

Fatigue Resistant Foundations

Where you need it most



 **BASF**
The Chemical Company

Construction Solutions for Sustainable Wind Energy

BASF - The Chemical Company

BASF is the world's leading chemical company: The Chemical Company. Its portfolio ranges from chemicals, plastics and performance products to agricultural products, fine chemicals, oil and gas. As a reliable partner, BASF helps its customers to be more successful in virtually all industries.

With its high value products and intelligent solutions, BASF plays an important role in finding answers to global challenges such as nutrition, mobility, climate protection and energy efficiency.

BASF's Construction Chemicals division is the leading supplier of chemical systems and formulations for the construction industry. Continuous innovation and tailor-made solutions ensure that its customers stay at the forefront of technology. Its Admixture Systems business unit specifically helps customers in the ready-mix, precast, concrete products and underground construction industries. The Construction Systems unit offers a wide range of products for sports and industrial flooring, external renders and wall insulation, expansion joints and wood preservatives as well as specialist repair mortars, tile adhesives and waterproofing membranes.

BASF's Construction Chemicals division operates production sites and sales centres in more than 50 countries.

Wind Energy: Economics and Future

To contribute to the targets set by the EU Renewable Energy Directive, the United Kingdom has committed to provide 15% of its energy requirements from renewable sources by 2020 – seven times more than the previous level set in 2008. Meeting this challenge requires sustainable innovation that is both cost-effective and deliverable. The supply chain is under pressure: but with the right construction systems, production can meet demand economically and keep pace with fast-developing new designs.

Key factors that impact on the engineering of wind farms are:

- **Rapidly advancing technology: increased turbine sizes, rotor diameters (now up to 60m) and tower heights**
- **Whole-life performance: wind turbine installations are being designed with a life expectancy of 20 to 25 years**



BASF is renowned worldwide for innovations in chemistry that can drive technology forward; sustainable development is a core strategic guideline for the group, balancing economic growth, environmental protection and social responsibility. Naturally, sustainability is at the heart of the development of wind energy: our research into the application of chemistry in this sector demonstrates that we can add value to accelerate production processes and increase the lifespan of wind turbines, from the foundations to the blades. BASF is proud to be making an important contribution to the future of wind energy and a low carbon society.

Sustainable construction is defined by BASF as the application of sustainable development along the construction value chain, and includes:

- Performance and quality
- Bespoke solutions
- Measurable contributions to sustainability
- Technological development driven by sustainable development
- Active, data-based contribution to improve regulations on sustainability

For concrete, BASF Construction Chemicals has continuously developed concepts to contribute to more sustainable construction, such as the Zero Energy System™ for precast concrete and Smart Dynamic Construction™ for robust, highly fluid ready-mix concrete solutions. The most recent concept – Crystal Speed Hardening™ – enables concrete producers, for both precast and onsite construction, to significantly contribute to the targets of sustainable construction by:

- Replacement/reduction of cementitious materials
- Reducing energy costs and CO₂ emissions
- Accelerating the production process
- Improving the production environment
- Focusing on product durability

Sustainability is also at the heart of the development of pre-blended materials used in waterproofing structures, concrete repair, flooring applications and much more. For example, our newest concrete repair mortars - EMACO® Nanocrete and EMACO® Fast - contribute to achieving ambitious climatic goals by considerably improved durability of the repair works while using recycled and lower energy consuming raw materials. With the new generation of MASTERFLOW® Exagrouts, we directly contribute to the creation of renewable energy from wind.

BASF is proud to have a positive corporate carbon footprint with many BASF products helping to reduce CO₂ emissions. In fact, overall, BASF products help to save three times more greenhouse gases than the entire amount generated by their production processes and disposal. Using our knowledge, we offer smarter, sustainable solutions with whole-life cost savings, supporting the supply chain in advancing wind turbine design.



Epoxy systems and coating materials for rotor blades



Ultra-high performance Exagrouts for wind turbines



Admixtures for the best concrete mixes in foundations

The Foundations: Offshore

Offshore wind turbine installations are extremely large, heavy and slender structures which are exposed to huge dynamic loads from wind and waves. Careful design of the foundations and selection of the grouting material is of the utmost importance.

