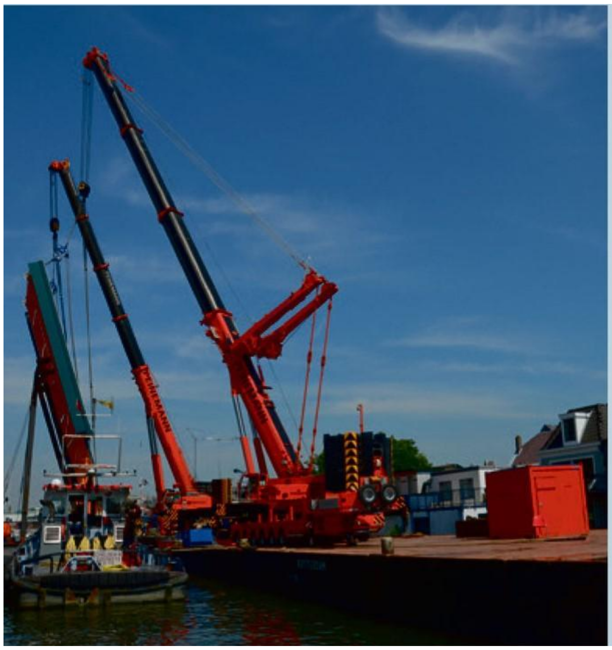
#1 – CAPSIZING BARGES
(Technical)



[1]"Lifting accident Alphen aan den Rijn", *Onderzoeksraad*, 2022. [Online]. Available: https://www.onderzoeksraad.nl/en/page/4008/lifting-accident-alphen-aan-den-rijn. [Accessed: 24- Jul- 2022].

It was August 2015, a hot summer day in Alphen aan den Rijn; town was quiet, children were on vacation and most families traveled for their summer holidays. A good period to plan the installation of a new section of the Koningin Julianabrug bridge onto the pre-existing structure. The new section of the bridge was transported by two barges which contained a crane each to suspend the bridge in the air. The situation seemed to be under control, but no…it was not: as the bridge was being handled by the two cranes, the barges capsized, bringing down with it the cranes and the bridge section. The entire system ended up crushing the surrounding houses, damage was significant…. luckily nobody was in those homes at that time and no lives were taken…

Let's have a look into what actually, unfortunately happened.

The entire configuration of the system included 3 barges; two of them had cranes mounted on top and were used to suspend and transport the new section of bridge to be installed. The third barge had the actual section of bridge that needed to be picked up by the other two. The two barges looked identical… however they were not! One of them was carrying a larger crane compared to the other which was slightly smaller in size and height. The two cranes slowly began lifting the bridge into the air, the operation seemed smooth with no visible problems to be noticed. Anyhow, once the bridge was fully suspended in the air by the cranes, it started swaying and swinging towards the smaller crane. The section of bridge was now moving in a dangerous, uncontrolled manner forcing both crane operators to evacuate from the cranes promptly. What happened next is unfortunately easy to imagine…both barges capsized leading to the overall failure of the entire technical system.
Following the accident, the Dutch Safety Board (DSB) conducted an investigation to understand the cause of the issue.

First of all, it is necessary to establish what caused the accident. Why did it happen?

For lifting rigs, stability is a fundamental requirement to avoid accidents and damage. A key parameter for lifting rigs and floating objects is the "Metacentric height" (GM/initial stability). GM is mainly affected by:

- Height of the combined center of gravity (COG) of the barge and elements on it
- The width-depth ratio of the barge

A higher GM is favorable and indicates greater stability of the barge. Typically, you want a GM above 1 to ensure sufficient stability. A GM near zero results in a very unpredictable response of the system whereas a GM with a negative value will most likely capsize. In complex and dangerous processes such as these, often a minimum GM requirement for safe procedure is formulated. This was also indeed done in this case, the barge operator prior to beginning had established that the GM of 2-2.5 was sufficient for the stability of this operation.
As aforementioned, the DSB reviewed the case and came to a conclusion as to the contributing factors of the accident. The DSB found that, contrary to what the barge operator detailed, a GM of at least 4 was needed for safe operation. Additionally, they found that the GM of the barges used did not even meet the requirements detailed by the barge operator but were rather much lower. The small and large barge had a GM of -0.03 & 1.17 respectively. The initial stability of the small barge was too low, leaving no margin to account for absorbing forces due to motion of the bridge, wind, etc. The DSB, already from this point had established that the initial stability was so low that the accident could not have been prevented.

The DSB also investigated the preparation of the lifting & crane operation phase. Preparation, in terms of developing the plan for the lifting of the bridge, began over one year earlier, in June 2014. At that point, the plan was rather rudimentary and was not fully developed. However, a configuration for the lifting had been drawn up and based on that, initial GM calculations were made of which the results had already been presented. What the DSB found was that naturally, over time, the lifting plan had been slightly altered and changes were made until its final configuration. However, the GM had not been updated as the configuration changed, but was rather left unchanged since the beginning. It is certainly not correct to assume that the GM stays the same and the value used should have been that of the final configuration, in fact the DSB did indeed calculate that the actual GM needed was 4, not the 2-2.5 specified by the barge operator. A rather tragic "small" mistake!

