

Offshore Wind Foundation Seals

SUPPORTING THE POWER OF OFFSHORE WIND



Creating Better Solutions for Today's Challenges

Wind energy is being increasingly embraced as a means to generate clean energy independently – and with it, the need for bigger and stronger foundations. When there's no room for failure, and innovations are happening quicker than infrastructure can be built, companies must turn to specialists with trusted track records.

With years of expertise and design knowledge, Trelleborg Marine and Infrastructure provides offshore wind foundation seal solutions that are recognized as industry-leading. Whether you are developing your first designs or innovating on your previous successes, our experience of working alongside contractors and subcontractors ensures that we deliver product excellence and support within your timelines.

From our unrivaled global reach, with feet-on-the-ground local presence, to our cross-industry expertise and in-house end-to-end solution capabilities that accelerate performance, we deliver improved integrity, sustainability, and efficiency to give you the confidence in the success of your projects for years to come.

Trelleborg has been pioneering the development of offshore wind foundation seals since 2007. Our long-term vision of design and fabrication of critical seals in offshore wind has been proven to perform time and time again. But it does not stop here.

As the market charges forward, so do we – continuously developing and testing innovative foundation sealing solutions with developers, designers and fabricators worldwide to meet new challenges. Discover how Trelleborg can work with you to realize your green energy visions.

For more information, please go to www.trelleborg.com/en/marine-andinfrastructure/markets-and-applications/infrastructure/wind

Bringing Design Expertise to the Practical World

With over 15 years' experience in offshore wind foundation seals, Trelleborg remains an industry leader. By combining our design expertise with decades of practical experience, we are well equipped to help you realize your visions for harnessing the incredible power offshore wind has to offer.

We work closely with consulting firms, contractors and subcontractors around the world to plan, design, and build offshore wind farms.

With our team of experts capable of predicting and designing customized solutions, Trelleborg is often the first and most trusted choice for innovative projects.

Our comprehensive approach enables us to deliver cutting-edge solutions to our clients. Our consulting spans the entire project lifecycle, from concept to implementation. Making accurate calculations, providing durable materials and providing ongoing support are all part of the process.

Innovations in the offshore wind industry are advancing at a rapid pace. Our team of highly experienced engineers will ensure that you stay on top of technological advances and evolving dynamics.

With our innovative, bespoke engineering, we guarantee that our foundation seals will perform as specified for the entire life cycle of your project.

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Wind Power: A Growing Contributor to the Global Energy Mix

More countries around the world are harnessing wind power to generate clean energy instead of relying on foreign reserves. This has led to an increase in demand for strong foundation seals for offshore wind farms operating in harsh climates. However, maturity of acceptance and development varies by region.

EUROPE

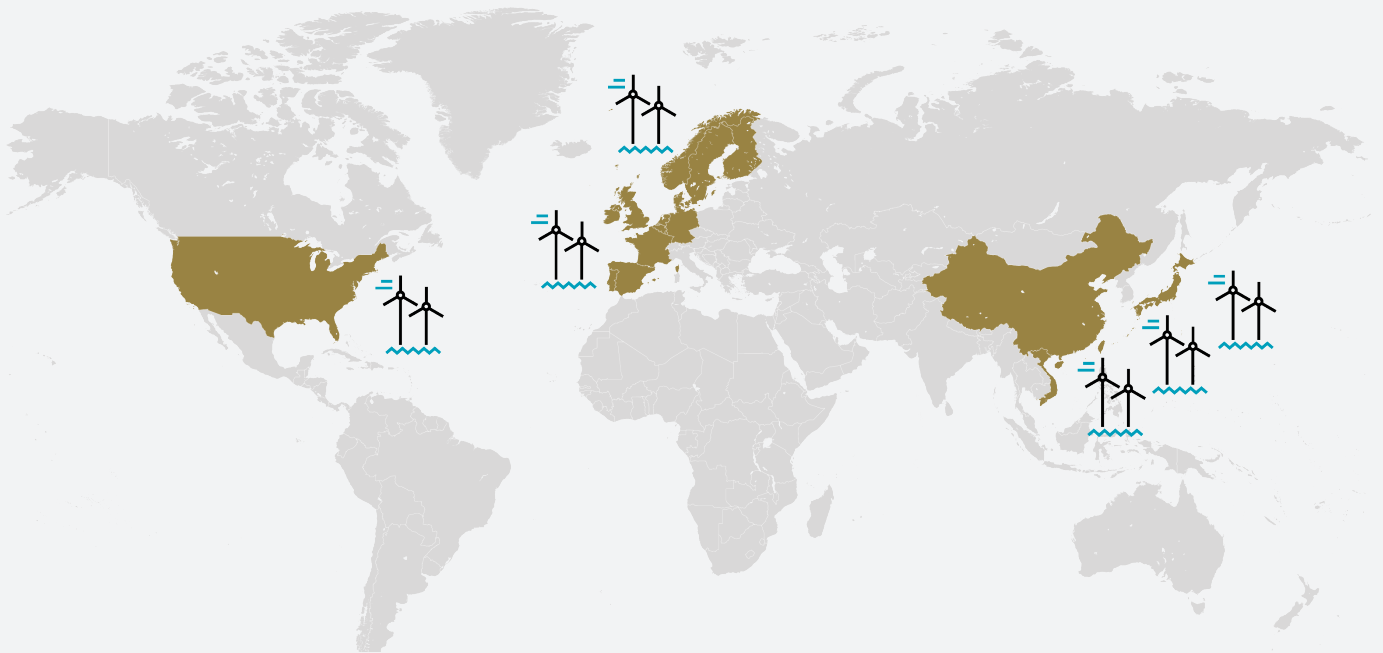
The first developments in offshore wind were initiated in Europe over 15 years ago, giving the region a head start compared to others. Since then, continuous innovation in turbines, foundations, and installation methods has resulted in major reductions in levelized cost of energy (LCOE). The EU Green Deal projects that wind farms will dominate European waters exponentially by 2050 due to this.

ASIA

The Asian region has recently taken off at high velocity, particularly driven by a high number of installations in China. Wind farms in the region need to be designed for harsher conditions than in Europe, due to possible typhoons, earthquakes and unfavorable soil conditions. Nevertheless, new investments are pouring in and offshore wind energy in Asia is considered to become the global forerunner by 2050 – ahead of Europe.

NORTH AMERICA

Although offshore wind energy is still in its early stages in North America, projected growth is dominated by the United States. The first large U.S. wind farms are scheduled through 2030. This is a key period for establishing supply chains and compatibility with the Jones Act. Most market growth is anticipated between 2030 and 2050.



Designing Solutions for a Solid Foundation

Offshore wind farms operate in some of the harshest conditions and environments, making a solid foundation one of the most critical requirements for offshore wind turbines. With all the investments, meticulous planning and labor, failure in design is not an option for offshore wind projects. Trelleborg's high-quality engineering guarantees fail-safe solutions and the success of seals throughout the foundations' lifespans.

TRUSTED ABOVE ALL

We have dedicated over 15 years to developing the best designs and materials in the industry that withstand the brutal conditions foundations face. As a result, we have been trusted to design and supply more foundation seals than any other company in the world.

QUALITY-TESTED MATERIALS

With our superior compounds, we can engineer detailed, custom designs for offshore wind foundations that can survive the most extreme conditions with minimal maintenance.