ExagROUT for Offshore Wind Turbine Installations

Where wind towers are to be installed on foundations using grouted connections, the grout specified must be able to absorb enormous bending movements, vibrations, wave actions, torque and wind power during the lifetime of the wind farm.

In response to these challenges, BASF has developed a new range of grouts – ExagROUTs – with MASTERFLOW® 9500 being a specially designed grouting mortar for the construction of offshore wind turbines. Formulated for large-scale underwater applications and short and limited weather windows, MASTERFLOW® 9500 offers:

- Proven and certified quality, which is independently tested
- Proven fatigue resistance, ensuring long durability
- Zero autogenous shrinkage, faster more cost-effective installation
- Rapid strength gain even at very low temperatures, for fast mounting of towers
- Applicable at temperatures down to 2°C, allowing for longer weather windows
- Installation cost considerably reduced due to faster overall installation
- Earlier operation of the wind farm and return on investment
- Wind turbines securely installed
- Easier and more secure design with high safety factor
- Validated by Det Norske Veritas (DNV)
- High early and final strengths
- No segregation of cementitious grout

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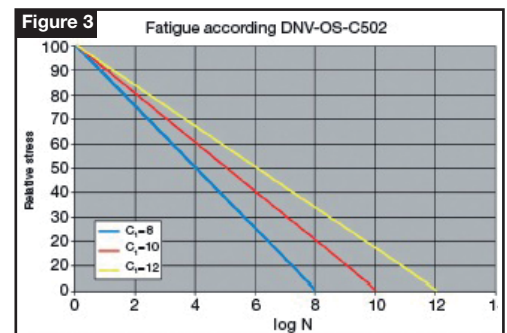
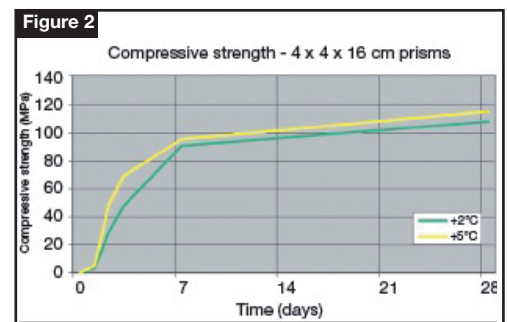
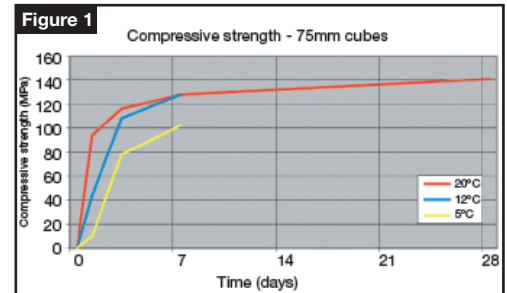
Compressive Strength

Compressive strength of MASTERFLOW® 9500 was tested in accordance with EN12390-3, using 75mm cubes. At each testing age 3 cubes were tested. The compressive strengths are plotted as a function of age in Figure 1.

Strength development at cold temperatures was determined in accordance with EN196-1. The results for MASTERFLOW® 9500 tested at +2°C and +5°C are shown in Figure 2.

Fatigue Behaviour

Fatigue resistance is the resistance to the progressive and localised structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values are less than the ultimate stress limit, and may be below the yield stress limit of the material. Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form. Eventually a crack will reach a critical size, and the structure will suddenly fracture. The offshore design standard DNV-OS-C502 gives design guidelines for how to take into account maximum and minimum stress levels for fatigue life predictions (see Figure 3).



Admixture Solutions

Already established as the typical onshore solution, concrete foundations are considered a practical option in near-shore marine environments. Whilst many projects are situated in shallow waters, new marine wind energy farms are planned for deeper waters, increasing the need for more technologically advanced engineering in a field where there are no standard solutions.

The cost of the specialist vessels and equipment involved in off-shore engineering means that speeding up the placement of foundations is a critical budgetary factor. The offshore installation of monopile foundations has sometimes proved technically challenging; BASF admixtures can help to facilitate the mass production of new gravity base foundation designs, giving designers the ability to tailor concrete mixes to suit the environmental profile and production method precisely.

As already outlined, BASF's concrete admixtures can be used to address many issues, from speeding up the precast process through high early strength gain, to delivering long-term durability, corrosion protection and waterproofing. Decreasing the weight of precast concrete foundations, to assist in transportation and installation without compromising on quality, is another key area in which our admixtures can contribute to mix design for more sustainable solutions.

