Heavy Movable Structures, Inc.

SEVENTH BIENNIAL SYMPOSIUM

November 4 - 6, 1998

Grosvenor Resort
Walt Disney World Village
Lake Buena Vista, Florida

"Bearing the Bascule - Erasmus Bridge"

by

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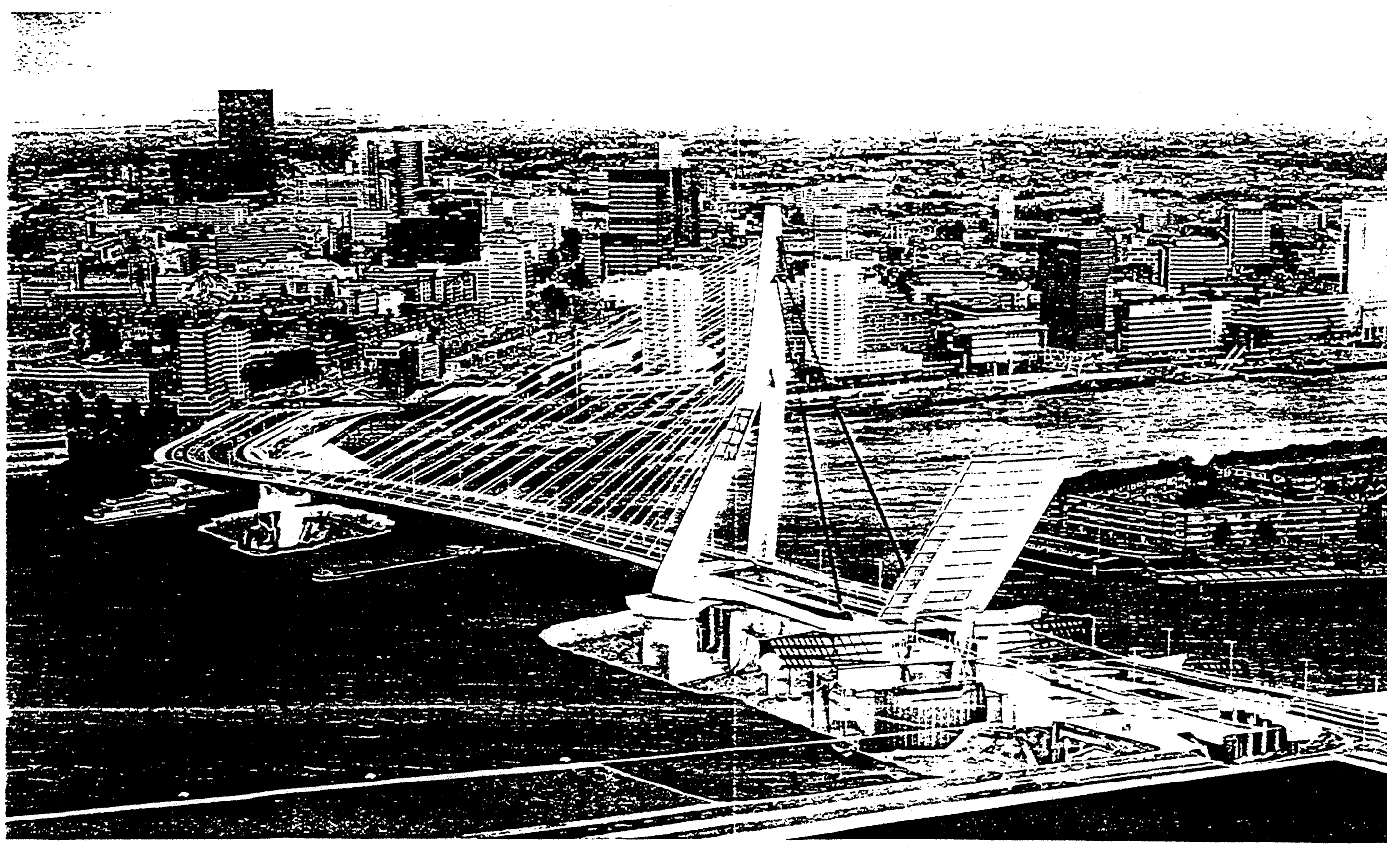
Spherical Plain Bearings for the Worlds Largest Bascule



The south bend of the River Mass, in the heart of the Dutch city of Rotterdam, is now an ambitious urban regeneration site known as "Kop van Zuid".