In order to ensure that our foundation seals are fit for purpose for every project, they are subject to rigorous testing procedures and are third-party certified.

ENGINEERING SUSTAINABILITY THROUGH PREMIUM PRODUCT DESIGN

At Trelleborg, our product designs are driven by sustainability. A large focus of our sustainability goals also involves research, product development and innovation that are key aspects of the UN's Sustainable Development Goals 9: Industry, Innovation and Infrastructure, and 11: Sustainable Cities and Communities.

Achieving these goals calls for smarter products that can survive the impact of frequent and erratic climate change. Through our premium product design, we create foundation seals that are both sustainable and enhance the resilience of today's infrastructure.



Partnering with you at Every Stage

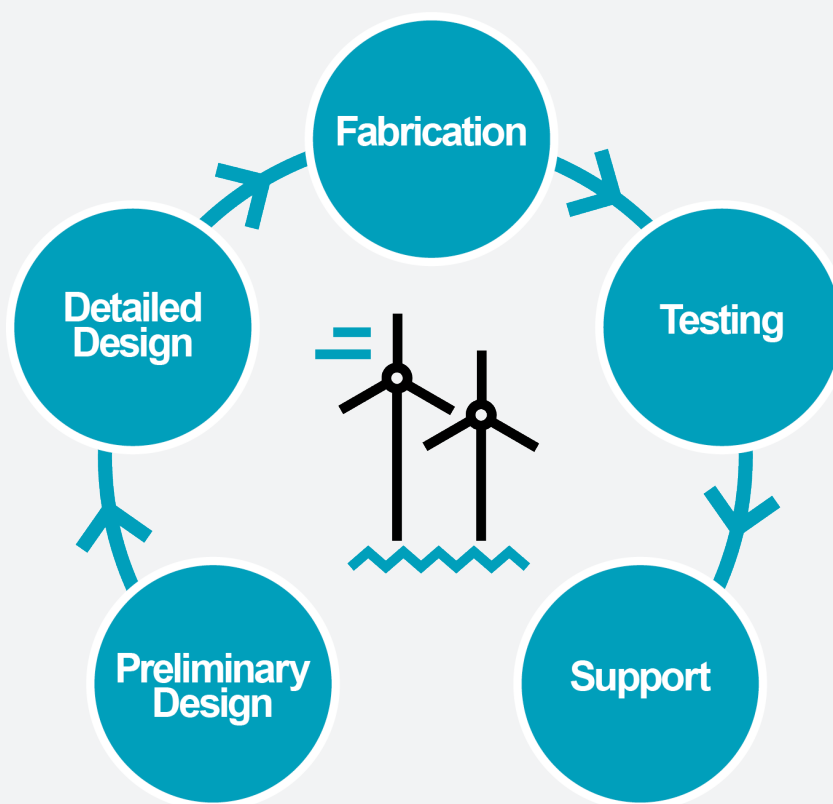
New, increased turbine power is rapidly decreasing LCOE, driving up efficiency. In turn, turbine sizes continue to scale at high pace. These higher-power-rating turbines allow a reduced number of foundations and installations, lowering LCOE even further. However, as turbines have grown bigger and heavier, design conditions for the foundation have become increasingly challenging.

From design concept to production and installation, our end-to-end approach delivers expertly engineered solutions to guarantee success across the entire life cycle of your project.

A CONSULTATIVE APPROACH

To ensure the most appropriate and fully reliable foundation seal is engineered, we work closely with consultants, contractors, and subcontractors at an early stage in the project.

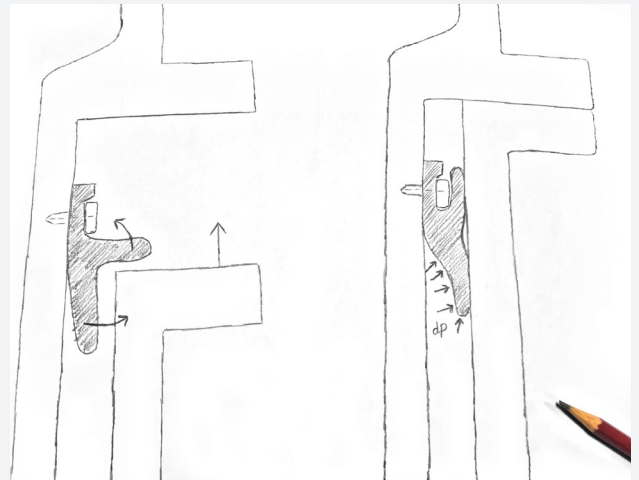
Our extensive involvement in every step of a project's life cycle makes it possible for us to gain a thorough understanding of the structure and its performance in the natural environment. We work collaboratively with consultants, contractors and subcontractors to deliver a bespoke design based on our expertise and, in the end, the most appropriate design for each individual situation.



BETTER BY DESIGN

As a result of our experience working on offshore wind power infrastructure projects around the globe, we have a comprehensive understanding of the requirements of various regions. In order to meet the needs of each region, our global network is complemented by local teams that offer support on the ground.

With a commitment to simplifying the design, scheduling, and documentation processes, we work closely with you throughout our partnership. This enables us to establish production schedules, resulting in coordinated, on-time delivery of our products.

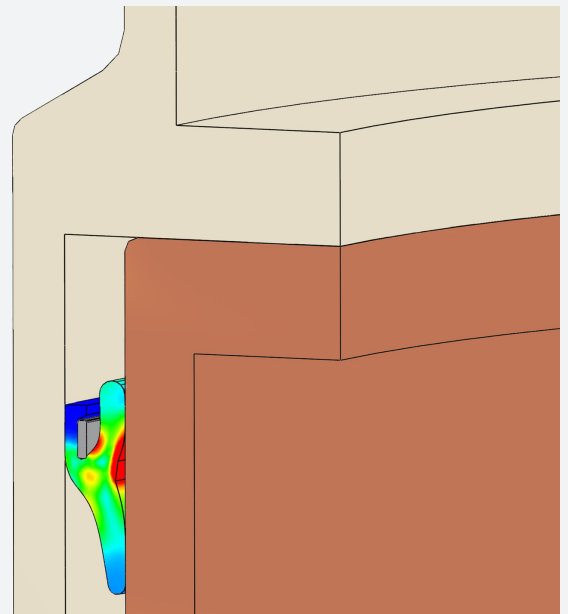


Preliminary design

Together, we identify project requirements and potential challenges. Following this, we draw on our extensive industry experience to develop a conceptual solution. The preliminary design proposal includes a test procedure for validating the product's performance.

Detailed design

To ensure the foundation seals meet project specifications, a detailed design is developed once project details are established. A Finite Element Analysis (FEA) is used to ensure that the products will function as specified even under the most extreme conditions. A complete set of technical documentation is provided to stakeholders in the form of a design report.



Bespoke Solutions to Seal Your Foundations

Depending on turbine size, water depth, seabed and climate-specific conditions, offshore wind farms require different types of foundations. The main fixed foundation types are monopile, pre-piled jackets and post-piled jackets.

We know that no two projects are the same. With our innovative engineering expertise, we are capable of designing the precise solution for your fixed foundation requirements to guarantee the success of your project.

FIXED FOUNDATION TYPES

Monopiles

Monopile foundations have proven to be the most cost-effective foundation type to date. The monopile is driven into the seabed, after which a transition piece is installed. The connection is either grouted or non-grouted, meaning that the monopile and transition piece are bolted together using flanges.