Contact us to find out how our range of superplasticisers, curing agents, release agents, air entraining agents, accelerators and corrosion-inhibiting admixtures can support sustainable production processes, mix design optimisation and material performance.

The Foundations: Onshore

An increasing number of failures have been observed in wind turbine foundation areas as soon as 3-5 years after installation. The key causes of these failures are design errors, dynamic loads, load cycles and the development of taller, larger wind turbines. The installation of onshore towers now involves developing solutions to address these issues.

ExagROUT for Onshore Wind Turbines

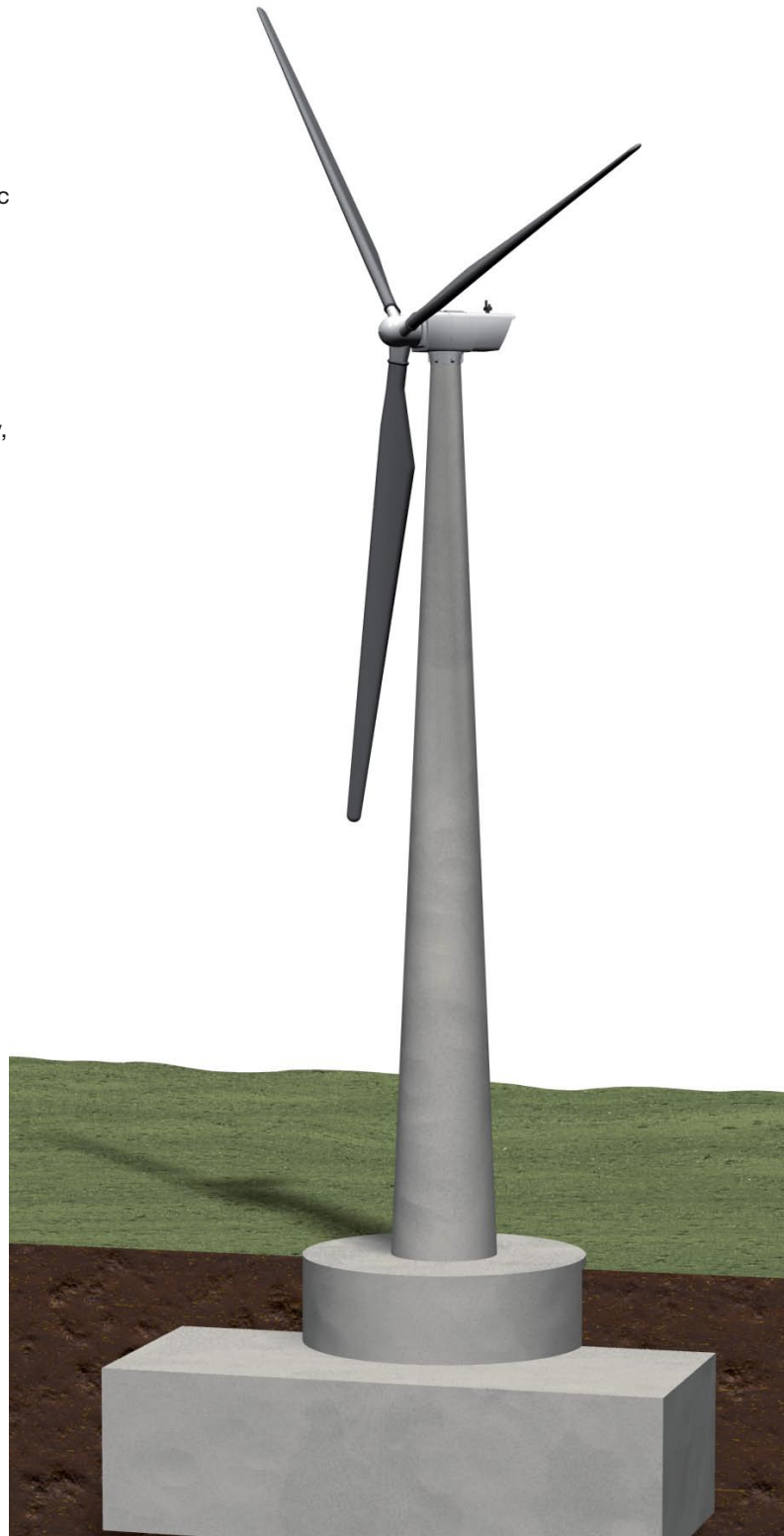
A typical standard precision grout is no longer sufficient for the tower base flange area as engineering demands increase. Higher initial strength development, earlier fastening/tensioning of anchors, ultra-high final strengths and the inclusion of metallic aggregate for the best fatigue resistance are all now essential elements to avoid early grout failure and ensure maintenance-free operation over the entire designed lifetime of the wind turbines.

