angles during loading and unloading in the loading manual, carrying out stowage plan and evaluating and controlling the ship floating state before operating, monitoring and adjusting of the ship floating state during operating.

1. Introduction

Container waterway transportation has the characteristics of large transport capacity, small energy consumption, low cost, less land occupation and less pollution, so developing vigorously over the years. At the same time, accidents of containers overturning and falling into water also happen frequently, not only in transit, but also in loading and unloading occasionally. "7.28” containers overboard accident in 2011 of Yueyang ChenglingjiSongyanghu International Container Terminal, resulted in 26 FEU scattered in the river, and the captain of the ship on the container missed in water at the same time[1], caused great loss and far-reaching influence.

Through qualitative analysis in macroscopic view, the cause of the Yueyang accident was the uneven weight distribution of the goods carried in the containers, and the stowage calculation wasn't carried out, and the random loading and uneven stowage, all of these led to the container falling into water. However, the author believes that it is necessary to carry out a mechanical quantitative analysis for the accident, to obtain the key quantitative algorithms and preventive measures, so as to prevent the recurrence of such accidents.

2. Accident process

By known information, the container ship was loading at the terminal before the accident. The ship had heeled by the starboard side before the last container lower down, and this container’s slot was located on starboard side, see figure 1(1). After lower down, the heel by starboard was aggravated, see figure 1(2). And then the container columns overturn to the starboard side, see figure 1(3). At last, Domino effect appeared, and the containers overturned and fell into the water, see figure 1(4).
3. Accident deduction

3.1. Deduction condition
The ship is a typical inland waterway container ship. The securing scheme adopts the splayed lashing to the whole container stack [2] [3]. The container was being loaded at the terminal during the accident. Therefore, the accident scene can be simplified as follows:

- During loading, bridge locks with transverse connectors had not yet been installed on the top of the containers, and neither the lashing wire nor lashing band for container stacking had been installed. Each container column was independent, there was no interaction force between columns. Therefore, the single column of the container stack can be taken as the study object.
- Stack cones were placed between adjacent tiers in the same container column (when loading the twist lock was opened, it was also considered as a stack cone). Therefore, the transverse constraint existed between the container tiers, but no vertical constraint.
- The ship berthed at the terminal. There was no the rolling, pitching and heaving motions caused by waves. Therefore, the analysis can be carried out according to the static situation, considering the container gravity, and centre of gravity located in container centre.
- When the accident occurs, the ship was being in the maximum heel. The heel angle should be the initial heel angle before the last container lower down, plus the increment caused by the last container lower down.

3.2. Force analysis

By further analysis of container overboard details, the author found that the top three containers were overturned at first, see figure 1(3), but then only the top two containers overturned together because
obstructed by the hatch or the container of the adjacent column, see figure 1(4), but in either case, they all overturned around the stack cone of the container corner. In combination with the above 3.1, considering a container column as an object, the overturning mechanics model as shown in figure 2 is established.

Overturning moment of the container column around the stack cone, \( M \), can be calculated as follows:

\[
M = nG\left[\frac{n(h_i + d_i)}{2}\sin\alpha - \frac{b}{2}\cos\alpha\right] = \frac{1}{2}nG\left[n(h_i + d_i)\sin\alpha - b\cos\alpha\right]
\]

where 
- \( \alpha \) —— the ship heel angle;
- \( b \) —— the space between the container left stack cone and the right, generally taken as 2.259m;
- \( h_i \) —— the container height, generally taken as 2.591m[4];
- \( d_i \) —— the space between the container tiers, generally taken as 0.028m;
- \( n \) —— the total number of the container tiers;
- \( G \) —— the average weight of the containers, taken as no more than the rated weight.

When the overturning moment \( M > 0 \), \( n \) tiers from top down will overturn.