Grouted connections have been the standard approach in the industry. Shear keys or a conical configuration are applied to ensure the strength of the connection.

Non-grouted bolted connections were introduced at a later stage to optimize designs, but soon proved to have challenges of their own, particularly in terms of corrosion protection of the bolts. To date, no standard design is available, and the connection type is highly dependent on project specifications.

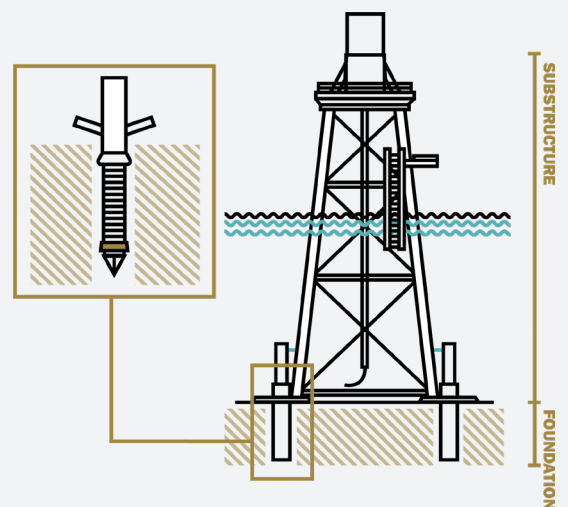
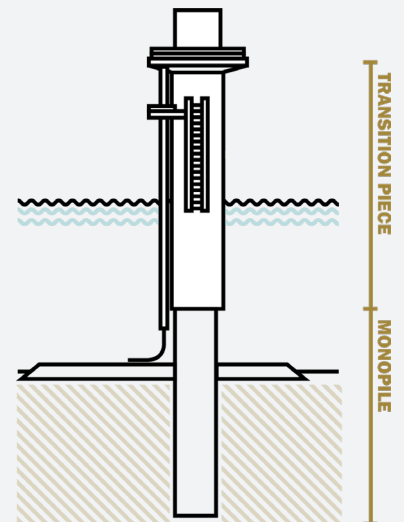
Pre-piled jackets

Pre-piled jacket foundations are typically applied for wind turbine generators in deep waters and harsh conditions. A template is employed to drive piles in the seabed. The template allows accurate positioning of the piles and increased installation efficiency. After pile driving the jacket, the substructure is lowered over or into the driven piles and grouted to ensure fixation.

Post-piled jackets

Post-piled jacket foundations have been applied extensively in the oil and gas industry for offshore platforms. In offshore wind, post-piled jacket foundations are typically applied for offshore substations that are heavily loaded or in deep waters.

Since only one or two are required per wind farm, it is not efficient to pre-pile due to template costs. Therefore, the jacket substructure is first placed on the seabed, after which individual piles are driven through the legs and grouted for fixation.



The Smarter Approach to Foundation Seals

Offshore wind farms operate in some of the harshest conditions. With the amount of investments, intensive planning and labor involved, failure in design or materials which will delay or even terminate your project in the final stage is not an option.

Larger turbines and blades generate more efficient wind power, but they also require a new level of foundation innovation. To stay ahead, you need a partner who understands your challenges and has the expertise to design customized seals that meet your new requirements.

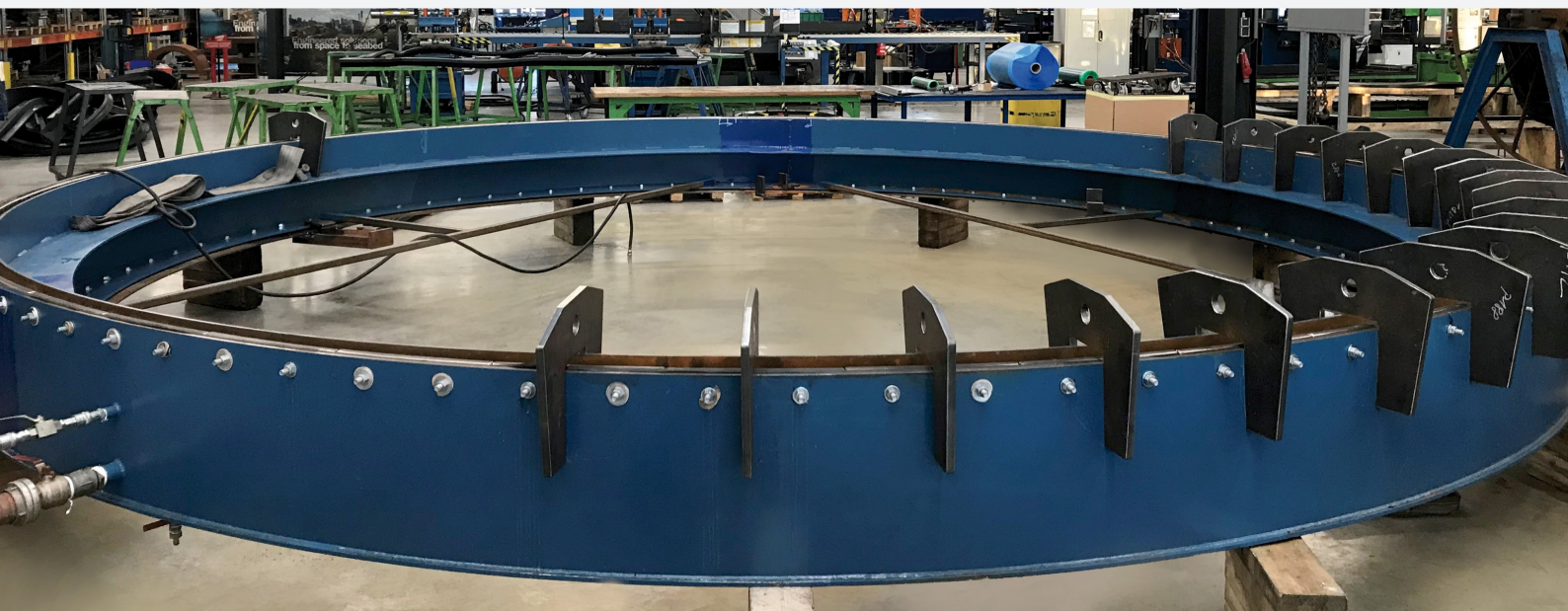
Our engineers have spent over a decade developing and testing the best designs and materials for our products. With Trelleborg as a partner, success is guaranteed.

RISK REDUCTION: DURABLE AND RELIABLE

- Factory Acceptance Test on full scale to validate the design and ensure offshore performance
- Testing on worst-case conditions including minimum and maximum gaps, and a safety factor of 1.5
- Design lifetime expectancy of materials used is beyond 30 years

EXTENSIVE, TRUSTED TRACK RECORD OF BESPOKE SOLUTIONS

- **2,781 grout seals for monopiles**
- **1,946 grout seals for pre-piled jackets**
- **159 grout seals for post-piled jackets**
- **450 skirt seals for non-grouted monopiles**
- **911 airtight platform seals for monopiles**
- **15 years active in offshore wind infrastructure**
- **129 flange seals since 2007**
- **3,600 foundation seals since 2007**



Grout Seals for Monopile Foundations

Trelleborg's grout seals are the industry standard for grouted monopile foundations. The seals are engineered to project specifications and designed to function for as long as the foundations.