To this end, BASF has developed an ExagROUT specifically for the installation of onshore wind towers, combining its existing specialist grout experience with the latest plasticiser technology, and the company's nanotechnology used in formulations for cementitious mortars. The result – MASTERFLOW® 9300 – combines BASF's offshore wind turbine grout formulation with a proven metallic aggregate that provides added toughness and energy absorption:

- Standardised and safe design process
- Universal product application due to high ultimate strength and thickness range
- Warranted/certified material
- Guaranteed installation quality with licensed contractors
- Application at low temperatures ($\geq +2^{\circ}\text{C}$)
- Minimises application/curing failures and increases safety
- Perfect filling and volume-stable best-in-class durability
- Zero autogenous shrinkage; no need for permanent post tensioning of tension bolts
- Excellent fatigue resistance and high modulus of elasticity absorbs dynamic loads
- Reduced maintenance and failure risk
- High impact resistance
- Very low water/cement ratio for low porosity and long-term durability
- Can be used as bedding and anchoring grout in a single application



Hardened **MASTERFLOW 9300**® ExagROUT & pre-stressed bolts



Performance Admixtures

Strong and durable foundations that can resist overturning forces are essential for all wind towers and concrete is the ideal material: flexible and adaptable, it can be designed to meet the increasing demands of onshore foundations as taller turbines increase the size of the foundations required:

- In-situ construction
- Concrete base solutions meet all requirements
- Economical, high-performance material
- Low maintenance, dynamic performance
- Sustainable

Meeting the minimum strength and rotational stiffness required and providing resistance to fatigue damage are all critical in combating the internal forces within the foundations caused by shear and dead loads. A further consideration as towers increase in size and height is the additional strain this places on the concrete: here, varying concrete strength options utilising admixtures should be considered to avoid premature fatigue.

The use of BASF's admixtures can be tailored to achieve the best concrete mix for the foundation design and geotechnical conditions, whilst minimising the CO₂ footprint of the concrete. Our range of superplasticisers, curing agents, release agents, air entraining agents, accelerators and corrosion-inhibiting admixtures provide the flexibility for material innovation to address these challenges whilst increasing productivity and delivering whole-life cost benefits.



Concrete being poured into on shore foundation



Concrete foundation ready to install turbine



Erecon Concrete Tower Foundation



The Concrete Tower

During the lifetime of the wind farm, wind turbine installations must withstand enormous vibrations, torque and wind power. BASF's systems can help to ensure that wind turbine towers remain fit for purpose for many years.

Admixtures for Precast and Slipform Structures

Research has shown that concrete can provide significant cost savings over steel in the construction of large diameter towers and offers a low-maintenance option long term.

BASF admixtures can be used to deliver a number of properties, depending on the appropriate construction method:

- Accelerated precast production using less energy
- Faster curing cycles for slipform structures
- Strong and durable concrete
- Corrosion-inhibiting systems for maximum protection
- High-performance integral waterproofing systems

Increasing Precast Productivity

Driven by improving precast processes, product durability and aesthetics, our precast admixture solutions increase productivity and quality. BASF's breakthrough Zero Energy System™ optimises the energy needed for precasting, using the Glenium® ACE molecule to create Rheodynamic™ concrete.

