NO STANDARD LOCK GATES FOR THE NEW SEA LOCK IN IJMUIDEN, THE LARGEST LOCK IN THE WORLD

by

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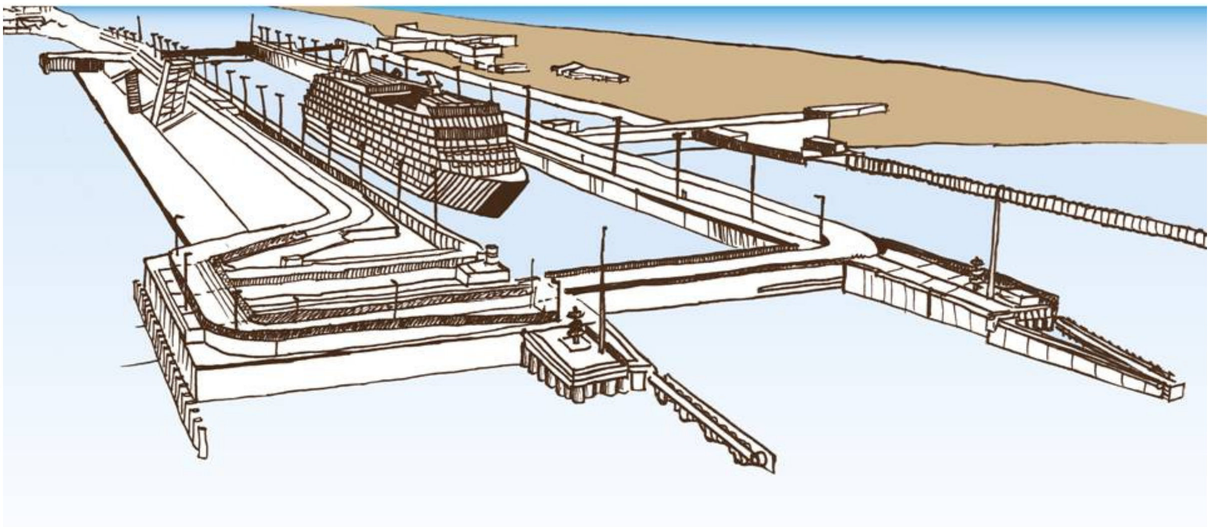
ABSTRACT

In the Dutch city of IJmuiden, a new sea lock is currently under construction. With a lock chamber of 500 m long and 70 m wide, it will be the largest lock in the world. The latest generation of seagoing vessels will be able to access the harbour of Amsterdam using this lock. At the same time, at an altitude of 8.85 meters above sea level, the Netherlands are protected from the rising sea water for the next two centuries. The lock must be constructed in between of the existing operational locks. Because of this lack of space, the water levelling system is incorporate in the rolling gates. The required performance of the gates as well as the drive mechanism, in terms of reliability, availability, maintainability, safety and robustness), was highly governing during the design process, and resulted in a final design that cannot be described as standard.



Key Words: inland navigation, locks, rolling gates, drive mechanism, levelling system

INTRODUCTION

After almost 100 years in operation, the existing Noordersluis (Northern Lock) in IJmuiden will be replaced with a new, larger lock system to improve the accessibility of the port of Amsterdam.

Because of the approaching end of the technical lifespan and the arrival of the end of the economic life of the Northern Lock, a new lock is needed. The new IJmond sea entrance is part of the clients (Rijkswaterstaat) lock renovation program. The scale of increase in vessel size makes it furthermore desirable to construct a new lock that is wider than the existing locks. This will simultaneously increase the capacity of the lock complex.

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The most important work involved in the project includes:

- the design and construction of a new sea lock, including other modifications in the project area (waiting facilities and dredging works of the navigation channel) to enable safe and easy navigation through the new lock;
- the planning and execution of maintenance on the new lock for approximately 26 years;
- the uphold of the primary water-retaining structure in accordance with the Dutch Water Act is an important element of the work.

Rijkswaterstaat awarded the contract to the OpenIJ consortium which consists of BAM-PGGM, VolkerWessels, and DIF. The construction activities will be carried out by a BAM Infra and VolkerWessels joint venture. The work commenced in early 2016. The dredging activities will be carried out by subcontractors Van Oord and Boskalis.

This paper presents the design of the new lock gates and drive mechanisms.

LARGEST SEA LOCK IN THE WORLD

The new sea lock in IJmuiden will be in terms of length of the lock chamber (500 meters) and width (70 meters) the largest sea lock in the world (Figure 1). With these dimensions, it allows passage to the world's largest ships, which will be able to pass through the lock, regardless of the tide, and will strengthen the international competitiveness of the port of Amsterdam. At the same time the new sea lock is built 'future-proof'. At an altitude of 8.85 meters above sea level, the Netherlands are protected from the rising sea water levels for the next two centuries.

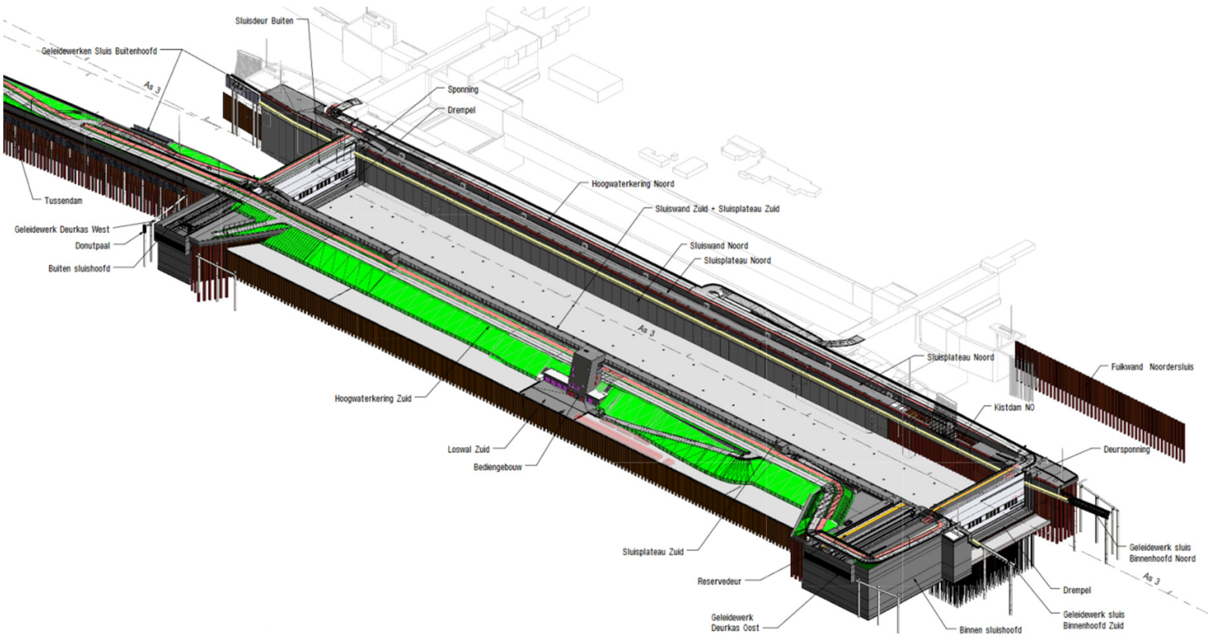

Figure 1: Overview of the new sea lock

REQUIRED PERFORMANCE

The functionality of a navigational lock is particularly determined by the lock gates and drive mechanism. Because the set of performance requirements, the environmental and spatial boundary conditions vary per lock, each lock requires a specific gate design and a standard solution is not available. This also applies to the new IJmuiden sea lock, where the design of the rolling gates (figure 2), measuring 72 meters in length, 11 meters in width and 25 meters in height, is governed by the required robustness and RAMS performance and the environmental conditions. A sufficiently reliable concept had to be developed, requiring minimal maintenance effort.