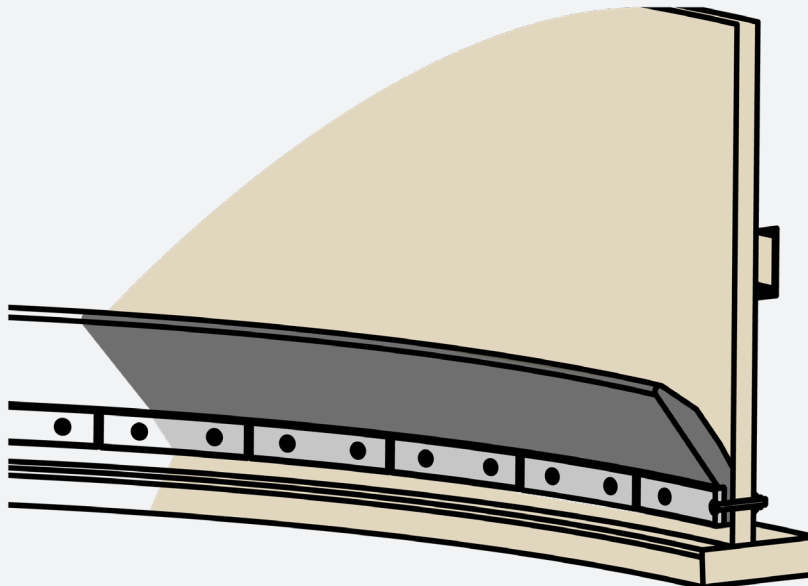
The grout seal is a critical component in the installation phase of the transition piece. The seal is designed to absorb fabrication and installation tolerances of the monopile and transition piece while also supporting the grout column during curing.

Since the grout seal is considered part of the structure, it is designed to be maintenance free and comply to a service life of over 30 years. The grout seal is suitable for floating vessel and jack-up installation, as it also allows upward and rotational motions.

Prior to grouting, the transition piece is lowered onto the monopile. The design of the grout seal ensures that it slides smoothly over the monopile wall. The grout seal is installed at the transition piece fabrication yard. It is supplied as a closed ring and installed in the yard using clamping strips and bolts. If needed, our experienced service engineers may provide onsite supervision for installation.

KEY FEATURES

- **Allows transition piece installation from both floating vessels and jack-ups**
- **Self-activating seal such that no offshore work is required**
- **Absorbing installation and fabrication tolerances between the monopile and transition piece**
- **No maintenance required**
- **Service life of over 30 years**



BASIS FOR DESIGN

Working principal

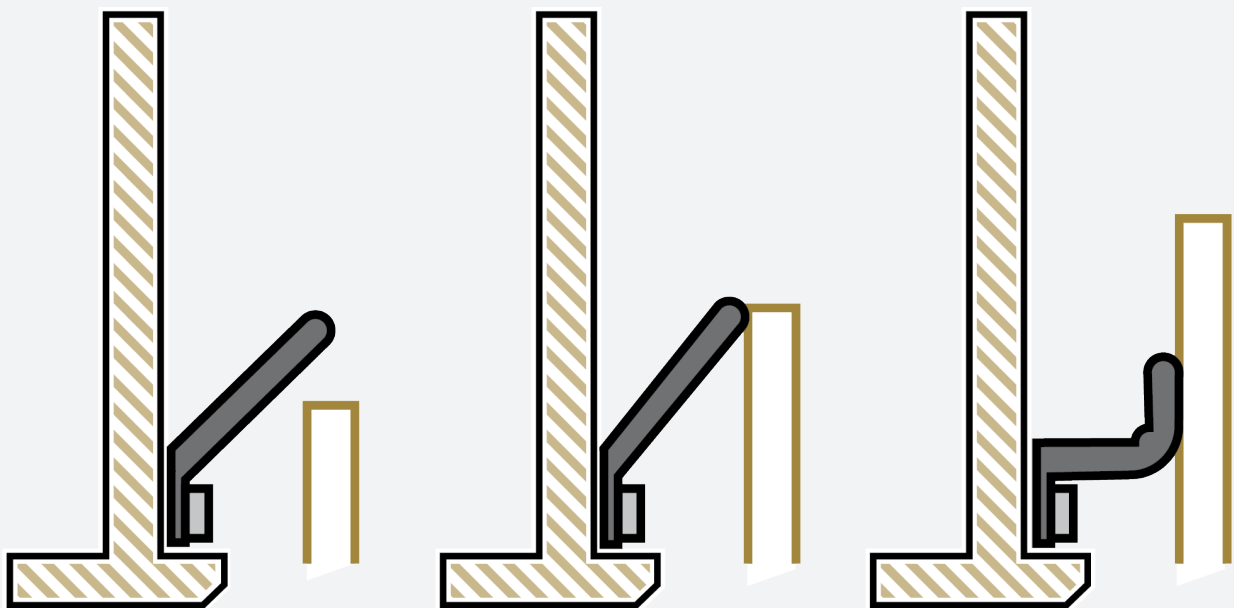
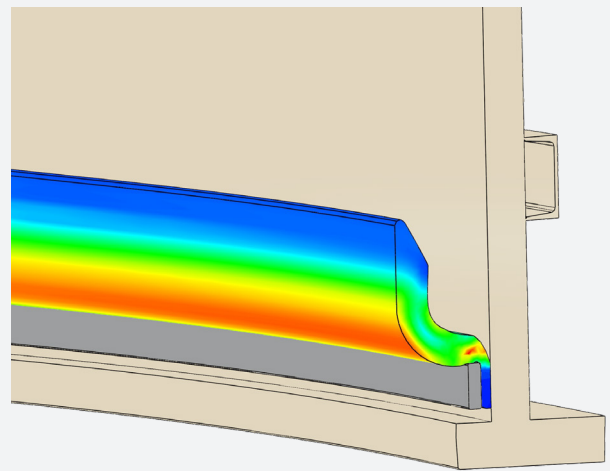
The grout seal activates itself when it is loaded by the grout column. Fabrication and installation tolerances of the foundation are absorbed by the seal. Performance of the seal is governed by grout pressure and the minimum and maximum gap, between the monopile and the transition piece, that the seal needs to overcome. After grouting, the seal remains functional as it prevents grout from washing out throughout the lifetime of the foundation.

Rubber grout seals

Rubber grout seals have been the most applied foundation seal over the last 15 years. These grout seals are fabricated using a high-quality elastomer in the required diameter. Correct positioning of the bolt holes is ensured using a full-scale drilling frame.

Reinforced rubber grout seals

Reinforced rubber grout seals may be applied for more demanding project specifications. These grout seals include a reinforcement fabric for increased performance. This implies that the seal can be designed for a larger maximum gap, a smaller minimum gap, or a higher grout pressure. The working principal and fixation of the reinforced rubber grout seal is the same as for the rubber grout seal.