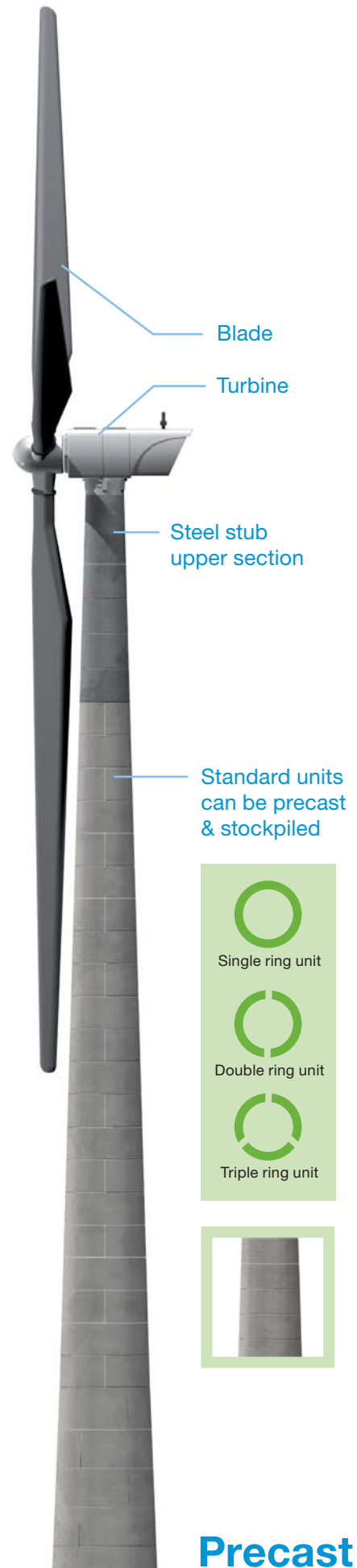
This optimised self-compacting mix has exceptional placing characteristics and accelerates hydration for high early strength. The Zero Energy System™ assists productivity by speeding up curing without the need for external heat. Further energy reductions are gained as mechanical vibration is also eliminated.

Improving Precast and Slipform Efficiency

BASF's newly developed Crystal Speed Hardening concept uses new concrete hardening accelerator X-SEED® to significantly speed up concrete curing at early ages (6-12 hours), supporting at least double strength development at low, ambient and heat curing temperatures.

As well as contributing to faster working for both precast and in-situ operations, it also addresses the key issues of energy demand reduction (lower carbon dioxide emissions), material optimisation and high quality specifications by providing high early strength development whilst balancing the requirement for an optimum mix through the use of more binding material and reduced clinker content.

In contrast to traditional acceleration methods such as heat application or normal chemical accelerators, X-SEED® does not interfere adversely with the final engineering properties of the concrete.



Precast

Integral Waterproofing

BASF's RheoFIT® admixture can be used for permanent integral waterproofing. Suitable for offshore concrete towers, this water-resisting admixture produces dense, structurally sound reinforced concrete for marine structures subject to tidal and wet/dry cycling.

Corrosion Resistance

BASF's Rheocrete® admixture can be used for elements requiring corrosion protection against chlorides from marine exposure. Rheocrete® admixture also inhibits the potentially corrosive effects of chloride-bearing ingredients used in the manufacture of concrete.

Protecting Concrete

Untreated concrete is vulnerable to the damaging ingress of carbon dioxide, chlorides and water. This can lead to structural damage and safety issues. BASF Construction Chemicals offers the MASTERSEAL® range of protective coatings, which can address these problems and give long-term structural protection from environmental damage.

If remedial work becomes necessary to ensure the longevity of concrete towers, our high-performance EMACO® repair products are suitable for the most demanding environments, and cracked concrete foundations can easily be structurally retrofitted with Concessive injection systems.

Protecting Steel

In engineered steel constructions such as wind turbines, with maintenance periods of up to 20 years, the requirements on corrosion resistant coatings and their durability are extremely high.

Whether permanently standing in the water or in splash zones offshore, every single component undergoes constant mechanical exposure, pressure and abrasion. Onshore, the mechanical forces are still extreme. BASF's RELIUS coatings have been developed to meet these critical challenges.



Additional BASF Products

BASF's technology extends beyond the base structure to support rotor blade manufacturers by supplying innovative epoxy resin systems for highly resilient, fibre-reinforced components as well as highly specialised protective coating materials for rotor blades.

Systems for Rotor Blades

Ever larger rotor blades, up to 60 metres long, are constantly increasing the power output of modern wind turbines. These huge rotor blades are exposed and subjected to enormous dynamic stress. The use of BASF's chemistry with its novel epoxy resin and hardener systems can help to cut blade production time by as much as 30%, one more way to relieve the pressure on the supply chain and lower the production costs of wind turbines.