Providing the key link to the 125 - hectare (309 acres) site is the new Erasmus Bridge, completed in September 1996. This impressive design provides the major aboveground link with the inner city on the north bank. The aesthetics of the bridge design are important as the set the atmosphere and character of the urban expansion on the south side. So, to satisfy both the aesthetic and technical considerations the choice of construction is three brides in one: 1.) a 280m (918 ft) main span, cable stayed bridge; 2.) a composite steel concrete side span viaduct and; 3.) a bascule bridge. The technical design for the bridge was carried out by the City of Rotterdam's Public Works Engineering Department.

The architectural design of the bridge provided a number of challenges. Not the least of which is the cable stayed bridge portion which includes an asymmetric knee bend in its 130m (426 ft) high pylon providing a distinctive and unique landmark feature to the project. Practically every piece of steel plate has a unique shape and dimension which creates and enormous jigsaw of structural elements. As the structure contains virtually no straight angles, it would have been impossible to create and build the bridge without the help of modern computer technology including 3-D, computer aided design and calculations systems as well as numerically operated flame cutting machines.

The Erasmus Bridge links the city centre (at right) to the new Kop van Zuid (at left). The Willems Bridge is visible at the far right of the photo.

Urban Changes

For many years the city of Rotterdam has had the world's busiest harbor in terms of volume of goods shipped. Post war growth has resulted in the main harbor's activities moving further seaward. The largest oil tankers, for example, are usually moored in the recently created, major industrial areas of Europort and the artificial offshore peninsula, Maasvlakte. Both of these areas have become centers for economic activity while older harbor sites, closer to the city center, have lost their usefulness. It is these sites that have the potential for urban renewal.

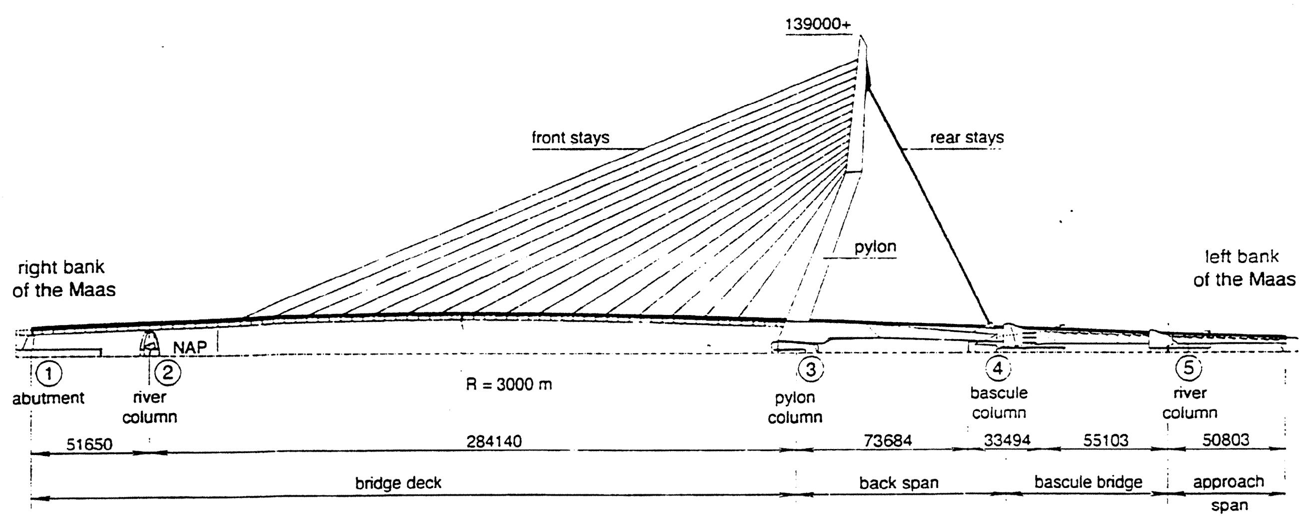
The first serious plans for "Kop van Zuid" were presented in 1987. This called for the construction of high quality office accommodations along the waterfront. The strategy for Kop van Zuid has been to put the publicly funded infrastructure in place before other work occurred.