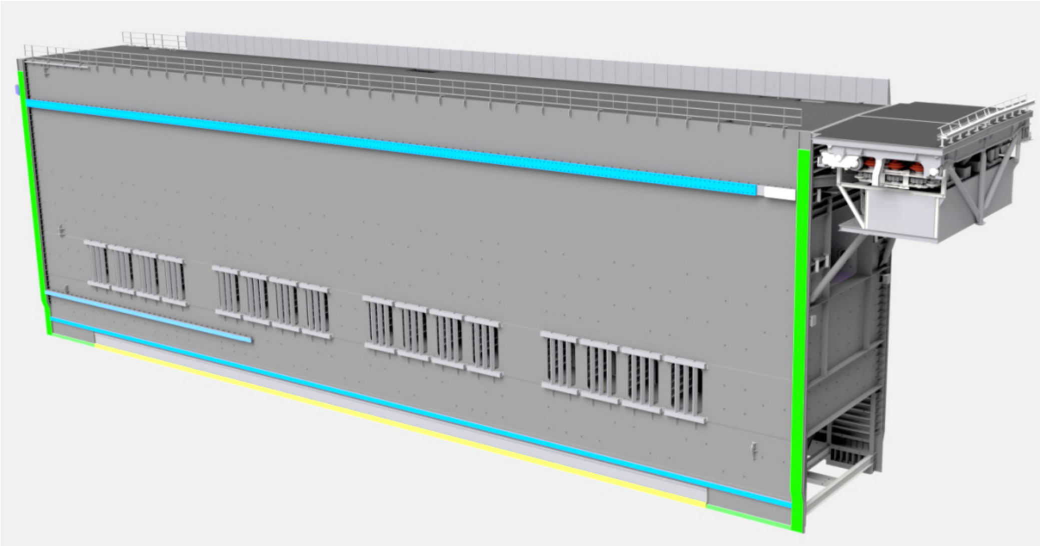

Figure 2: New rolling gate (72x25x11 meters)

Due to the small construction space, the limited width for the new lock heads and the rolling gates proved to be a difficult design challenge. The new sea lock is built between the existing locks, which will largely remain open to shipping and road traffic during construction (Figure 3). Because of the length of the gate recess, a common type of drive mechanism like a cable-winch gear, cannot be properly fitted.

Figure 3: Construction site in the middle of existing lock complex (February 2018)

Reliability

To meet the requirements of the reliability of the high water retaining function, the outer head as well as the inner head are being designed to such elevation, that they are both able to resist maximum sea water levels of up to 7,80 meters, while the water level of the inland channel will be at 0,40 meters below sea level. On top of both gates a motorway is provided to allow road traffic to cross the lock complex. To accommodate traffic, the height of the gate has been fixed at 6,25 meters above sea level, where an additional retaining wall serves as a high water barrier (Figure 4).

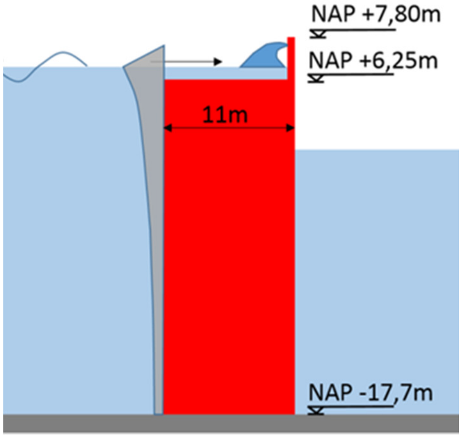

Figure 4: High water retaining function

Because of the design decision to construct the complete lock for maximum water retaining height, only three similar lock gates are being constructed, two operational gates and one spare gate, which is stored in a maintenance dock next to the inner head (Figure 5).

