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# Safe Drive And Control System For Movable Link Spans and Passenger Walkways

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SAFE DRIVE AND CONTROL SYSTEM FOR MOVABLE LINK SPANS AND PASSENGER WALKWAYS[1]

## Introduction

This paper discusses safety considerations for link spans including single deck ramps, double deck ramps, multi-leaf ramps, and passenger walkways. Often, these transfer spans are referred to as Ro – Ro Bridges from the term “roll – on / roll –off” of passengers and cargo.

In ports with a reasonably significant tidal range or where a large range of ship sizes have to be loaded, a height-adjustable hinged bridge known as a “link span” is needed to transfer cargo. The span is supported and adjusted for height on either a floating pontoon or by lifting equipment. Height adjustment is required for the link span due to several factors:

- The access doors on different ferries are not always at a fixed location
- Tidal changes
- As the load increases on the ship, the ship’s draft also increasing.

In comparison to other structures such as movable bridges, international standards regarding the design and safety requirements of the drive system for link spans, historically, were vague. However, due to some serious accidents involving passengers, new safety standards are slowly being mandated such as Canada’s CAN / CSA-S826 Series-01. Consequently, the industry has begun a renewed focus on safety.
This paper also discusses a product developed by BoschRexroth that can be used to enhance the safety of both existing installations and new designs.

## Types of Drive Systems for Ro Ro Bridges

According to a survey conducted in 1998 by CIRIA (Construction Industry Research and Information Association), an organization based in the UK, the prevalence of each type of drive is per the below:

- 32% of the wire rope hoist / winch
- 66% hydraulic cylinders
- 2% rack and pinion

## Disadvantages of Existing Systems

The level of safety varies widely among existing installations. In one extreme, some wire rope hoists have a single-point catastrophic failure modes.
Spans actuated by hydraulic cylinders offer more favorable modes of failure, and redundancy is easily designed into those systems. However, total redundancy is extremely rare regardless of the type of drive. Furthermore, conventional safety provisions do not provide a smooth transition from the primary drive to the auxiliary drive in the event of a dynamic failure. As a result, there is no ability to regulate the deceleration of the link span and thus prevent the damage to the structure.

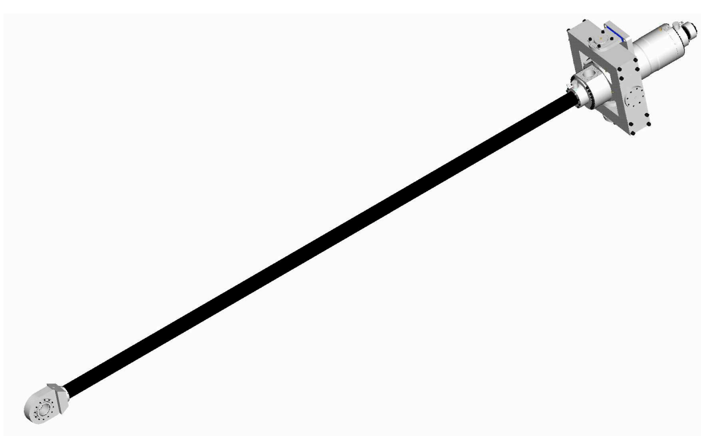
## Features of a Truly Safe System

For a truly safe system, the following criteria must be obtained:

- 100% redundancy for both the electrical and mechanical devices
- 100% redundancy of the position measuring and control system
- Ability to detect misalignment of the bridge during operation
- Ability to detect over-speed due to main drive or mechanical failure
- Ability to minimize structural damage of the span in the case of failure

## Benefits of Ro-Safe

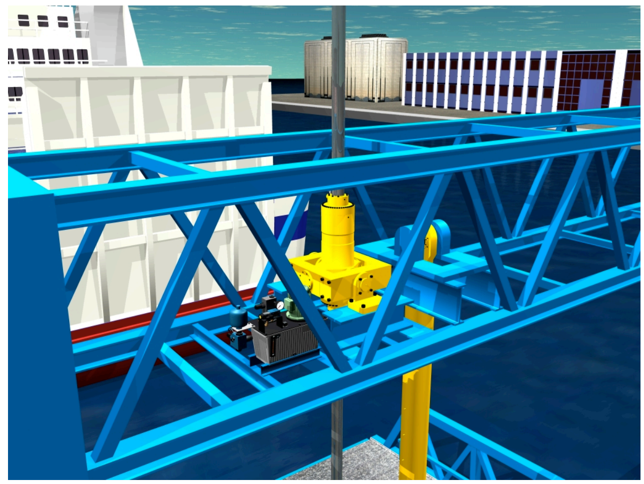
To fill this market need, Bosch Rexroth developed Rosafe to be used for both new and existing installations. The intention was to create a standard product that operates completely independent of the main drive system and can be easily added without significant modifications to the structure.