The opposite approach was taken when the London Docklands regeneration scheme was begun in the 1980's. By the time the first inhabitants move in, a major network of public transport facilities, bus, tram and metro will be available.

The key element in the new infrastructure is the new north-south traffic axis, which includes the Erasmus Bridge. The new bridge deck is 35m (114.8 ft) wide providing twin tram lines, two double traffic lanes plus free lanes for cyclists and pedestrians on both bridge sides. Although major harbor activities lie closer to the sea, a number of shipbuilding and maintenance industries still exist upstream of Rotterdam. As a consequence, the harbor authorities required a 50m (164 ft) free navigational width. This is provided by the bascule section of the bridge.

Bascule Bridge

Unlike the cable stayed bridge. the functional specification governed the complex technical design of the single-leaf, movable bascule bridge. Apart from the sheer size, the 52.3m (171.6 ft) by 35.8m (117.5 ft) leaf dimension making it the largest of its kind in the world. There are other features that also make this bascule bridge unique. The main "eye catcher" is the oblique 67° crossing of shipping and traffic. The bridge deck has a parallelogram shape and leans 19m (62.3 ft) sideways in its open position reaching a maximum height of 63m (206.7 ft) above water level.



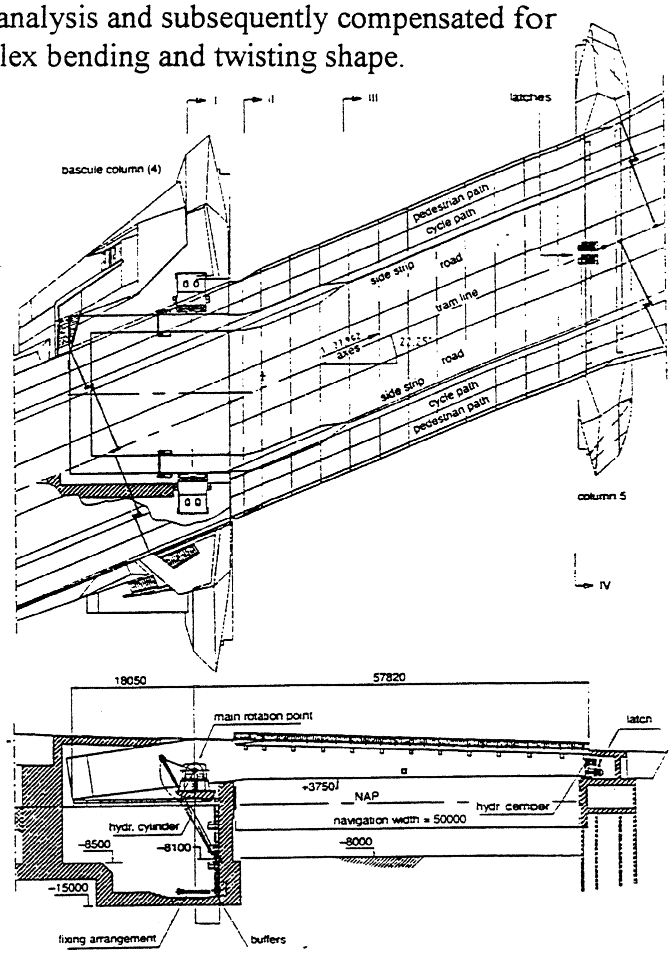
Survey of the Erasmus Bridge, main dimensions and major components.

The large in-situ cast concrete bascule basement which is 60m (196.9 ft) long by 31m (101.7 ft) wide houses both the hydraulic cylinders and the bascules counterweight. The concrete basement is also used to anchor the two 4,500 tonne (4,960 ton) main span reaction forces from the back-stays. The basement floor is 13m (42.7 ft) below water level and is made of 10m (32.8 ft) thick concrete to prevent the basement from floating.

The two main bascule supports are shaped as plate girders on the front elevation and as box girders at the rear elevation. They have a maximum height of 6.8m (22.3 ft) close to the main support bearings. Additional box girders for the rear cross member (located at the sideways twist of the main supports) and counterweight result in a closed square providing a large resistance to the enormous tilting movements during opening and closing of the bascule. Member torsion is increased by the eccentricity of the main rotation supports and the position of the counterweight. The counterweight is eccentrically weighted opposite to the bridge obliqueness in order to provide an equal distribution of the weight responses in the main rotation supports. This allows for optimization of the main supports.