Let \( M = 0 \), the formula of critical heel angle after lower down is obtained as follows:

\[
\tan\alpha = \frac{b}{n(h_i + d_i)}
\]

If \( n \) taken respectively as 1, 2, 3 and 4, the corresponding critical heel angles are shown in table 1. From the table, it can be concluded that the more stacking tiers are, the more prone to overturn.

| \( n \) | \( \tan\alpha \) | \( \alpha \) (deg) |
|-------|----------------|-----------------|
| 1     | 0.863          | 40.779          |
| 2     | 0.405          | 22.028          |
| 3     | 0.271          | 15.163          |
| 4     | 0.205          | 11.578          |

The heel angle \( \alpha \), consists of the initial heel angle before lower down, \( \alpha_0 \), and the incremental angle after lower down, \( \theta_h \), that is:

\[
\alpha = \alpha_0 + \theta_h
\]

where \( \theta_h \) can be taken as the incremental angle on the stability arm curve[5] corresponding to the heeling arm \( l_h \) caused by lower down, shown as figure 3.

![Figure 3. Stability arm curve and heel angle.](image-url)
The heeling arm, \( l_h \), can be calculated as follows:

\[
l_h = \frac{c G}{\Delta} \left[ G \cos \alpha + (Z - \frac{d}{2}) \sin \alpha \right]
\]

where \( c \) —— the dynamic coefficients while lower down, generally taken as 1.3;
\( G \) —— the weight of the operating container;
\( \Delta \) —— the ship displacement;
\( Y, Z \) —— the respective distance from the ship center line plane and base plane to the center of the operating container after lower down;
\( d \) —— the ship draft;

At last, the heel angle before lower down, \( \alpha_0 \), can be obtained as:

\[
\alpha_0 = \alpha - \theta_l
\]

It is worth pointing out that, the above analysis also applies to the situation of lifting up a container from the ship. For lifting up, the heeling arm \( l_h \) is caused by lifted up, at this time the container weight is taken as negative value; the heel angle \( \alpha_0 \) is the heel angle after lifted up; the heel angle \( \alpha \) is the heel angle before lifted up.

3.3. Overturning criterion

Some simplified assumptions are adopted in the above analysis process:

- Each container weight in the same column is even;
- No wind load when loading and unloading is considered;
- No ship swaying when loading and unloading is considered.

The partial safety factors are taken into account for the above uncertainties, the critical heel angle in 2.2 of this article can be converted to the allowable heel angle as follows:

\[
[\alpha] = \alpha / \gamma_o
\]

\[
[\alpha_0] = [\alpha] - \gamma \beta
\]

where \([\alpha] \) —— the allowable heel angle after lower down or before lifted up;
\([\alpha_0] \) —— the allowable heel angle before lower down or after lifted up;
\( \gamma_o \) —— the partial safety factor of the uneven weight and the wind load etc., generally not less than 1.3;
\( \gamma \) —— the partial safety factor of ship swaying, generally not less than 1.1;
\( \beta \) —— the incremental angle caused by the heel moment \( l_h \), determined according to the method of figure 3, \( \alpha \) in the figure corresponding to \([\alpha] \) here;

Now, it is possible to determine whether the container will overturn by these two indicators, the allowable angle \([\alpha] \) and \([\alpha_0] \), as follows:

- The allowable heel angle before lifted up or after lower down \([\alpha] \): if the ship heel angle exceeds this indicator before lifted up or after lower down, the overturning may appear; to be determined by the formula (2) (6) of this article.
- The allowable heel angle before lower down or after lifted up \([\alpha_0] \): if the ship heel angle exceeds this indicator before lower down or after lifted up, the overturning may appear; to be determined by the formula (4) and (7) of this article, taking the operating container as the variable.

4. Verification of criterion

According to the collected information of the accident ship, at the accident time, the maximum tiers number of container stacks was \( n=4 \), the columns number is 3; the ship moulded depth is 3.3m; the design draft is 2.5m; the ship displacement is 1600t; the stability arm in the design full loading is shown in table 2.
Table 2. Stability arm \( l \) in full loading.

| \( \theta \) (deg) | 0  | 2  | 4  | 6   | 8  | 10 | 12 | 14 |
|-------------------|----|----|----|-----|----|----|----|----|
| \( l \) (m)       | 0  | 0.065 | 0.130 | 0.196 | 0.263 | 0.313 | 0.341 | 0.354 |
| \( \theta \) (deg) | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 |
| \( l \) (m)       | 0.355 | 0.344 | 0.324 | 0.297 | 0.262 | 0.222 | 0.177 | 0.123 |

The allowable heel angle after lower down \( \alpha \) is obtained according to the formula (2) and (6); the heel arm after lower down \( l_b \) is obtained according to the formula (4); the incremental angle \( \theta_b \) is obtained according to the method of figure 3 and table 2; the allowable heel angle before lower down \( \alpha_0 \) is obtained according to the formula (7). The results are shown in table 3. From the table, the larger container weight corresponds the smaller allowable heel angle.