Regarding the preparation of the crane operation phase, there were also some issues with the technical system. The Vertical Transport system (VTS) drew up a plan for projects where multiple cranes are used to carry the same load. The VTS states that "The permitted working load per crane amounts to 75% of the working load at the necessary working radius"; That means each crane is at most allowed to carry 75% of the mass of the bridge. However, the working plan from VTS also stated that deviation from this is allowed as long as the same level of safety and health is maintained. The project manager opted against using this restriction for a few reasons. A larger crane that could handle the weight better was not available and was also too wide for the bridge opening. Additionally, a well detailed lifting plan was set in place and a very experienced foreman was to be present on site that day therefore, the project manager figured the rule was unnecessary. By overlooking this rule, the cranes were working above their Safe Working Load (SFL). In practice, the small crane was loaded to 99.9% of its SWL and the big crane at 101.6%.

Ultimately, the difficulty and precision required to accomplish such a task were not reflected in the preparation & configuration of the technical system. Considerations regarding the GM were rather superficial and not relevant as the value was calculated for a configuration which was not used and did not account for external factors. No margin for error was left for deviation in crane operation, rather the machinery was pushed beyond its limit. Overall, not enough attention had been given to stability analysis and crane lifting capabilities and rather several elements were overlooked leading to a design of a technical system which simply wasn't suitable for the task at hand.

Based on the findings, let's have a look at what could have been done to minimize the risk of an accident.

ISO 12100 specifies a 3-step iterative method to ensure risk has been adequately reduced:

- **Step 1**: Inherently safe design measures
- **Step 2:** Safeguarding and complementary protective measures
- **Step 3:** Information for use

From what we have seen above, the failure of the technical system is directly related to its design and plan. Failure is attributed to the calculations of the GM and crane lifting procedure. These are both issues that most resemble Step 1 of risk management. Therefore, it would appear that the technical system, from a design perspective, was simply already not inherently safe. Meaning that any potential use of secondary & tertiary safety measures still could have likely led to failure. In order to ensure proper functionality and minimize the risk of damage multiple options are possible.

Step 1:
To address the problem at the root, thus making an inherently safe design, the GM calculations should have been done for the final configuration and should have considered external factors, the same way the Dutch Safety Board conducted their formulation. Furthermore, it would have been wise to follow the Vertical Transport System recommendations of not exceeding the 75% capacity rule as that would have certainly avoided the overloading of the cranes despite it may not have been logistically easy.

Step 2:
In the event that the recommendations for Step 1 cannot be accommodated or are still not sufficient, additional safety measures could have been used. What seems to stand out is that no safety considerations had been done for the immediate surroundings of the technical system which was rather densely populated and is what ultimately proved to be the most worrying in terms of safety. It seems that safety in this case was restricted to the workers and system despite the fact that the municipality of Alphen aan den Rijn stressed the importance of the surroundings and its residents. What could have been done is that a Construction Safety Plan could have been demanded by the municipality prior to licensing the innovation. This would have forced the companies responsible to broaden their scope in terms of safety and increase the level of safety to avoid damage to both the system and environment. This likely would have increased overall safeguarding and complementary measures. Alternatively, the use of complementary hooks and support chains could have also been used to either stabilize the barge & crane or also to simply alleviate some of the weight off of the cranes and reduce the likelihood of failure.

Step 3:

In the event that the above recommendations are unfeasible or not sufficient in terms of safety, then this needs to be communicated and information for use must be available. If the GM and crane lifting procedures are not already safe enough, this must be communicated to those responsible such that guidelines can be formulated. If that was the case, the team could have reviewed their overall approach to the plan and either decided that the operation should not be carried out or the demands on the technical system could have been loosened. Perhaps a weight limit could have been put in place for the crane operators to know that the weight of the new bridge section is likely too much. In that case, the new section might have been split in two and the assembly would have been done in two smaller safer iterations than done all at once and push the technical system to its limit.

In this situation, we clearly see the importance and necessity of a clear and detailed concept and design phase of a technical system. The decisions and considerations that are made at that stage of the technical design & system are what largely affect the outcome and unfolding of subsequent steps. When safety and design feasibility is not accurately measured and assessed at that stage, it becomes very hard subsequently to ensure that safety is not compromised and oftentimes, because of the large amount of work needed to be done in later stages, these crucial aspects of safety can easily be overlooked. This in fact, is what we have seen and learnt from this story. Ultimately, safety must be an integral part of the design process and must be addressed from the beginning of a system's lifetime; it is simply insufficient to address safety at any later stage and also becomes increasingly difficult to do so.

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