The bridge dead weight results in a 300mm (11.8 in.) vertical bending displacement at the front of the bridge and a 90mm (3.5 in.) distortion between both front supports. These deformations figures were determined by detailed finite element analysis and subsequently compensated for during fabrication by building the bridge in a complex bending and twisting shape.

Rail transport on the steel bridge demanded special attention. The rail is embedded in a specially developed, poured rubber material in order to reduce sound emission. This also avoids steel-to-steel contact resulting in a reduction of sound by at least 5 dB. To allow for vertical alignment at the bridge front rail interruption, the forward cross member is pre-stressed downwards by 100 tonnes (110 ton) after bridge closure. The resulting 25mm (0.98 in.) pre-stress displacement exceeds any temperature or mobile loading deformations, ensuring correct vertical rail alignment. Due to the passage of public transport, the bridge must also be able to operate quickly, opening in only 130 seconds and closing within 135 seconds.



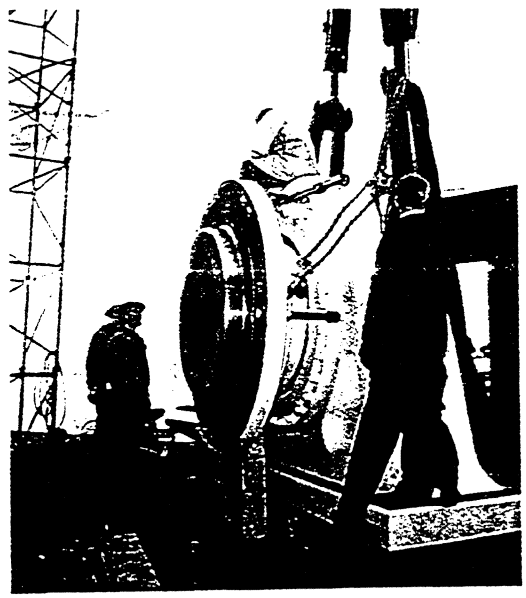
The drive mechanism selected for the bascule span of the Erasmus Bridge is essentially similar to most other modern movable bridges in Rotterdam. The bridge operation system used is a PLC controlled, remotely operated, open type hydraulic system with controlled pump adjustment.

A major problem that needed to be solved was stabilization of the bridge movement, since the four drive cylinders act as huge springs for the large dynamic driving forces. Numerical simulations and tests at the fabrication site were executed to optimize the hydraulic parameters for the bridge response. To avoid problems at the end of the opening and closing sequences of the bridge, buffers and dampers were installed to avoid vibration or shaking bridge movements and for further speed reduction.

Spherical Plain Bearing Arrangements

For the bascule, unusual single sided flanged axle supports were used. The more commonly used symmetric through trunnions with double sided bearing supports turned out to be unfavorable. Calculations showed the latter would act as a constraint for the large tilting moment, resulting in a significant increase in support reactions. The 2m (6.6 ft) diameter steel trunnion flanges are connected to the outer web of each main support member by 66 high strength M48 bolts. To spread the reaction forces in the main box girder, a large diameter tube was applied between both outer webs.

The two main bridge support bearings have to carry the 1,500 tonne (1,650 ton) bridge weight, the 1,000 tonne (1,100 ton) counterweight and a maximum of 1,600 tonnes (1,760 ton) reaction force from the four hydraulic cylinders. The normal cylinder loads lie between 150 tonne pressure (165 ton) and 160 tonne tension (176 ton), and the exceptional loads at 400 tones pressure (440 ton) and 280 tonne tension (308 ton). The SKF GEP...FS series maintenance free spherical plain bearings satisfied the high quality and technical demands of the Rotterdam Public Works Department. SKF series GEP...FS spherical plain bearings were selected for both the main support bearings as well as for the hydraulic cylinder support bearings.