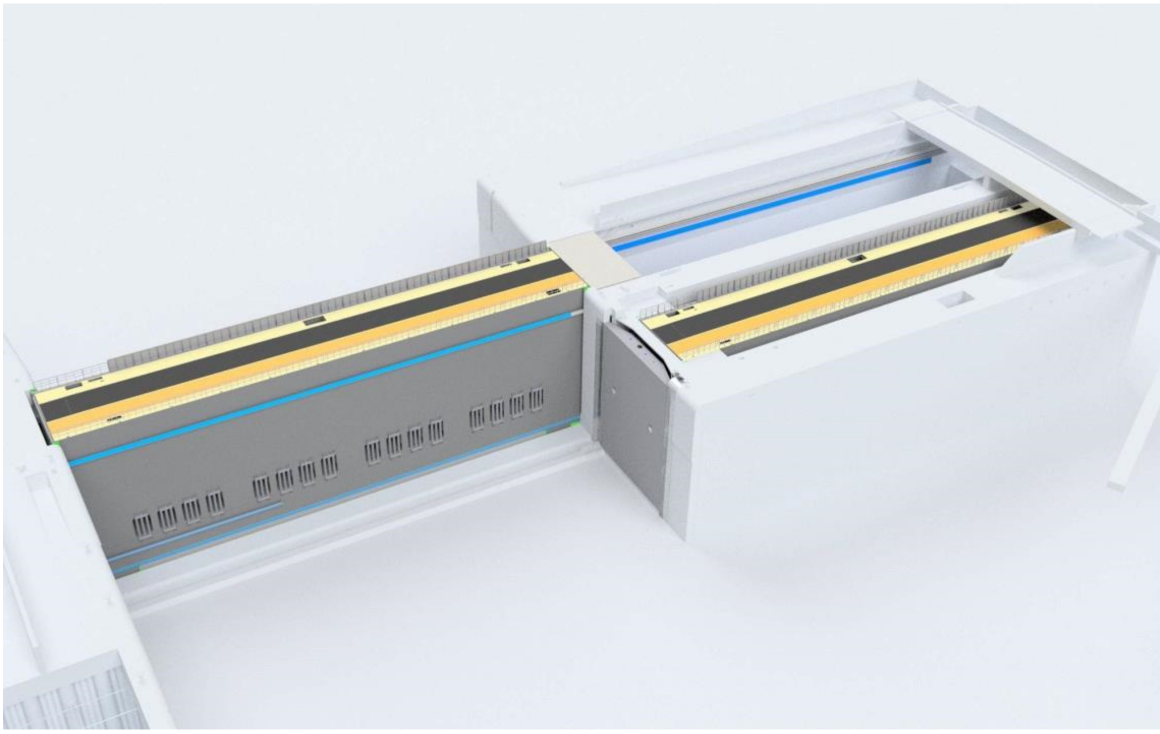

Figure 5: Inner lock head with maintenance dock

Availability and maintainability

Once the reliability of the lock as a flood defence is guaranteed, the most governing design challenge is to create a reliable functional lock facilitating a save and quick passage of vessels. An availability of 99% is required, which means that no more than 70 hours per year are available to carry out scheduled maintenance and that a maximum of 18 hours per year is available to solve unexpected malfunctions. In addition, a maximum delay of 24 hours is required to exchange one operational lock gate. To meet the availability requirements, the replacement frequency of the gates will be once in 15 years. The objective during the design process was. to reduce the amount of maintenance of difficult accessible parts. Therefore, the rolling gates are designed according to the 'wheelbarrow principle'. The gate rests on a lower roller carriage on the lock chamber side and on an upper roller carriage on the gate recess side (Figure 6). The upper roller carriage also serves as a road surface by means of which onshore traffic can drive on and off, across the gate. In favour of maintainability, it is decided to minimize the amount of maintenance sensitive moving parts. During opening and closing, the gate will be guided horizontally by means of polyethylene guide strips fitted at different elevations on both long sides of the gate and in the rail beam structure at the sill level of the gate bay. Super-duplex stainless steel guidance blocks slide against the UHWMPE strips. In case of a critical failure of the rail track or the horizontal sliding pads, the rail beam structure can be rapidly lifted out of the water in one piece, after which a spare one can be put in place.

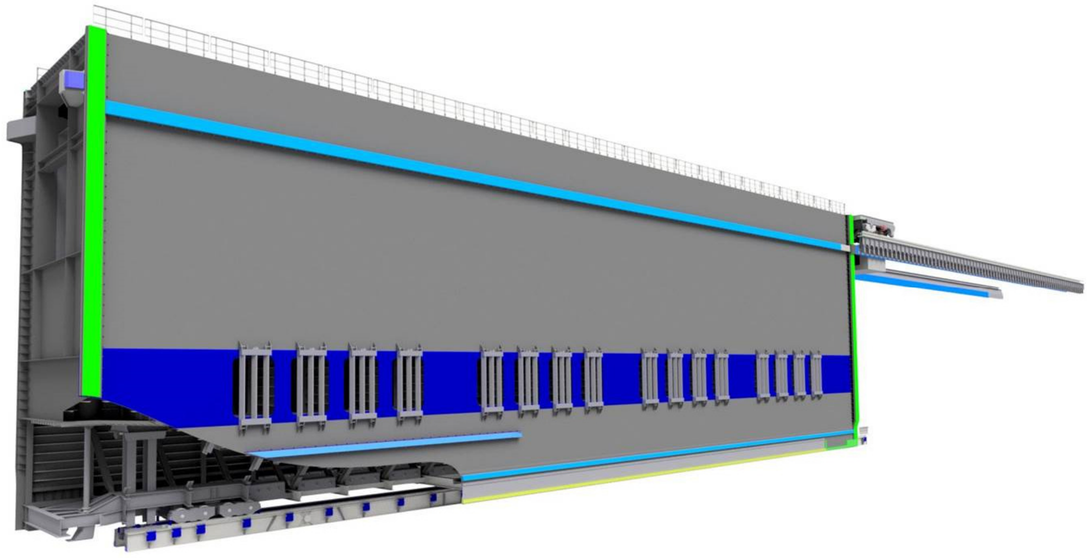

Figure 6: Wheelbarrow type rolling gate with horizontal sliding pads

GATE STRUCTURE

Steel structure

The lock gates resist high water levels on both sides and comprises two retaining shell sheets, with horizontal sheeting sections in between (i.e. the road deck, the bottom and top plate of the buoyancy chamber and the bottom plate of the levelling sluices), which requires minimal use of steel. In fact, the gate structure could be described as a girder resting on two supporting points and bending around the vertical axis (Figure 7). The gate will only start to bear down upon the concrete floor by the use of vertical columns and diagonal stays in the event of extremely high water levels or ship collisions. A flexible steel plate with UHWMPE blocks along the bottom side of the gate, works as a seal, and is also capable of distributing high bearing loads to the sill structure.

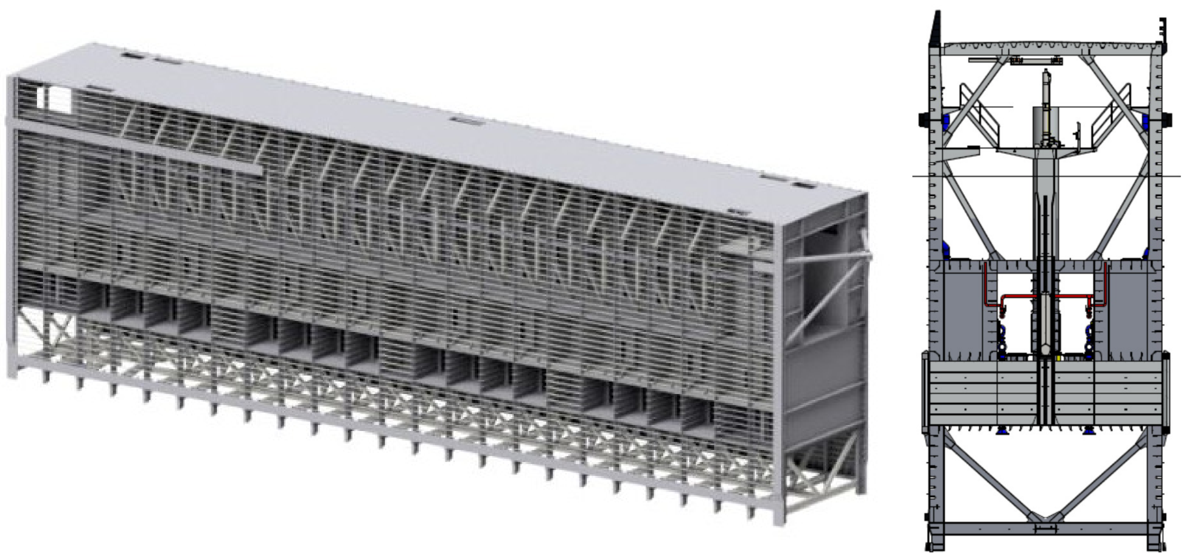

Figure 7: Gate steel structure (stripped outer sheeting) and cross section

The water retaining skin of the gate is constructed of plates that are stiffened by bulb profiles. This also applies to the horizontal plates of the buoyancy tanks. To prevent accumulation of sediment on top of the buoyancy chamber all stiffeners are located inside of the tanks.

The road deck is stiffened by trough profiles, commonly used in the Netherlands in steel bridge designs. The extra amount of buoyancy at water levels up to the top of the gate is taken into account.

In total, the steel structure (without hydraulic and electrical equipment and ballast water) weights about 2700 mTon.

Buoyancy and ballast system

To limit the deadweight on the roller carriages and rail structures, the gate will be equipped with a large rectangular buoyancy and ballast system with air chambers over the entire length and width of the gate. It is located on top of the levelling culverts, and reduces the self-weight of the gate from about 3000 mTon to an average service weight of 400 mTon. There are special ballast tanks to compensate for marine growth and sedimentation. All ballast tanks can be emptied in the event of a gate change, which causes the gate to float upwards and allowing transportation. Emptying of the buoyancy chambers will be carried out by the use of compressed air (Figure 8).