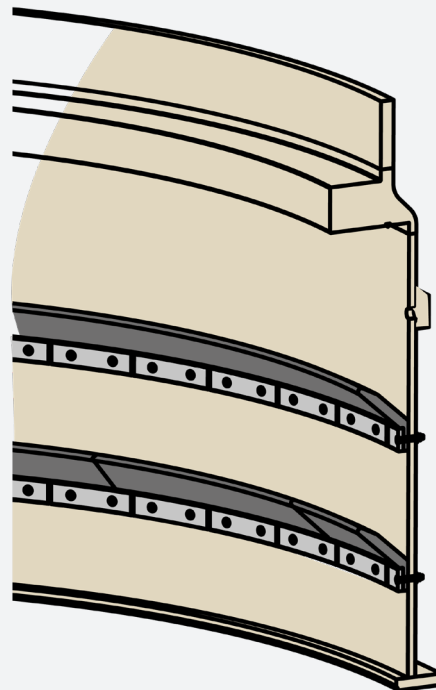
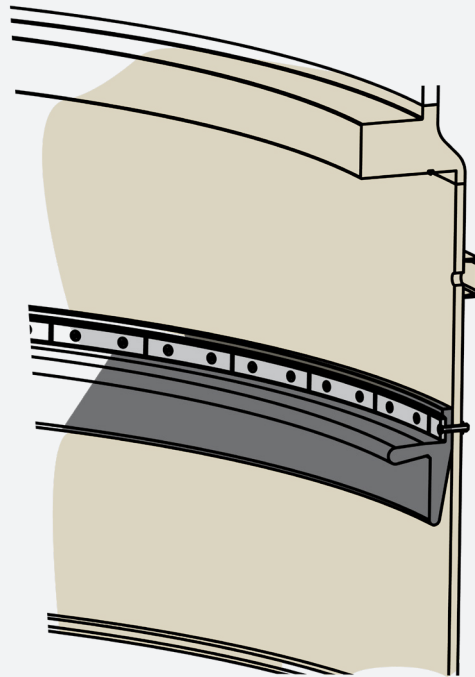
Skirt Seals Non-Grouted Monopiles

Trelleborg's non-grouted monopile foundation seals are a market innovation for bolted flange connected monopiles and transition pieces. Corrosion protection of these bolts is critical for the design life of the foundation.

Ever since bolted flanged connected monopile foundations have been introduced to the offshore wind industry, reliable corrosion protection of the bolts has been critical for success. It has been observed in the industry that a single seal between the flanges is not sufficient to protect the bolts. The smoothness of the flange surface is unpredictable after pile driving and small openings between the flanges may appear during load cycles through which seawater may ingress.

KEY FEATURES

- ▮ **Protection of the critical bolts in the flange between the monopile and transition piece**
- ▮ **Allows transition piece installation from both floating vessels and jack-ups**
- ▮ **Self-activating sealing system such that no offshore work is required**
- ▮ **Absorbing installation and fabrication tolerances between the monopile and transition piece**
- ▮ **No maintenance required**
- ▮ **Service life of over 30 years**



BASIS FOR DESIGN

MP-TP Flange Seal

The flange seal between the monopile and transition piece is the primary seal for a compression lip seal configuration. Since the compression lip seal cannot guarantee 100% water tightness, the flange seal is designed to do the job. For ESA3- seals, the flange seal is considered a secondary seal, providing additional protection.

Compression lip seal

A sealing system using a stiff compression lip seal may be applied to protect the flange bolts during their service life. Although the compression lip seal will prevent most water ingress, it cannot be guaranteed to be 100% watertight due to the lip orientation. It is therefore not considered the primary seal.

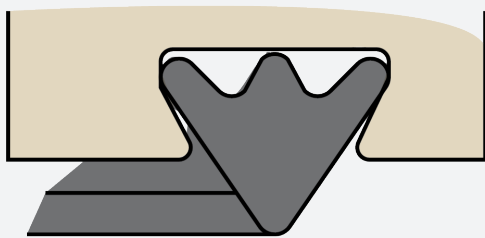
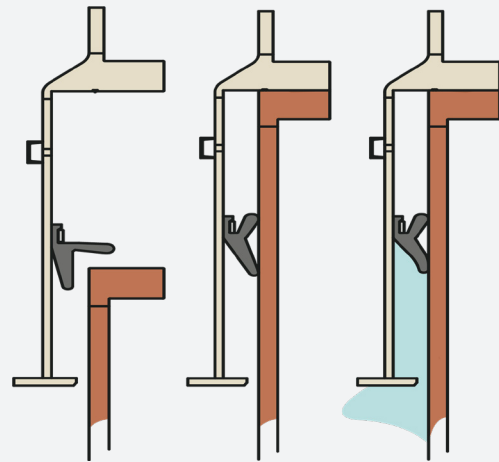
Wavebreakers

A set of wavebreakers may be applied at the bottom of the transition piece skirt. The wavebreakers are designed to absorb a substantial part of the wave impact energy and therefore reduce the pressure on the seal positioned above. The wavebreakers are segmented to prevent enclosed water in the cavity, allowing a small amount of water to flow in and out.

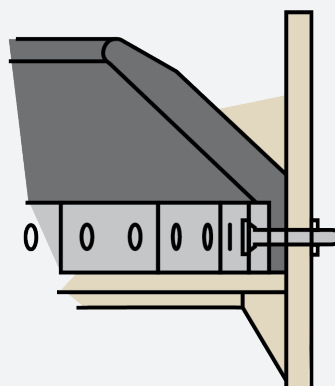
ESA3- Type Seal

The ESA3- Type seal is applied as the primary seal for corrosion protection of the bolts. The upper lip of the seal deflects upwards during lowering of the transition piece onto the monopile. Due to the deflection, the lower lip is then pressed against the monopile wall. Upon water impact, the lower lip closes itself against the wall, providing a tight seal.

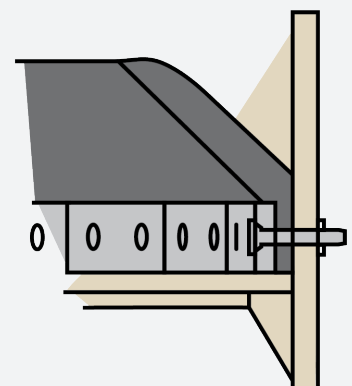
In this configuration, the flange seal offers a second barrier of protection. For the harshest conditions, wavebreakers may be applied at the bottom of the transition piece skirt.



MP-TP Flange Seal



Compression Lip Seal



Wavebreaker

Flange Seals Monopile-Transition Piece

The flange seal installed in a groove in the transition piece flange is a crucial component in the configuration of non-grouted monopile foundations.

In the early days of bolted connections, a simple O-Ring was applied between the monopile and transition piece flanges. However, it has become evident that such a seal provides insufficient protection of the bolts. In harsh offshore conditions, it was observed that flanges may open several millimeters due to high cyclic loading.

At Trelleborg, we have designed several flange seals for this application that perform even at the most demanding conditions.

The flange seals are installed at the transition piece fabrication yard. The transition piece flange includes a dovetail groove to which the seal is easily inserted.

Some monopile foundations include a hybrid of bolts and grout to transfer the loads. In this case, grout is injected in the cavity between the transition piece skirt and the monopile and offers corrosion protection of the bolts.

In other cases, a non-structural grout is applied that functions solely as corrosion protection. Either way, a flange seal is crucial in this application to prevent excess grout from flowing between the flanges.

KEY FEATURES

- **Protection of the critical bolts in the flange between the monopile and transition piece**
- **Absorbing installation and fabrication tolerances between the monopile and transition piece**
- **No maintenance required**
- **Service life of over 30 years**
- **Vulcanized to closed ring**



BASIS FOR DESIGN

Working principal

Flange seals are activated by their compression and perform through the resulting contact pressure.

To ensure functionality over the complete service life, the initial contact pressure is designed to compensate for stress relaxation in time. The overall design is based on the projected maximum opening of the flanges and the anticipated differential pressure acting on the seal.