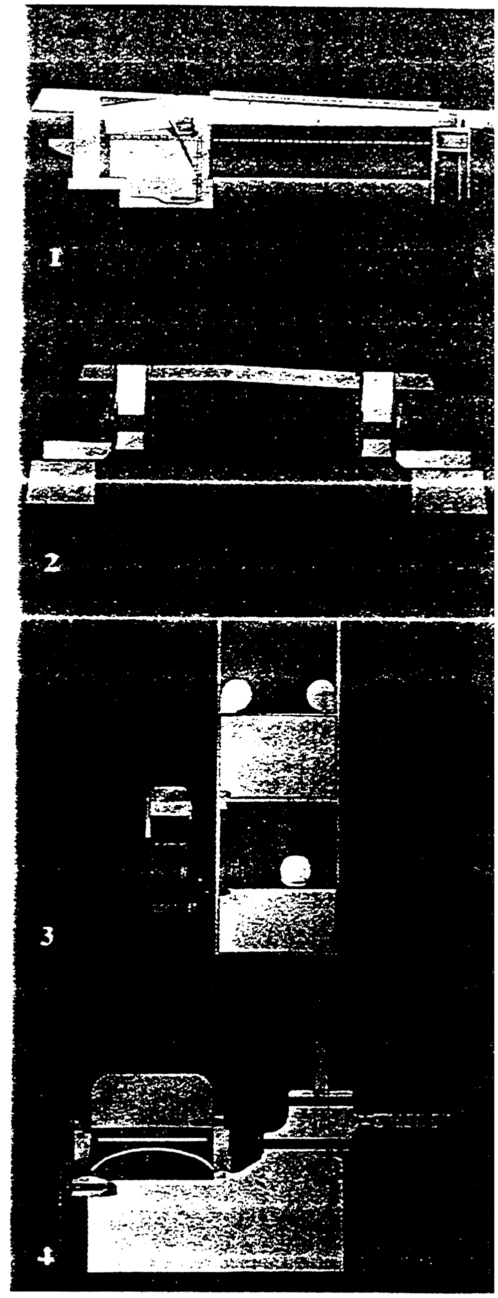
The 40-ton pre-assembled steel shaft, bearing and housing just before being mounted on the bridge.

Spherical plain bearings are suitable for all applications where there are oscillating and/or tilting movements and/or where the shaft must be able to align itself relative to the housing. They are also used for bearing arrangements which are exposed to alternating and single load conditions, vibrations and additional axial forces and where influences like contamination and corrosion cannot be avoided.

As with a number of large welded structures and constructions these conditions particularly apply to modern movable bridges. Therefore spherical plain bearings offer an optimum solution both technically and economically. Consequently these bearings have become increasingly popular since their introduction in the 80's in these types of applications.

Misalignments or alignment errors between the two bearing seats of the main support bearing journals or hydraulic cylinder bearings can be tolerated to only a very limited extent when plain bushing are used. Misalignments in excess of permissible amounts, produce high edge stresses on both ends of a bushing even if no external load is applied. These edge stresses must be take into consideration when determining the dimensions of a plain bushing and large bore diameters and wide dimensions may be then required.

Spherical plain bearings in general, the special series GEP...FS, offer the following advantages:



1: Longitudinal section of the bascule and cellar with main bearings with the canti-levered main box bearing supports and the four cylinder rods in the background.
2: Cross section at the site of the main bear-ings, the main box girder and the four cylin-der rods in the background.
3: Cross section of the main bearing.
4: Inner ring and outer ring with sliding layer of the axially-split main bearing.

Insensitivity to misalignments and deflections.

Their sphered sliding surfaces accommodate misalignments and deflections without affecting the pressure distribution within the bearings load zone.

Transmission of both radial and thrust forces.

Because of the sphered sliding area SPB's can accommodate both radial and axial forces, thus eliminating the need for separate thrust washers.

Optimum sliding surface contact combination.

From extensive laboratory test and practical experience of more that 30 years, the sliding layer area between the two steel rings has been optimized. The outer ring is completely lined with highly wear resistant, high performance thermoplastic (HPTP) sliding shells which are glass fiber reinforced and contain PTFE additives for low friction properties.
This sliding combination allows for unidirectional as well as defined alternating loads during operation under maintenance free working conditions (see under lubrication).
The sliding movements takes place between the inner and outer rings of the bearing, not between the inner ring and the bore of the bearing.

Vibration damping.

Due to the "soft" sliding material, the SPB's show excellent damping properties which can absorb shocks and "swallow" vibrations thereby increasing reliability and comfort.