In case of extreme high water levels, the dry installation room in the upper level of the gate will become buoyant. To guarantee that the lock gate won't float, the service-weight will automatically increase by letting in water in overflow tanks.

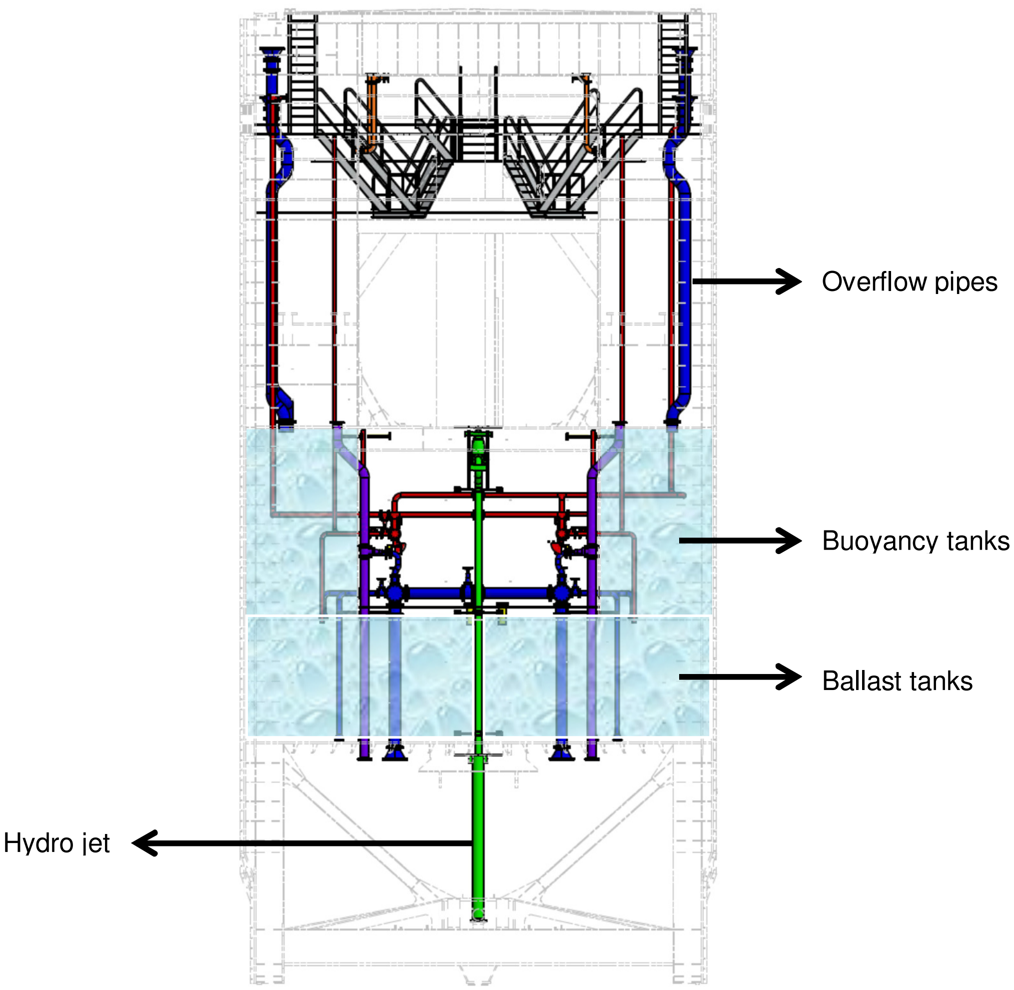

Figure 8: Filling and emptying system of the buoyancy tanks

Environmental conditions

The presence of floating debris, marine growth and sediment can lead to accelerated wear of the rail tracks, thus impairing the availability of the lock. To prevent this as much as possible, special facilities have been incorporated in the lock gate. At the front of the lower roller carriage a bull bar and dirt scraper have been fitted to the gate structure to push any obstacles encountered on the rail structure and on the guide beam into a collector well as the gate moves forwards. Additionally, a hydro jet pipe (Figure 8) will blow sand and sedimentation from the rail track.

In case the amount of sedimentation on the buoyancy tanks during operation seems to be much more than expected, external mixers or agitators can easily be installed.

To avoid that the lower roller carriage becomes overloaded due to accelerated marine growth or sedimentation as time passes, it is provided with a load sensor that will be continuously monitored. If there is an increase in the service-weight, it is possible to respond rapidly and compensate weight by pressing water out of these ballast tanks.

ROBUSTNESS

Ship collision

The steel gates were designed to be more collision-resistant than required by the client. The gate must retain its high water retaining function in case of a ship collision with a total impact energy of 34MJ. At the same time the gate should still be able to function properly after a collision up to a maximum impact energy of 12 MJ, without any lack of availability. In the event of these kind of ship collisions, the gate structures will undergo plastic deformation in a way that cracking does not occur in the shell sheeting. Computational dynamic FEM-analyses that simulated various collision scenarios demonstrate that the lock gate is sufficiently robust (Figure 9). Several scenarios have been established in consultation with the client Rijkswaterstaat, taken into account different variables like the water replacement (DWT) of the ship, its maximum speed, its bow shape and the water levels in front of the gate.

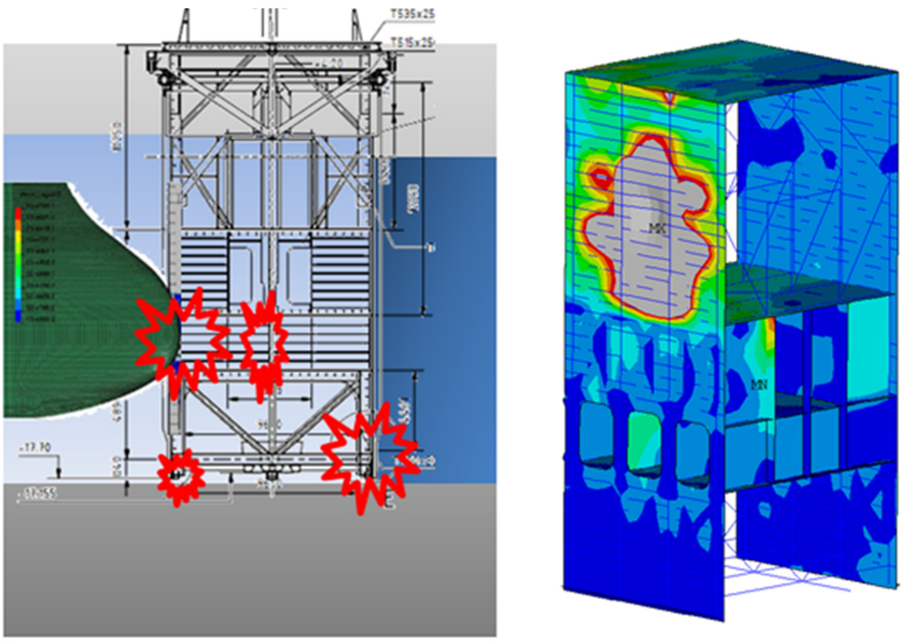

Figure 9: Impact scenarios and dynamic FEM-analyses

All hydraulic and electrical installations in the gates have been placed outside the collision-sensitive zone. For the same reason, the 16 levelling valves, each with their own hydraulic cylinder, have been placed at the center of the gates to prevent the slide guides from sustaining deformation in the event of a collision. The air chambers have been compartmentalized to limit loss of buoyancy to a maximum of 10% in the event of a leak. In such a situation, the lock gate will still be able to fulfil its operational function and allow navigation through the lock.