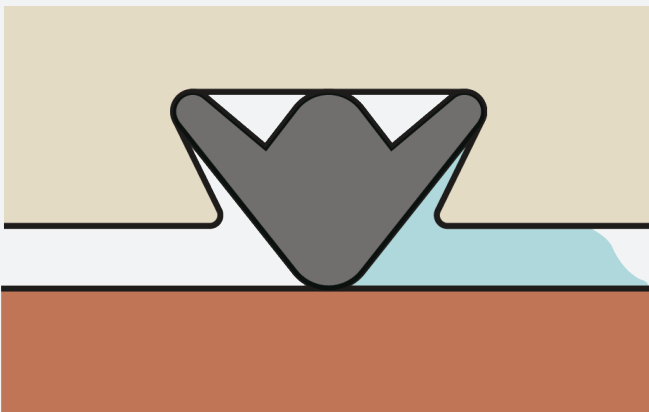
The flange seals are supplied as a vulcanized closed ring, meaning that a weak adhesive joint is avoided, which would pose a risk to functionality over its service life.

Type VW-

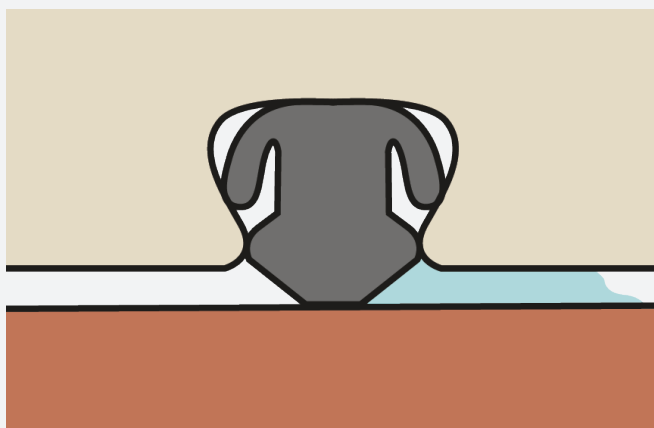
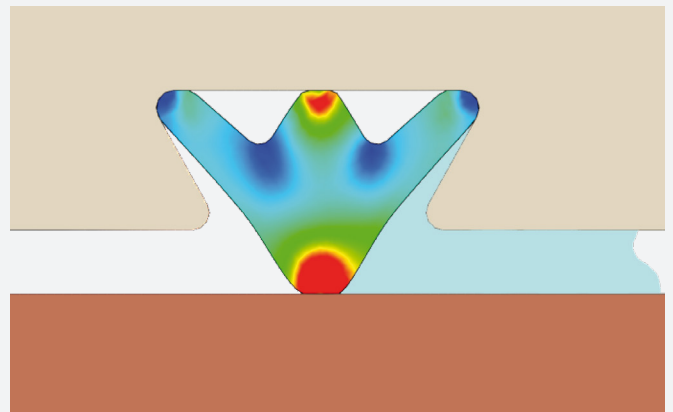
Flange seals of type VW- are manually inserted in the transition piece groove. The geometry is designed to maximize contact pressure and sealing performance, protecting the critical bolts in the flanges in the harshest conditions.

Type VT-

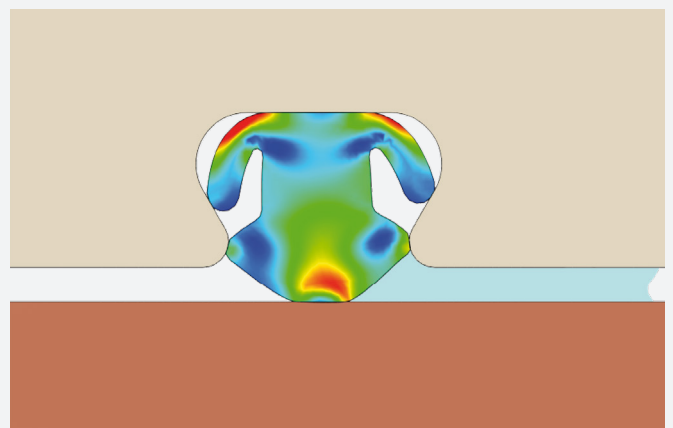
Flange seals of type VT- are designed for transition piece flanges in the most demanding environments. The flange seal allows installation in a small groove with large radii to avoid fatigue and sensitive stress concentrations in the flange. The seal allows manual installation in the transition piece groove.



Type VW-



Type VT-



Airtight Platform Seals Monopile Foundations

Trelleborg's airtight platform seals protect the transition piece from corrosive and dangerous gases inside the monopile. The seals are engineered to project specifications for absorbing fabrication tolerances and service life of over 30 years.

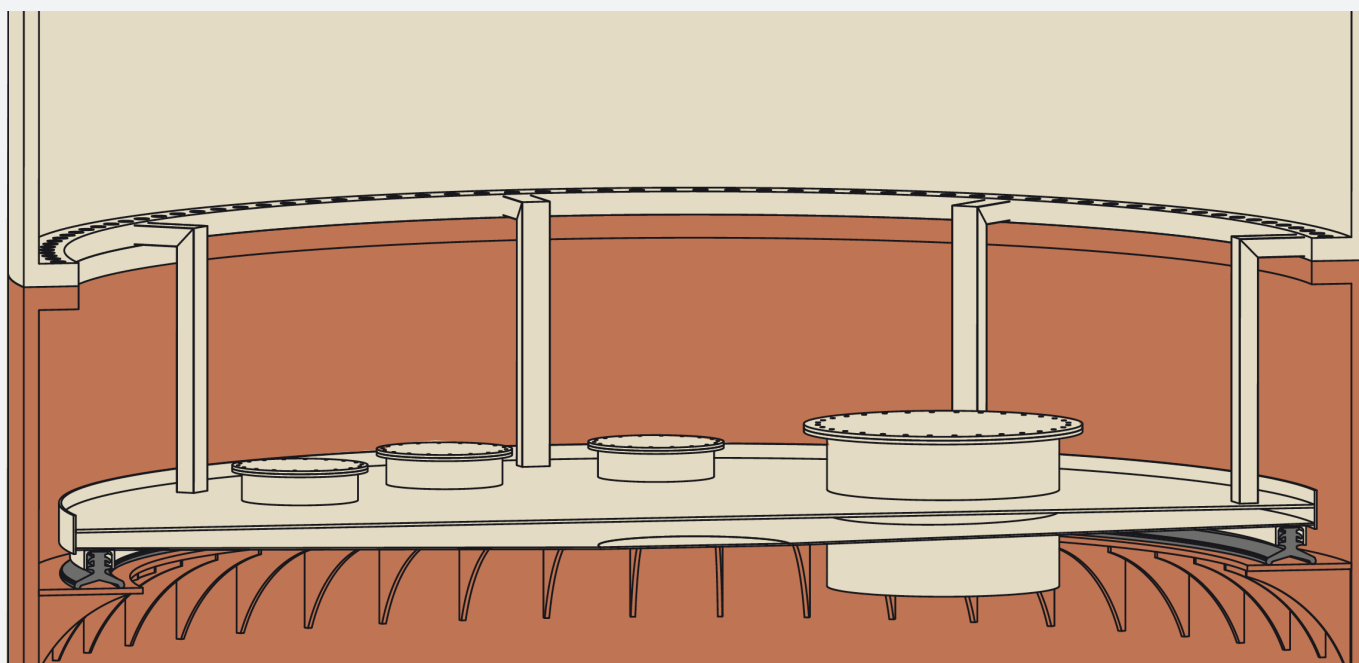
The airtight platform seals are designed to operate in the chemically demanding environment below the airtight platform. Although a (passive) ventilation system is present in the platform, low concentrations of chemicals generated by the ICCP system are present continuously throughout the foundation service life.