Compact bearing design.

Compact bearing designs aim at maximizing load carrying capabilities. The inner ring is made of ball bearing steel which is hardened and ground. The sliding surface is hard chromium plated and polished. The outer ring is made of heat treatable C35 steel (1.0501). In order to avoid deposition of dirt and wear particles and to facilitate relubrication, the HPTP sliding shells are equipped with axial and radial grooves.

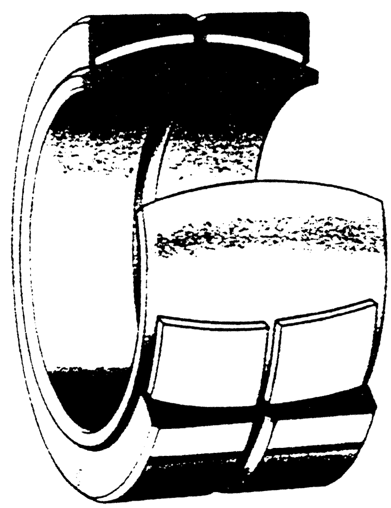
Lubrication.

The bearings can be relubricated by either the inner or outer rings through lubrication holes in the rings. Circumferential lubrication grooves are provided in the inner ring bore and the major diameter of the outer ring along with axial and radial grooves in the HPTP sliding materials. Nevertheless, the sliding contact surface combination does not require lubrication. An initial lubrication is, however, advantageous for the following reasons:

* Friction is additionally reduced; this prolongs the service life even more than if the bearing is used in a maintenance free condition.
* Grease has a sealing function and prevents dirt from entering the bearing.
* Protection against corrosion is improved.

Drive Cylinder Bearings

The four hydraulic cylinders (stroke 6.8m (22.3 ft); bore 600mm (23.6 in.); piston rods 400mm) generate a maximum driving moment of over 100,000 kNm ($73.7x10^6$ ft-lb) to resist wind induced forces up to 7 Beaufort (32-38 mph). In case of higher wind speeds, the start sequence of the bridge opening is automatically blocked. Two separate electro-hydraulic units, each with 440 kWh installed power allow the bridge to move at the predetermined high speed.



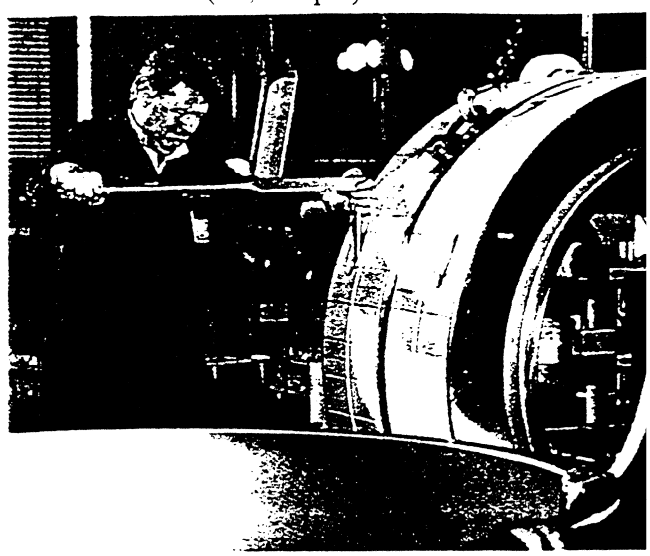
GEP..FS

Eight spherical plain bearings, series GEP 360 FS, are used for the hydraulic cylinder supports. Fail safe analyses were executed to optimize the reliability of the hydraulic cylinders during bridge operation. As a result of these analyses a number of fail critical electric and hydraulic components, such as the main power supply, hydraulic units and cylinders were installed in parallel. This layout allows bridge operation to continue during emergencies or maintenance periods.