Wave impact

To prevent overloading of the UHWMPE sliding pads and rail beam structure during opening and closing of the gate, the super-duplex guidance block in front of the gate is secured against overloading by a flexible suspension construction, mounted on rubber fenders (Figure 10). In case of high wave loads during opening or closing of the gate, the gate is pushed aside and then re-distributes the reaction forces to the sill structure. As a result of that, the gate drive mechanism will automatically reduce its speed.

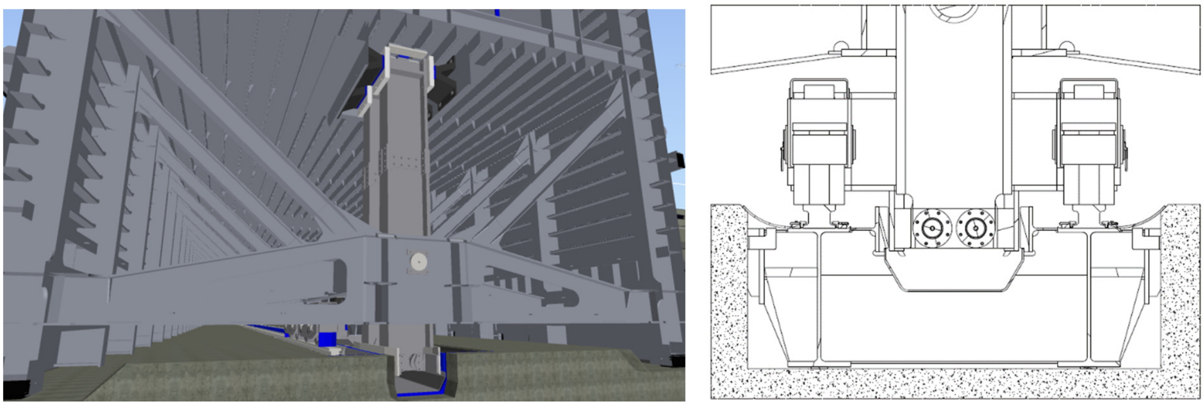

Figure 10: Cross section of horizontal guidance structure and rail beam structure

LEVELLING SYSTEM

General

The levelling system consists of sixteen levelling openings (2,2 meters wide and 3 meters high), positioned about 10 meters below the water level. They can be closed by means of hydraulically powered steel sluice gates (Figure 11), located in the middle of the gate structure. The decision to incorporate levelling through the gate instead of through short culverts in the concrete lock heads was once more the result of limited space in combination with the vulnerability of the foundations of the existing adjacent structure of the Northern Lock.

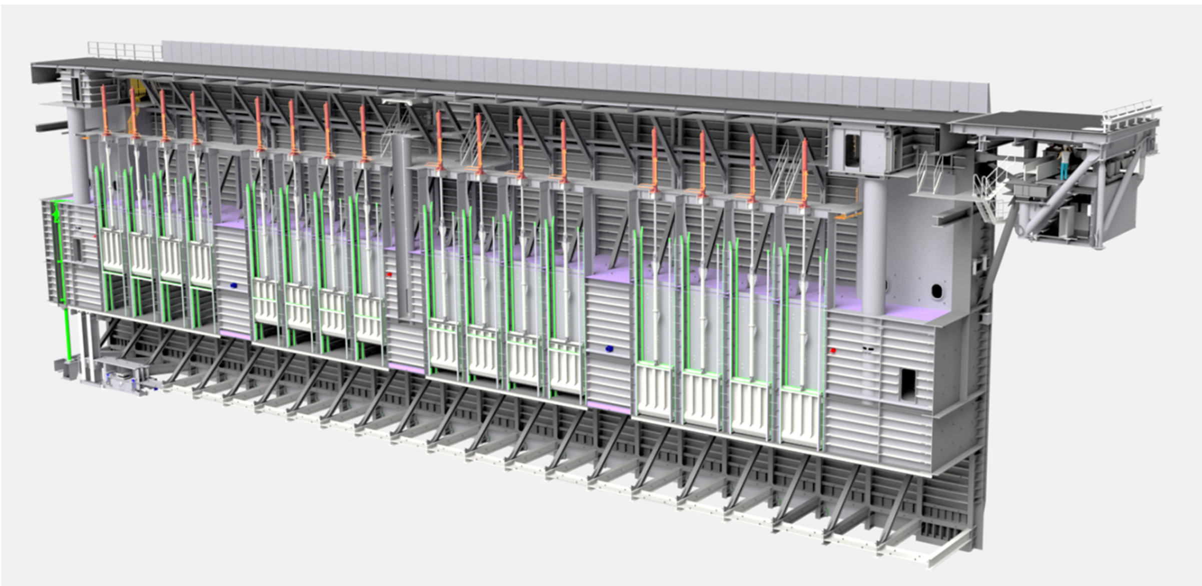

Figure 11: Isometric cross-section of the lock gate with 16 levelling sluices

Because the levelling system has to meet the high availability requirements, it is able to operate with only 14 sluices in most situations of differential head. That means in case one or two of the levelling sluices fail, time is available for maintenance or replacing the levelling gates.

Research and testing

The design of the levelling system (in particular determined by the dimensions and shape of the 11 meters long sluices, together with the triangular energy dissipation bars) must ensure that the required duration of the water levelling process in the lock chamber is met. At the same time hydraulic forces on the ship – and as a result of that the tensile forces in the mooring lines – should not exceed a critical value, due to the inlet of salt or fresh water. The maximum allowable force acting on the ship during filling or emptying the lock chamber is 0.20‰ in the longitudinal direction and 0.12‰ in the transversal direction expressed as a permillage of the displaced weight of a prescribed bulk carrier or container vessel. To verify the levelling system to be quick and save enough, a CFD-analysis has been carried out to determine the discharge coefficient at different sluice openings. Lockfill-calculations were made to determine the specific lifting programs at all possible differential heads over the active lock head and showed that the correct filling curves of the lock chamber have been achieved.

The Dutch research institute Deltares had been assigned to develop a scale model of the new sea lock. The design for the new lock, including the lock gates with detailed levelling sluices, gates and energy-dissipation bars, was built to a scale of 1:40. The total scale model, including the lock chamber and the entrances, was approximately 56 m long in total and 20 m wide (Figure 12).

The model tests make it possible to simulate the physical process during operation of the lock. The results of the scale-model were used to validate the numerical models (CFD and Lockfill). Besides aspects like the required levelling time and the measured hydraulic forces on the ships, the flow of fresh water and salt water when the doors are opened has been investigated.