The elastomer materials used for Trelleborg's airtight platform seals offer chemical stability through their thick solid profile, while their geometry allows absorption of fabrication tolerances between the platform and landing ring.

The seals are installed at the platform fabrication yard after they have been coated. The seals are installed using Trelleborg Sealant, which is only functional prior to offshore installation. Once the platform is lowered onto the landing ring in the monopile, the sealant loses its function, with the airtight platform seal compression keeping it in place.

KEY FEATURES

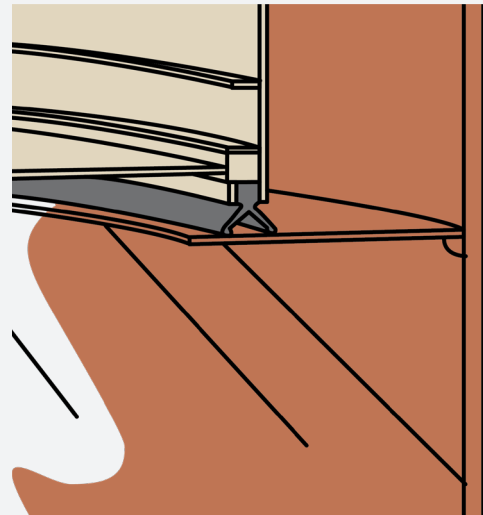
- Design for stiffness and performance
- Absorbing fabrication tolerances between the airtight platform and the landing ring
- No maintenance required
- Service life of over 30 years



BASIS FOR DESIGN

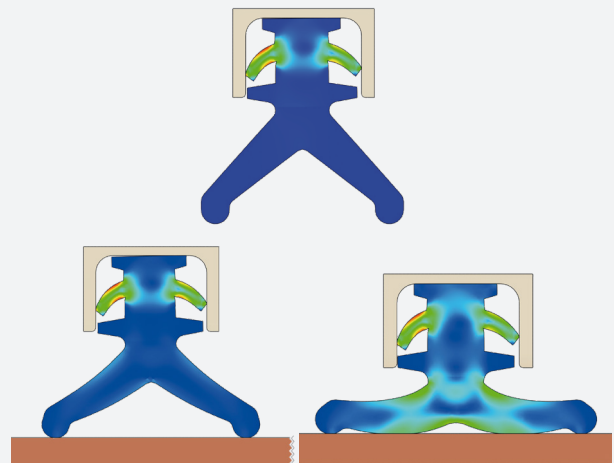
CS-111/114

The CS-111/114 airtight platform is installed between two ring plates and is designed for low stiffness and a large compression range. In most cases the weight of the airtight platform is sufficient to activate the seal over a large compression range. This implies that little compression force is required to absorb large fabrication tolerances and ensure functionality of the seal over its service life.



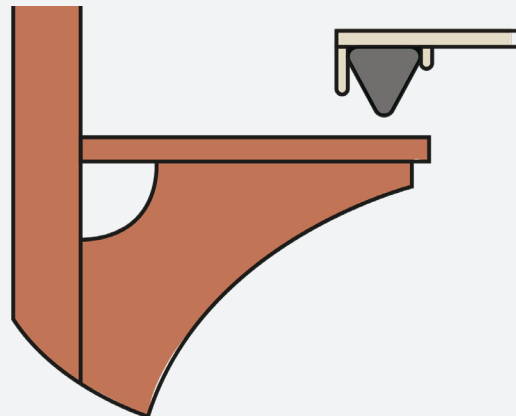
CS-111/114-UPE80

The CS-111/114-UPE80 airtight platform seal has the same performance as the CS-111/114. However, this seal has been developed to simplify installation in the yard by mounting it in a standard UPE-80 steel section bent in the platform diameter. The top lips of the seal allow manual fixation in the steel section so that the adhesive can cure without supporting the seal.



CS-80/70

The CS-80/70 airtight platform seal has been designed for minimum overhang of the monopile landing ring. The triangular geometry minimizes the seal footprint. This seal is particularly effective when the platform is hung off from the transition piece flange, so that a large compression force is available.



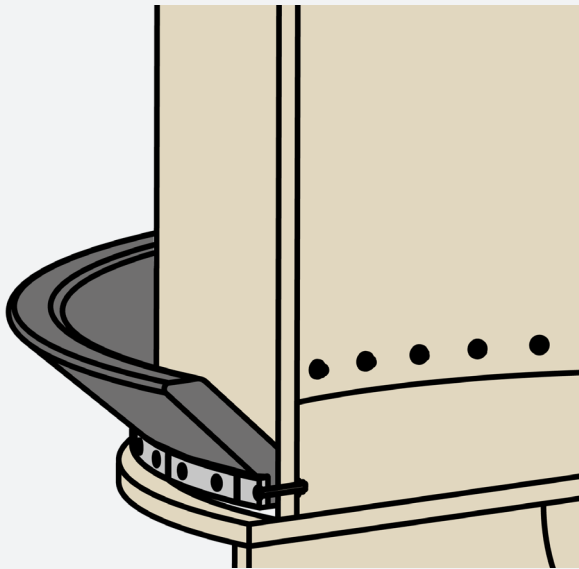
Grout Seals Pre-Piled Jackets

Trelleborg's grout seals for pre-piled jackets prevent grout spillage and seawater pollution during offshore installation. The seal allows the full capacity of the grout column to be used over the lifetime of the foundation.

Many pre-piled jacket foundations in the North Sea have been successfully installed without grout seals. Favorable soil conditions, such as sand on the seabed, prevent major leakages of grout on these locations. However, other regions with more demanding environmental conditions require a more certain approach.

In unfavorable locations that have a muddy seabed and harsher conditions like typhoons and earthquakes, a grout seal secures full strength of the grouted connection. The grout seal prevents mud from mixing with the grout so that its full capacity is utilized.

The grout seal may be installed on the jacket pin or in the jacket sleeve, depending on the construction. Having several connected legs, a pre-piled jacket typically poses large gaps on the grout seal.



KEY FEATURES

- Utilize full capacity of the grouted connection
- Self-activating seal such that no offshore work is required
- Avoid waste and pollution by preventing grout spillage
- Absorbing installation and fabrication tolerances between the pile and sleeve
- No maintenance required
- Service life of over 30 years



BASIS FOR DESIGN

Working principal

The grout seal is supplied as a closed ring and it is installed with clamping strips and bolts in the yard. The seal is protected during offshore installation using guides or shims. Offshore injection of grout into the cavity then activates the seal as the lip is pressed against the wall.

The flexible seal absorbs fabrication and installation tolerances and allows upward and downward sliding motions - it can even slide safely over shear keys.

After curing the grout, the seal protects the grout column from washing out over the lifetime of the foundation.