Rotation Supports

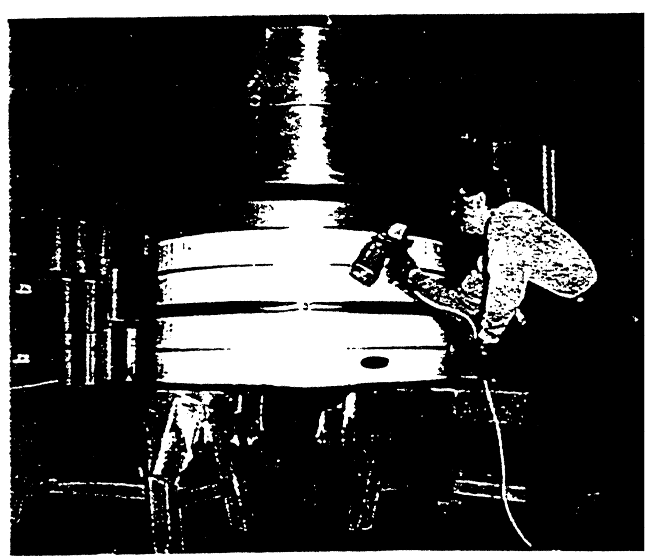
Besides the load and working conditions of the bridge, the choice of the main support bearing size for the Erasmus bridge was governed by: 1.) the required service life corresponding to a sliding distance of over 400 km (250 miles); 2.) the requested 1mm friction diameter reduction over the service life and; 3.) the stresses in the steel trunnion shaft. The SKF series GEP 1000 FS bearing, having a sphere diameter of 1,312mm (51.7 in.), are the largest ever used for this type of application. They are particularly suitable for motions under unidirectional loads, alternating loads along with superimposed high frequency vibrations and relatively high axial loads. To cope with temperature expansions only one of the two main support bearings was axially fixed.

The float bearing has an additional cylindrical sliding bushing added around the outer ring diameter to accommodate the calculated +/-10mm (0.39 in.) axial displacements. An axial steel-to-steel sliding combination was considered inappropriate due to the higher friction and stress levels in the large diameter trunnion shafts. These shafts are made from high strength 34CrNiMo6 steel with a guaranteed yield strength above 500N/mm2 (72,500 psi). To allow for optimum performance, the non-locating spherical plain bearing outer ring has been designed with an axial split instead of a radial split. These deviations from the standard bearing design (fixed bearing) changed the bearing designation to a BLR-0075 for the floating bearing. This allows bridge movements to take place between the bearing's outer cylindrical sliding layer since both layers were made with identical HPTP sliding materials and thickness'.



Fabrication of the axially-split main bearing.

The HPTP glass fiber reinforced sliding materials, for both the fixed and floating bearings, are initially lubricated with SKF LGEP2 grease which combines a low friction coefficient with a high resistance to corrosion and contamination. The low friction coefficient is of special importance because bearing friction results in unfavorable constraint reaction. For example, a friction value of $\mu=0.15$ results in a additional 300 tonne (330 ton) horizontal axial reaction (break-away) force, which is lowered during rotation of the bearing. This happens when due to a temperature rise the bridge span expands and may cause the floating bearing to move axially.



The nitrogen-cooled steel axle is lowered into the pre-assembled bearing and housing.

Particular attention had to be given to avoiding local stress concentrations and fretting corrosion in the heavily loaded steel trunnion shaft. This was achieved by smoothly curving the axle by applying a spacer sleeve and using tight machine tolerances for the trunnion shaft (m6) and for the housing bore (K7). To allow for future dismounting of the bearing, the trunnion shaft surface was provided with grooves connected to internal channels for oil injection. At the factory site the bearing was mounted into the preheated housing prior to installation of the nitrogen cooled steel trunnion shaft.

The Erasmus Bridge was completed in September 1996. After installation of the main pylon, the last section of the cable stayed bridge and the installation of the bascule bridge, testing of the bridge driving system too place during the summer of 1997. This was the last phase of calibration for the many computer simulations and calculations that, to a major extent, governed the technical design of the bridge.

Combined with fanfare, the ceremonial opening for the bridge too place on September 4th, 1996 with the opening address and inauguration by Queen Beatrix (Netherlands).

Summary

The key to revitalizing Rotterdam's inner city harbor area is the Erasmus Bridge, which provides a vital communications link with the old and new portions of the city. The architect and city engineer were given the task of creating a landmark bridge having an aesthetically appealing design under demanding engineering requirements. One of the key elements of the bridge is the uniquely designed bascule section which allows for utilization of the upper harbor area by shipping facilities. The Erasmus Bridge with the largest bascule span in the world today is supported and operated by some of the largest specially designed spherical plain bearings ever manufactured.