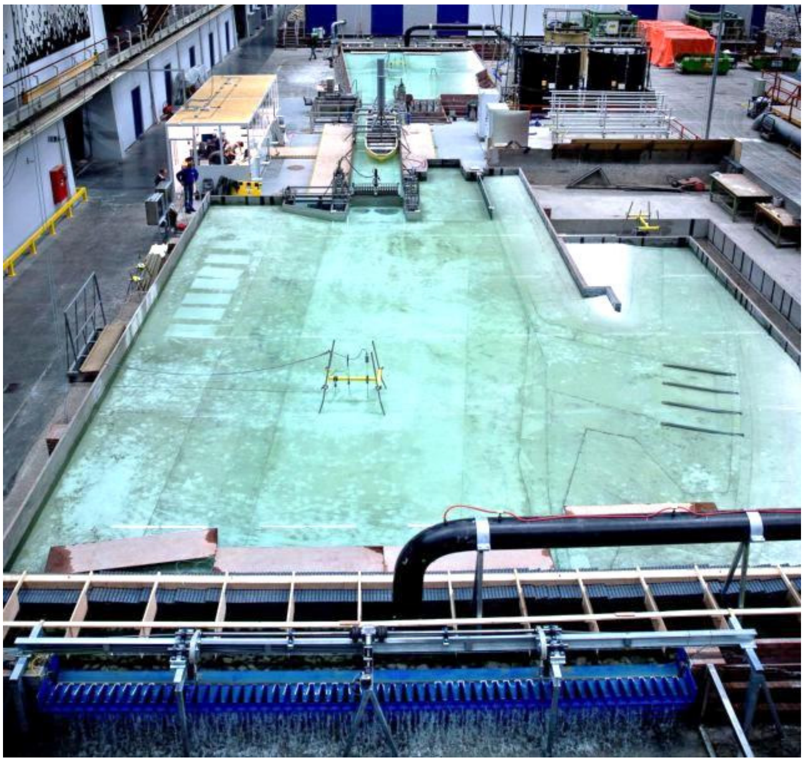

Figure 12: Scale (1:40) model test

Vortex induced vibrations

Dynamic calculations of the horizontal and vertical eigenfrequencies of the sliding sluice gates relative to the excitation frequencies of the water flow underneath the gates prove that the risk for unwanted vibrations is low. A specific design of the sluice gates (Figure 13), with a drop-shaped bottom girder and point-shaped rubber sealing, reduces the risk of vibrations due to vortex excitation of the water flow.

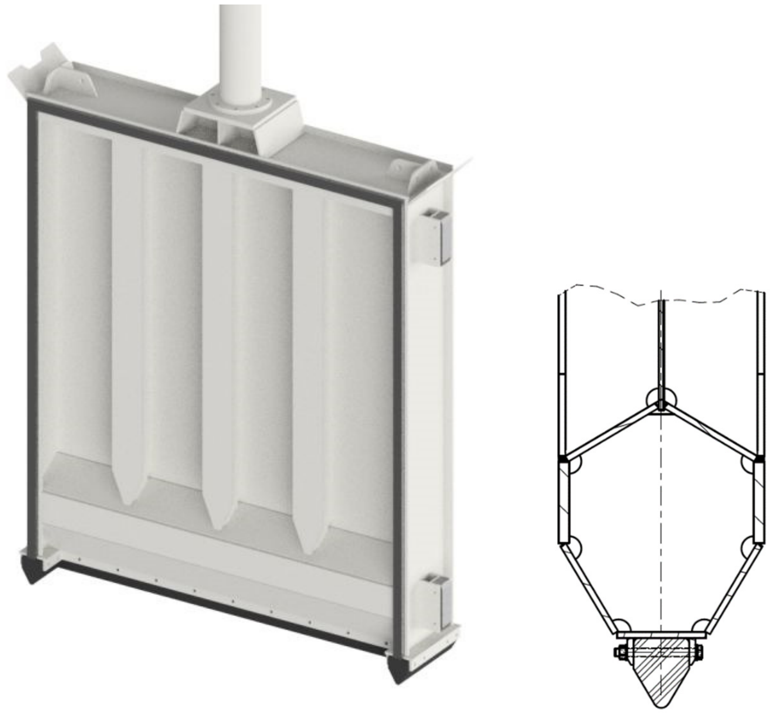

Figure 13: Sluice gate and cross section of bottom girder

LOWER AND UPPER CARRIAGE

General

At the location of both roller carriages, the gate will be supported centrically by one single elastomeric rubber bearing. These bearings allow the gate to move horizontally causing the gate to be pressed against its granite supports on the lock heads due to hydrostatic water pressure. In this way unwanted horizontal loads, which negatively affect the degree of wear, on the roller carriages wheels and rails are being prevented. This principle of load bearing of the supports of rolling gates is often being used in the Netherlands.

Lower carriage

For the design of lower wagon (Figure 14) this results in a relatively small carriage, compared to the size of the gate, with a total length of 4.5 meters and a wheelbase of 1.8 meters. It can be compared with the lower wagons of the new Panama Locks. Furthermore, the aim for the design of the lower wagon is to minimize the amount of maintain sensitive rotating parts. Because of this, the flexibility of the lower wagon is necessary to create a proper load distribution to each of the eight wheels (with a diameter of 800 mm.). To reduce the fatigue stresses on of the steel structure of the lower wagon, the construction tolerances of the concrete sill and the rail beam are very strict. The use of high strength steels (42CrMo5-04 for the wheels and 110CrV for the rails) and hardening up to 450-500 HB make that the wear is limited.

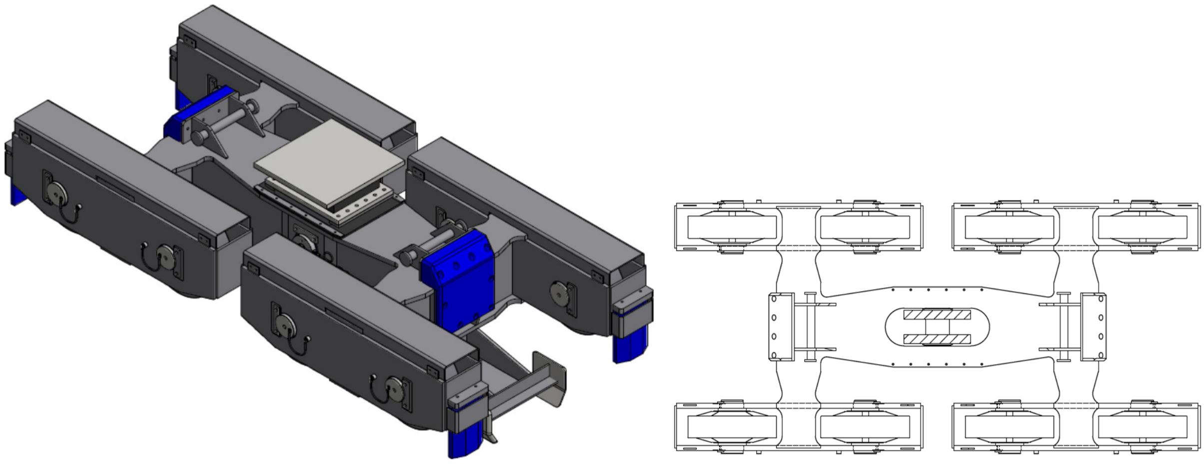

Figure 14: Isometric view and section of lower carriage

Upper carriage

The main objective of the upper carriage (Figures 15 and 16) is to transfer the vertical load of the lock gate to the concrete structure of the gate recess.