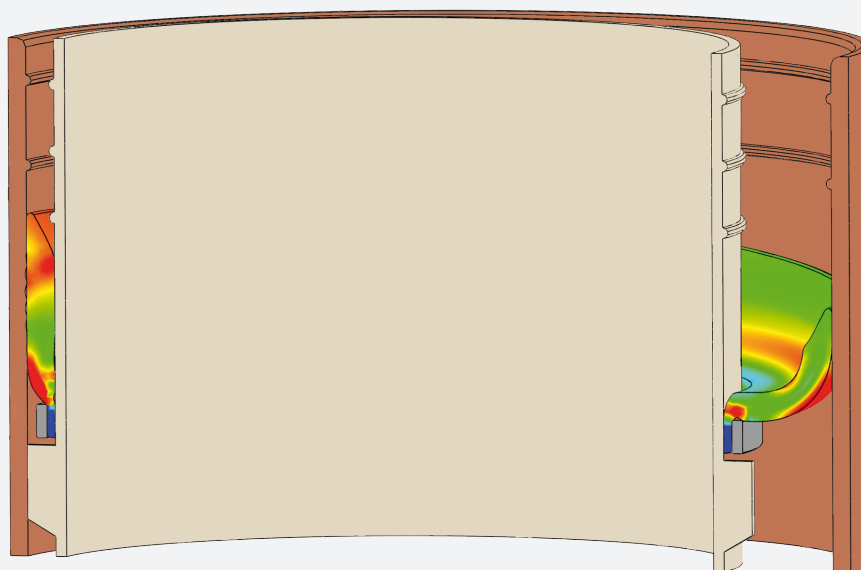
Rubber grout seals

Rubber grout seals are suitable for most pre-piled jacket foundations. The most important design parameters to consider are the minimum and maximum gaps, as well as the grout pressure.

Reinforced rubber grout seals

Reinforced rubber grout seals have been developed to meet the most demanding project specifications. The seals include fabric reinforcement, so that the largest maximum gaps, smallest minimum gaps or highest grout pressures can be supported.

The grout seals are installed with clamping strips similar to the rubber grout seals.



Grout Seals Post-Piled Jackets

Trelleborg's grout seals for post-piled jackets secure the grout in the construction during curing, and prevent grout spillage. The seals are designed to operate at large water depths and are engineered to project specifications.

Post-piled jacket foundations have been applied in the oil and gas industry for many years. In offshore wind farms, these foundation types are mainly used for the offshore substations. As the foundation type, grout seals for post-piled jackets show great parallels to oil and gas constructions.

Installation tolerances can be well controlled because an individual pile is driven through the jacket sleeve. Guides or shims are included in the jacket sleeve to ensure concentric position. Fabrication tolerances are limited as well, due to jacket pile diameters being relatively small. These factors highlight that the grout seal is barely impacted by a minimum and maximum gap.

It is crucial that the grout seal withstands the impact and high accelerations during pile driving. Furthermore, pile driving may push up mud on the seabed into the grout cavity. The grout seal may be applied in conjunction with a wiper and diaphragm to avoid grout mixing with mud and ensure full strength of the grouted connection.

KEY FEATURES

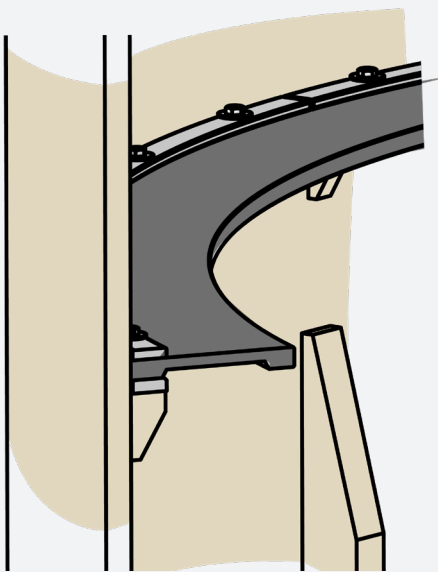
- **Avoid waste and pollution by preventing grout spillage**
- **Different sealing systems available**
- **Wiper and diaphragm may be applied to prevent grout mixing with mud**
- **No maintenance required**
- **Service life of over 30 years**



BASIS FOR DESIGN

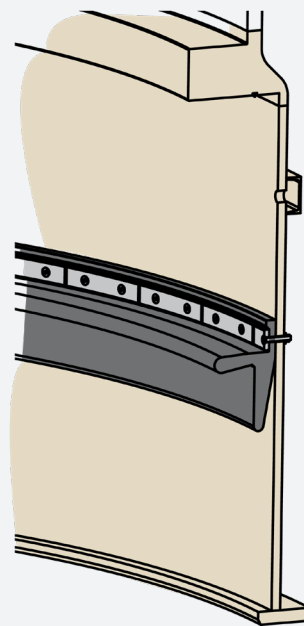
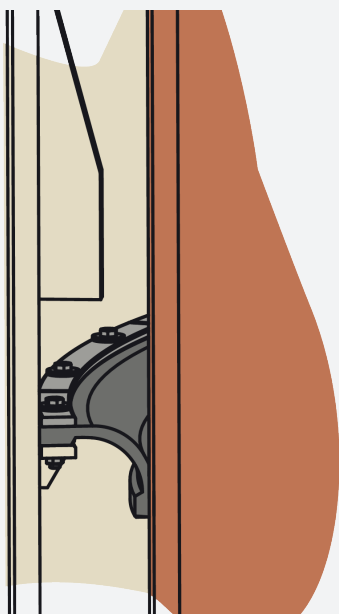
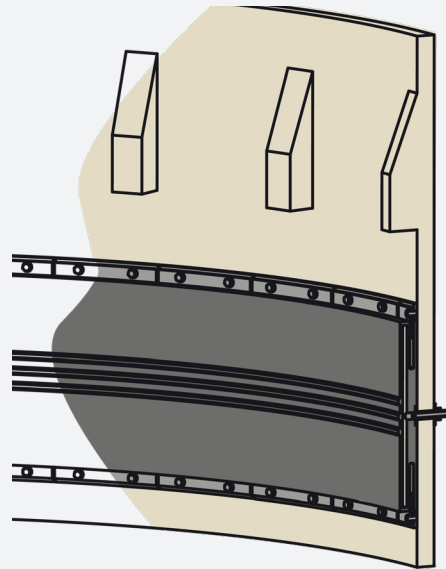
TS-Lip Seal

The TS-lip seal is a self-activating system, requiring no offshore work. The circumferential reinforcement is carefully designed so that it is flexible enough to stretch and follow the diameter of the pin. On the other hand, it is designed with stiffness that will generate enough contact pressure to hold the grout column. Furthermore, additional reinforcement fabric is applied to ensure the seal can withstand high accelerations during pile driving.



PS-Inflatable Seal

When the highest performance is needed, inflatable PS-grout seals are the best option. The seal can be well protected during pile driving due to their limited deflated thickness. Prior to grouting, the seal is inflated using water or air, and its performance can be verified by monitoring the seal internal pressure. This ensures that the grout column can be held at all times.



DISCLAIMER

Trelleborg AB has made every effort to ensure that the technical specifications and product descriptions in this brochure are correct.

The responsibility or liability for errors and omissions cannot be accepted for any reason whatsoever. Customers are advised to request a detailed specification and certified drawing prior to construction and manufacture. In the interests of improving the quality and performance of our products and systems, we reserve the right to make specification changes without prior notice. All dimensions, material properties and performance values quoted are subject to normal production and testing tolerances. This brochure supersedes the information provided in all previous editions.

If in doubt, please check with Trelleborg Marine and Infrastructure.

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