Table 3. Allowable heel angle \( \alpha \) and \( \alpha_0 \) during loading and unloading.

| \( n \) | \( G \) (t) | \( \alpha \) (deg) | \( l_b \) (m) | \( \theta_b \) (deg) | \( \alpha_0 \) (deg) |
|--------|----------|--------------------|---------------|--------------------|--------------------|
| 4      | 30       | 8.906              | 0.125         | 4.036              | 4.466              |
| 4      | 25       | 8.906              | 0.105         | 3.456              | 5.104              |
| 4      | 20       | 8.906              | 0.084         | 2.846              | 5.775              |
| 4      | 15       | 8.906              | 0.063         | 2.216              | 6.468              |
| 4      | 10       | 8.906              | 0.042         | 1.546              | 7.205              |

From the figure 1(2) and 1(3), the heel angle before lower down is about 5~6 degrees at the accident time, and the heel angle after lower down is about 8~10 degrees.

Where the operating container weight is about 18~30t, the estimated results according to the algorithm described in this article, are basically consistent with the ship states at the accident time.

5. Preventive measures

Based on the above analysis, it is necessary to take the following precautionary measures to prevent the recurrence of this kind of accident of containers overturning at terminal:

- In the loading manual the allowable heel angle \( \alpha \) and \( \alpha_0 \) should be added, shown as Table 2. A series value of the maximum tiers \( n \) and the container weight \( G \) in the table can be present according to the ship situation.
- Before loading and unloading, the stowage plan and the floating state simulation should be carried out, to evaluate the ship heel angle, and to control the allowable indicators \( \alpha \) and \( \alpha_0 \) not to be exceeded, respectively corresponding to the heel angle after lower down and the heel angle after lifted up.
- During loading and unloading, the ship heel angle should be monitored, and the heel angle before lower down should be controlled not greater than the allowable heel angle \( \alpha_0 \), or the heel angle before lifted should be controlled not greater than the allowable heel angle \( \alpha \). If necessary, adjust the floating state and then continue the operation. Where, the ship heel angle can be seen in wheelhouse, and the current allowable heel angle can be interpolated in Table 3, according to the current operating container weight which can be can be obtained from the terminal or the consignor.

General principles are: during loading, if ship has heel angle, the next container should not be lower down as far as possible on the heel side; during unloading, if ship has heel angle, the next container should not be lifted up as far as possible from the opposite side of the heeling; for example, if the ship heel by starboard before lower down, the container cannot be located on the starboard side after lower down.

6. Conclusion

In this article, through the analysis and deduction of the container overboard accident in loading, a criterion and the corresponding quantitative calculation algorithm about the indicators, is concluded to
determine whether the container is possible to overturn through the ship heel angle during loading and unloading. The feasibility of this method is preliminarily verified by the study accident. Measures to prevent such accidents are put forward, including adding allowable heel angles during loading and unloading in the loading manual, carrying out stowage plan, and evaluating and controlling the ship heel angle before operating, monitoring and adjustment of the ship heel angle during operating.

Acknowledgments
Foremost, I would like to show my deepest gratitude to my wife, Mrs. Zhu, who is also my partner, has provided me with great encouragement and support in the studying and writing of this article.

References
[1] Lu Jiqing and Qu Shengguo 2012 On loading and securing of inland waterway container ships Inland River Container Transport Forum (Qingdao: China Institute of Navigation)
[2] Chen Zhibiao 2013 Status and improvement of container securing design in inland waterway shipping J. Marine Tech. 1 29-32
[3] China Classification Society 2016 Rules for the construction of inland waterways steel ships vol 1, China Communications Press Co.,Ltd. (Beijing) p 1-104
[4] ISO 1496-1:2013 Series 1 freight containers
[5] Sheng Zhenbang 2015 Ship Theory, SHANGHAI Jiao Tong University Press (Shanghai) p 95-98