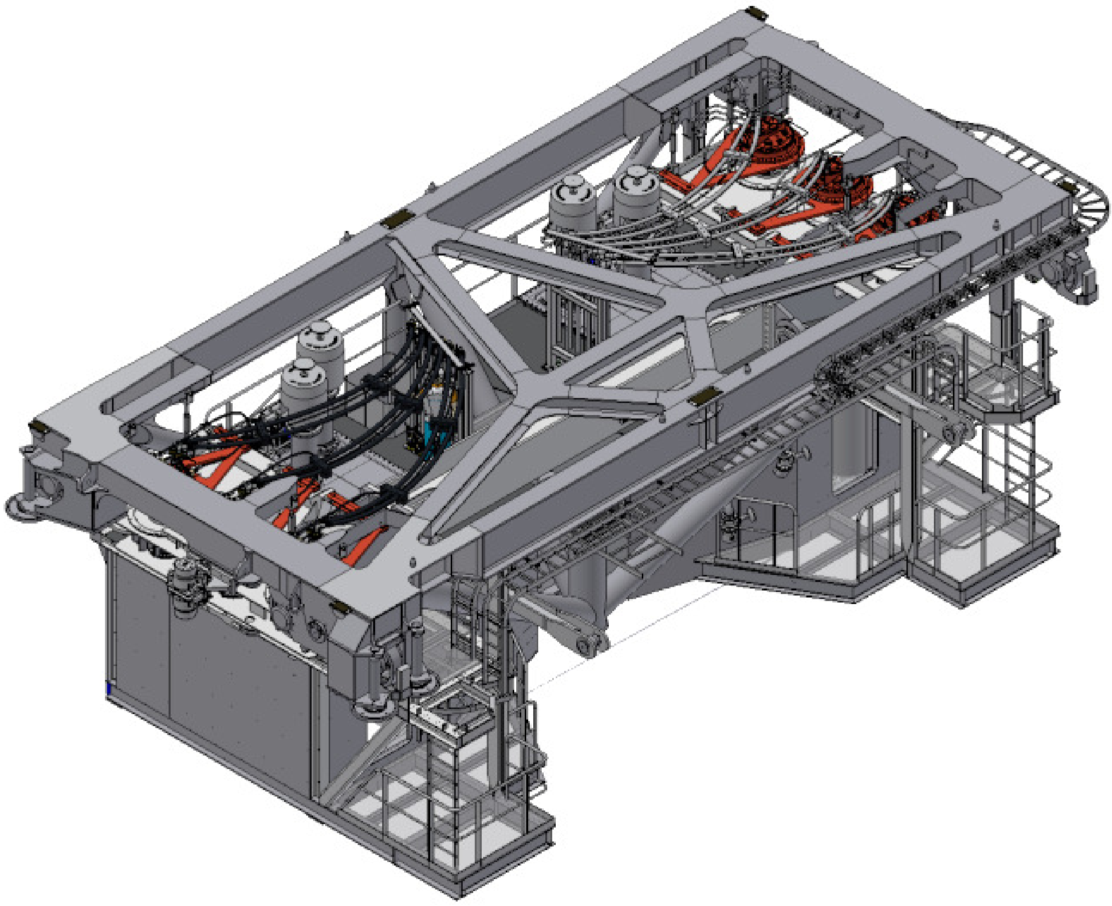

Figure 16: Isometric view of upper carriage without road deck

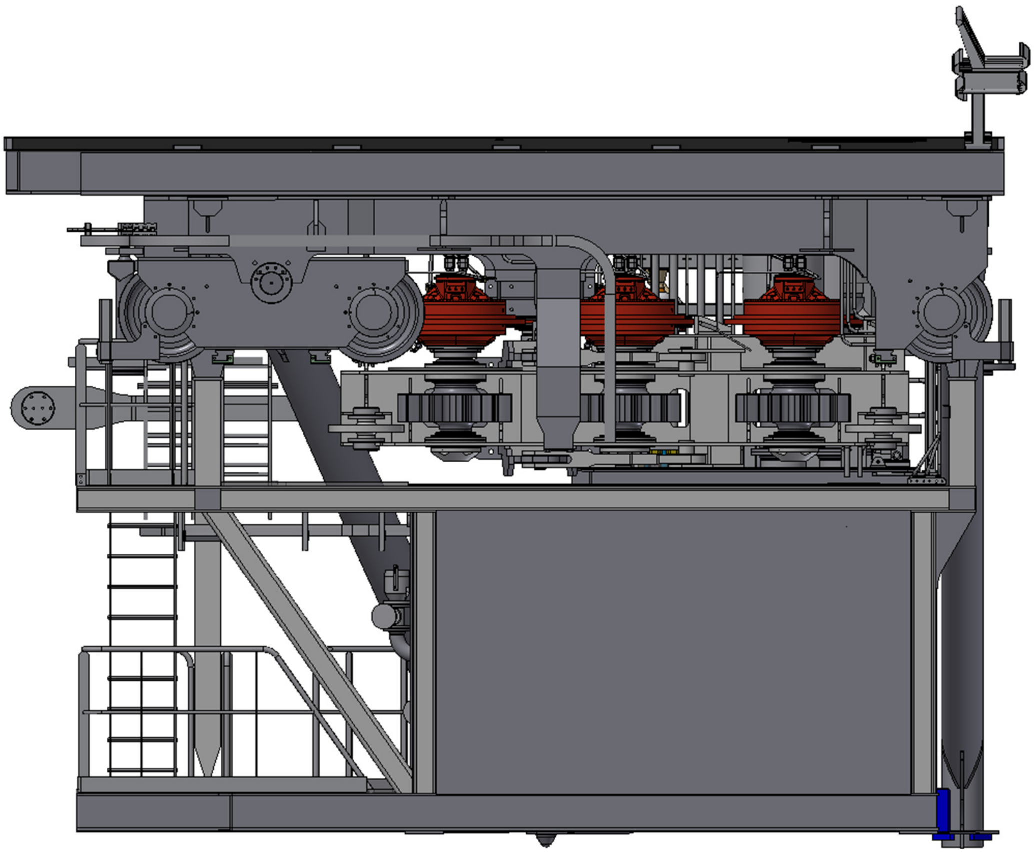

Figure 15: Side view of upper carriage

The gate transmits the vertical load to the upper wagon via a support frame. From the rubber bearing, the load is distributed over 6 wheels that run on 2 rails, one on each side of the gate recess. By using a bogie all vertical load is equally distributed (Figure 17). Besides the service-weight of the gate, the structure also carries the road deck used by traffic crossing the lock gate.