*Provides 100% Redundancy / Safety*
**Ro Safe is completely independent of the main drive system and includes its own position measuring system and over-speed detection**. In addition, unlike the mechanisms used on wire rope systems, Ro-Safe positively detects position and can therefore misalignment of the span during normal operation.

*Versatile / Compact Physical Design*

Ro-Safe can be used on spans that operate with either a wire rope hoist or a hydraulic drive. Because existing installations represent a very large market, a key requirement of the design was ease of installation. The rod is attached to the span with clevis, and a cardanic ring is bolted to the frame. **The connection points and space requirements are limited**.

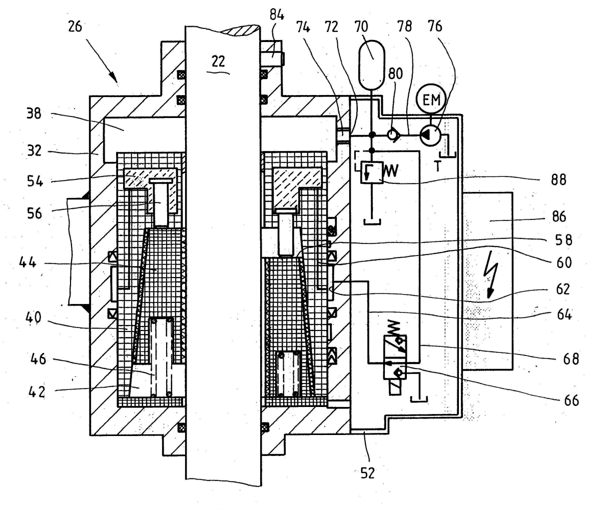


*Prevents Structural Damage / Harm*
In the event of dynamic failure in which the span becomes completely disengaged of the main drive system, Ro-Safe uses hydraulic cushions to safely decelerate the ramp. **Ro-Safe is typically sized to limit force on the structure to 1.2 * max static load.**

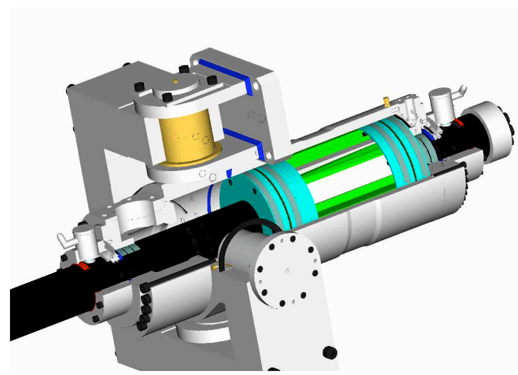
*Parking Brake*
**Ro-Safe can be used as a "parking brake" for the deck in any position.** The brake design is analogous to a check valve; the span can travel upward with the brake engaged. Consequently, there is no danger to leave the brake engaged for periods of time in which tidal changes may actually raise the span.

When the span is stopped in position, the brake is "softly" engaged, and the span's weight is likely to be primarily supported by the main drive. However, if the main drive drifts due to slack in the cable or drifting of the hydraulic system, the brake will fully engage and support the load. (In this mode, as opposed to a dynamic failure which is discussed later in the paper, the hydraulic cushions are not utilized.) The brake merely sets without any movement of the span. **As a result, auxiliary pinning systems are no longer needed, and the operator does not have to align the span at set locations.** Efficiency is increased in the loading and unloading process.

## The Design Principal




Simplified Illustrations



Rosafe is the combination of a brake manufactured by Sitema, and a hydraulic cylinder with cardanic ring mounting. As shown, the brake is incorporated into what is normally the cylinder piston. A small power pack and electronic control enclosure is integral to the unit, and CIMS (Ceramax Integrated Measuring System) is used to detect position. (Rosate is <u>not</u> a hydraulic cylinder and has no capability to move the span)

Under normal operation, the area designated by “38” is full of oil and the brake is clamped on and off the rod as needed by shifting the directional valve “66”.

Under a dynamic failure, the directional valve, “66”, is de-energized, and the brake instantly clamps the rod. Fluid from space “38” is routed to the bottom of the brake through the port near “52”. The span and the brake housing continue move a distance that corresponds to the height of space “38”. This decelerates the structure in a manner similar to that used be hydraulic cylinder cushions.

## Simulation to Prove Theoretical Design

To investigate the feasibility of the design concept, an elaborate analysis including computer simulation was preformed prior to the construction of a prototype. In particular, a dynamic failure of 1500 kN was investigated:

| Parameter | Metric | U.S Units |
|---|---|---|
| Static Load | 1500 kN | 337 kips force |
| <u>Size of brake:</u><br>Piston<br>Rod<br>Stroke | <br>530 mm<br>280mm<br>250 mm | <br>20.9 in<br>11.0 in<br>9.8 in |
| Max Brake Force | 1.2 * Static Load | 1.2 * Static Load |
| Initial Velocity | 0.6 m/min | 1.97 ft/min |
| Critical Velocity | 0.8 m/min | 2.6 ft/min |
| Reaction Time of Brake | 100ms | 100ms |
| Friction Force of Brake | 3 bar/47.7kN | 43.5 psi/10.7 kips-force |
| Gravity | 10m/s2 | 32ft/s2 |

The simulation considered a failure in which the span completely disengaged from the primary the drive:

- Acceleration is the free fall of the ramp due to gravity.
- The ramp is traveling at a constant speed of $V_o$ when the failure occurs.
- At the critical speed $V_1$, the brake process is initiated.
- The reaction time to achieve full braking force is assumed to be 100 ms.
- The time to accelerate from $V_o$ and $V_1$ (failure detection time) is:

$$\partial t = \frac{\partial v}{a} = \frac{(0.8-0.6)\frac{m}{\min}}{10\frac{m}{s^2}} = 0.333\,ms$$

The total time to achieve full braking force is the sum of the reaction time and acceleration time: 100ms + 0.333ms=100.333ms.

During this entire time period, the ramp has reached the following velocity/position:

$$v = a \cdot t = 10\frac{m}{s^2} \cdot 100.333ms = 1003.33\frac{mm}{s} = 60.2\frac{m}{\min}$$
$$s = \frac{1}{2} \cdot a \cdot t^2 = \frac{1}{2} \cdot 10\frac{m}{s^2} \cdot (100.333ms)^2 = 50.3mm = 0.0503m$$

By design, the maximum braking force is not allowed to exceed 1.2 x static load. Therefore, the braking deceleration must be 20% of 10 $m/s^2$ = 0.2$m/s^2$.

Since the deceleration is limited to a fifth of g (1/5g), the brake track (distance of ramp till full stop) must be at least five times the acceleration track:

$$s_{Brake} = 5 \cdot s_{Beschl.} = 5 \cdot 50.3mm = 251.67mm = 0.25167m$$

The static pressure within the brake is:

$$p_0 = \frac{F_{static}}{A} = \frac{1500kN}{(530^2 - 280^2) \cdot mm^2 \cdot \frac{\pi}{4}} = \frac{1500kN}{159043mm^2} = 94.31bar$$

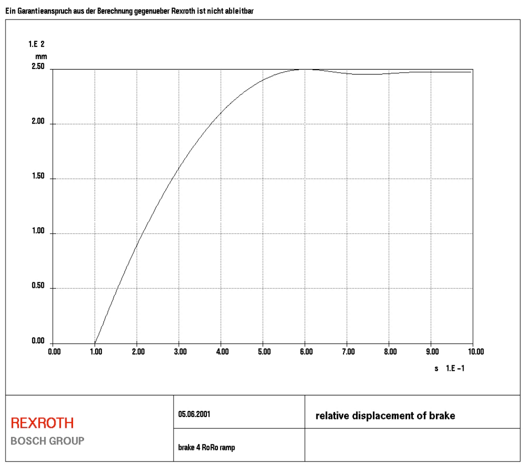
The dynamic part of the brake pressure must not exceed:

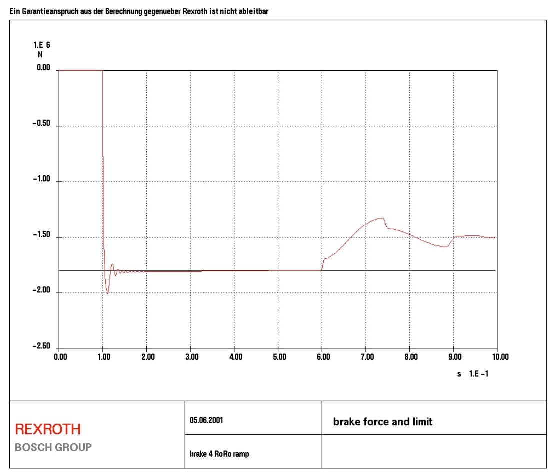
$$p_{Brake\_dyn} = \frac{0.2 \cdot F_{static}}{A} = 0.2 \cdot p_0 = 18.86\,bar$$

Therefore the total pressure must not exceed:

$$p_{Brake} = p_{Brake\_dyn} + p_0 = 113.17\,bar$$

The simulation, performed with the parameters listed in the previous table, confirms the theoretical predictions. The braking distance and housing size are verified.
The output of the simulation revealed the performance of the hydraulic system. One concern was the need for a very large relief valve.