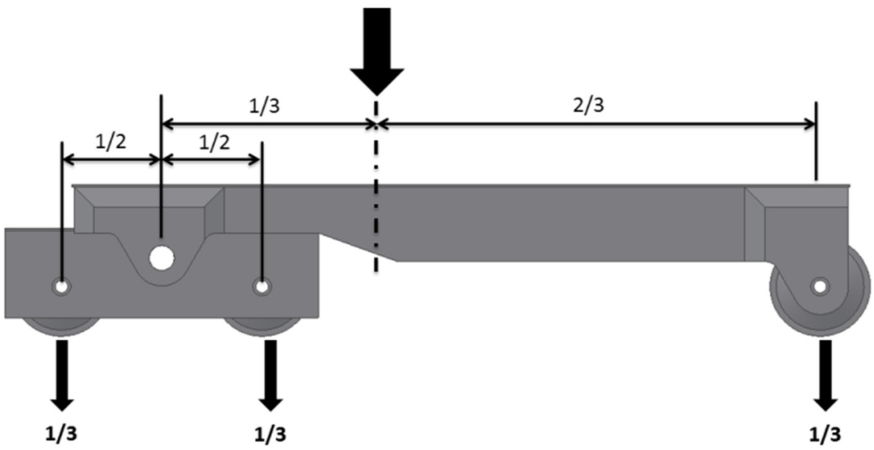

Figure 17: Load distribution upper carriage

In order to ensure the wheels run well on the rail during the entire movement distance of the gate, horizontal guided wheels are placed on one rail. Shifting of the upper carriage therefore is limited to a minimum, while the freedom of deformation of the concrete recess structure is not limited by fluctuating loads due to different water levels.

DRIVE MECHANISM

The upper carriage houses the machine room for the hydraulic driven transmission drive. The gate will be moved by six hydraulically powered pinions and two pin tracks on each side of the gate recess (Figure 18). Because of limited construction space, a conventional kind of drive mechanism like a cable-winch gear was not applicable. Finally, a life-cycle-cost analysis resulted in the design decision to move the gate by a pinion gear. Six 110kW electric motors give power to six hydraulic drive units which are connected directly to the pinions. A total traction force of 1500kN can be generated.

Due to the potentially large deformations of the concrete recess walls a penned track is preferred above a toothed track. In addition, a penned track results in a nearly longitudinal load transfer.

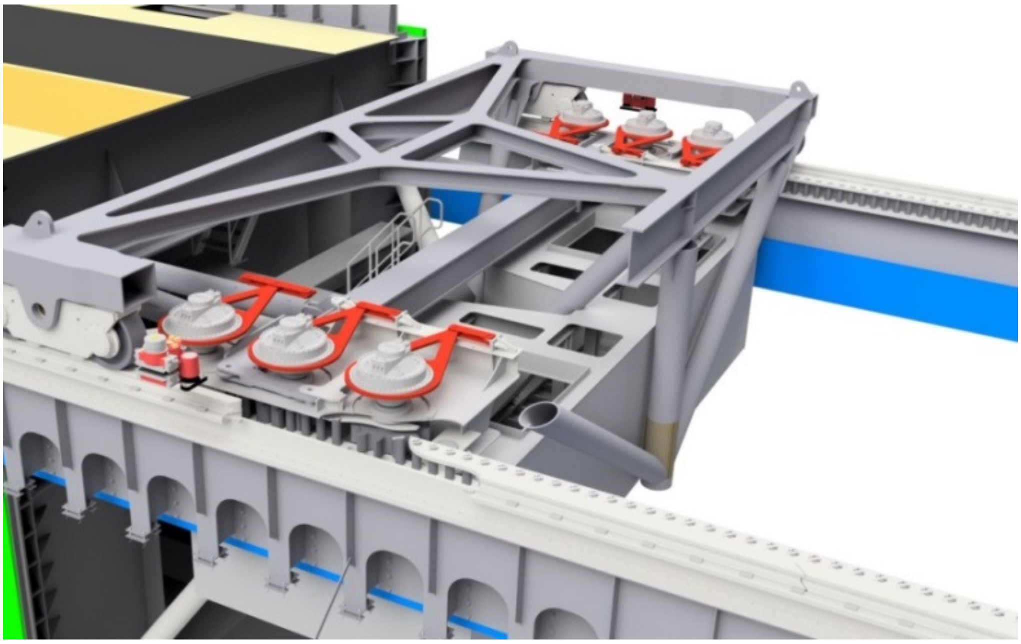

Figure 18: Pinion - pin track drive

The recess walls can undergo horizontal deformation by several centimetres. For this reason, the drive trains are pressed against the pin tracks by a central pressure bar with spring buffers (Figure 19). The drive trains are connected to the gate by two drive rods and suspended by pendulums to the main structure of the upper carriage.

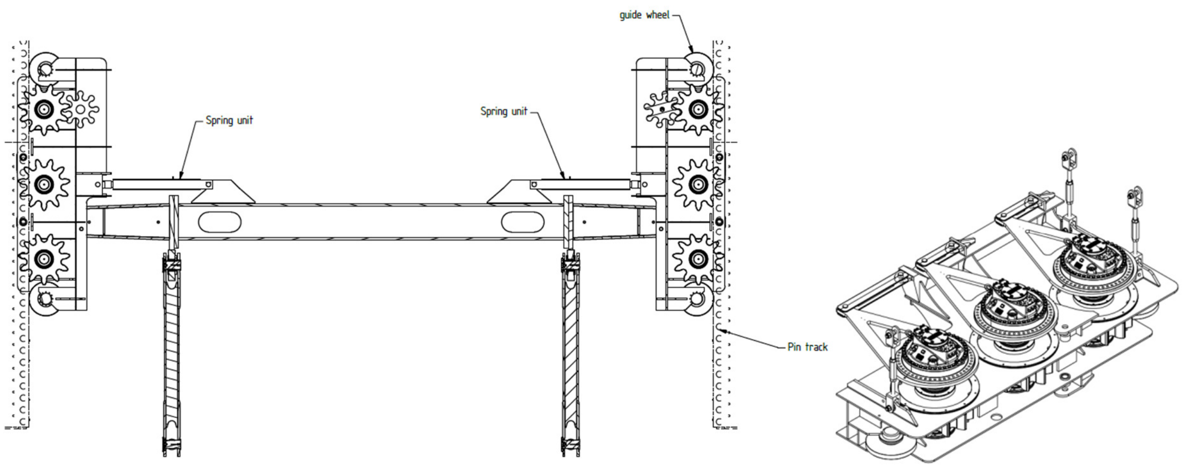

Figure 19: Suspension of drive trains

For the purpose of the required lock availability, redundancy of the drive mechanism is achieved through the installed overcapacity of the hydraulic gears. To meet the requirements of the speed of the gate movement during all possible environmental conditions (wave loading) only four of the six pinions are needed. If an electrical or hydraulic failure occurs in one of the gears, it will automatically isolate itself so that the movement of the gate will not stop. On the other hand, in favour of the lifespan (fatigue) of the mechanical components, all six engines will have to work.

CONSTRUCTION OF THE GATES

The fabrication of the steelwork is taking place in South-Korea (Figure 20). Since the lock is part of a flood defence and the gates are fatigue sensitive, the highest execution-class EXC4 according to Eurocode NEN-EN-1090 is required for the construction of the gates. In general, this results in an extra effort to the meet the required quality of the welds, the dimensional tolerances and the traceability of all steel plates.

To inform the steel manufacturer about these specific requirements clearly and correctly, it was decided to include the Korean manufacturer in the design process from the start of the preliminary design. Furthermore it was important to try to stay close to their practical experience of shipbuilding practice.

Figure 20: Steelwork fabrication of the lock gates in South Korea

The construction of the three gates takes about one and a half year. As soon as they arrive by a submersible vessel in the Netherlands, all electrical installations and hydraulics will be installed. After a testing period, they will be transported to the construction site and installed into the gate recesses.

Figure 21: Final situation

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