**Excerpts of Simulation output**

Given an initial Velocity of 1 m/s, the theoretical initial flow through the DB-valve is calculated:

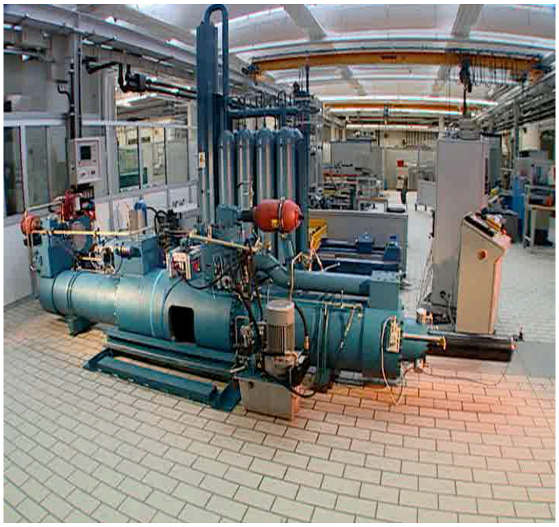
$$Q_{DB\_theoritical} = V \cdot A = 1003.33\frac{mm}{s} \cdot 159043\,mm^2 = 9574.36\frac{L}{\min}$$

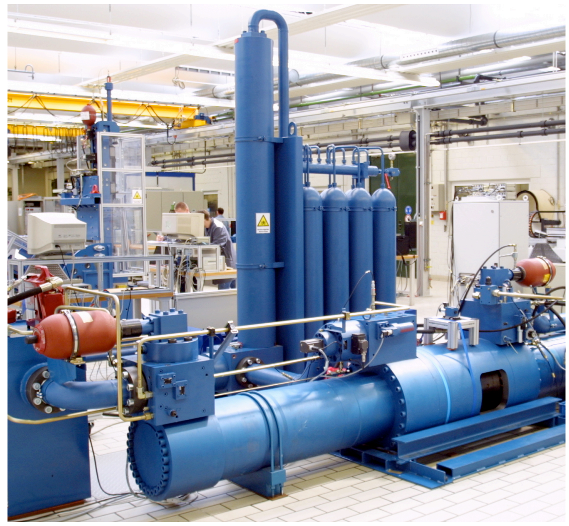
Because of this large flow rate of 9574 L/min, we worked closely with the brake manufacturer, Sitema, to modify the brake’s design. The dimensions of the brake were changed to 400mm (15.7 in) piston / 180 mm (7.09in) / 00 mm (19.7in) stroke. The length of the brake was increased to keep the braking surface area equal. And, consequently a more standard relief valve could be used.

## Prototype Testing

The simulation output proves without question the theory and performance behind the Rosafe concept. Furthermore, in the field, the parking brake, over-speed detection, alignment detection, etc., can easily be verified. However, it is certainly not practical to test a dynamic failure in the field. First of all, it is difficult to disengage the span from the main drive system without some sort of damage. More importantly, if the test is not successful at the first trial, the span can be damaged. Therefore, Bosch Rexroth constructed a test rig arrangement that simulated a dynamic failure.

As shown, a single piston rod was connected to both a Rosafe brake and a conventional cylinder. A large accumulator bank was used to generate a speed and pressure to coincide with a dynamic failure of a span in free fall. After many iterations and slight derivatives of such tests, the Rosafe was disassembled and inspected to investigate the condition of both the piston rod coating (Ceramax) and the brake. Neither showed any damage or wear. In addition, static testing was preformed to prove that Rosafe could support the span an extended period of time without any slipping.





## Conclusion

Most existing link spans do not incorporate a truly safe redundant design, and are thus can be susceptible to catastrophic failures. Adding a second drive system may be cost prohibitive in new designs, and nearly impossible to implement to existing installations. Therefore, to meet the increasingly stringent requirements of new international regulations, Ro Safe was developed.

Ro-Safe can easily be added to existing link spans or included in new designs to provide:

- 100% redundancy for both mechanical and electrical devices as well as the controls system
- Safe deceleration of the span in the event of a dynamic failure
- Ability to detect misalignment of the bridge during normal operation
- Ability to detect over-speed
- Acts as a “parking brake” in any position, and thus eliminates auxiliary pinning systems

Through theoretical simulation as well as elaborate full load prototype testing, the Rosafe design has been proven.

[1] Erich Wirzberger, Dept. Head of Hydraulics for Civil Engineering, Bosch Rexroth Corp. and Janine Krempa, Applications Engineer, Bosch Rexroth Corp.