BASF supplies two-component systems under the Baxxodur® brand, consisting of epoxy resin and hardeners for rotor blade production.

Coatings

To resist climatic conditions such as wind and water, UV-rays, erosion and flexural load, all materials have to be made to the highest requirements; at the same time, functionality and ease of maintenance are essential for wind turbines' effectiveness and profitability. RELIUS coating systems are available for all components, from the base to the rotor blade edge, and are characterised by the highest weather and corrosion resistance, excellent elongation and tensile strength and cost-effective production.

Polyurethanes

Polyurethane solutions from BASF (PU foams) include solutions for stabilising rotor blades, basic materials for formulating PVC foams and special PU-based adhesives for blade production – all systems being supported by many years of expertise in these fields.

Case Studies/Technical Information

Rødsand 2 Offshore Wind Farm

The Rødsand 2 Offshore Wind Farm has been built between Nysted Havmøllepark, Gedser and Rødby in the south of Denmark, on a site extending over 34 square kilometres. Gravity base foundations (GBFS) were installed in five rows of 18 in 2009 and 2010. The Siemens wind turbines, each 115 metres high, were installed on top of the GBFS at a rate of up to one a day. Grouting the cavities between the wind turbine and the concrete gravity foundation was done at a record speed of up to three installations per day.

Rødsand 2 consists of 90 wind turbines with a total output of 207 megawatts and will produce 800 million kilowatt hours a year and supply 200,000 households with electricity.

“Everyone in the project can feel proud that they have delivered what is the second largest wind farm in the world, three months ahead of schedule and within the planned budget,” said Anders Ljungman, E.ON Vind's project manager^[1].

Client:	E.On Sweden
Foundation manufacturer:	JVAB
Foundation type:	Gravity base
Wind turbines:	Siemens SWT-2.3-93
Number of turbines/foundations:	90
Grouting material:	MASTERFLOW® 9500
Licensed grouting contractor:	Østermark Entreprenørforretning A/S

^[1] E.ON, The Rødsand 2 Wind Farm, (<http://www.eon.se>, 23rd September 2010)



Case Studies/Technical Information cont.

Arecleoch Onshore Wind Farm

Arecleoch Wind Farm is Scotland's fourth largest Wind Farm and produces 120MW of power through its 60 turbines, or enough for about 70,000 homes. The £42M Wind Farm Project was a huge logistical challenge. The site lies within 24 sq. km of commercial forest plantations, the majority of which is Forestry Commission land leased by the client, ScottishPower Renewables, for the 25 year design life of the Wind Farm. Approximately 617 hectares of trees were felled throughout the construction, initially to clear the way for the 65km of access roads and the 60 turbine locations themselves. The second phase of forestry works cleared over 450 hectares of the remaining trees.

At first there was only a single access to the site through a 2.5m wide stone railway arch with the main railway line from Stranraer to Ayr running overhead. Access and deliveries were monitored by Network Rail to ensure no damage occurred to the arch structure. Having negotiated this, a further 2.5 miles of stone track were added to reach the site compound. To alleviate this and provide an access route for turbine deliveries, a new railway overbridge was constructed at a different location along the main access road. This upgraded a 20km stretch of the existing forestry road network and all turbine component deliveries used the route to avoid passing through the local village of Barrhill and under the railway.

The 70,000m³ of stone required for the access roads came from quarries on site: the number and location of these borrowpits were carefully planned to ensure the most efficient balance of haul distances against development costs. Most of the roads were of a 'floating' construction due to the very low bearing strength of the peat. An 800 mm thick sandwich of high strength geogrid and stone provided a running surface capable of withstanding 45 HB loadings on a subformation with CBRs as low as 0.5%.

All the concrete for the project came from local supplier Barr Limited, at the height of the project supplying over 1000m³ of concrete a week. This enabled the site team to pour three of the 350m³ reinforced concrete foundations each week.

Due to the environmentally sensitive nature of the location, the site team and subcontractors became very environmentally aware. Stringent planning conditions regarding issues such as pollution prevention, ecology and archaeology resulted in the evolution of environmental procedures and monitoring, with valuable experience and lessons being learned for future projects.

Client:	ScottishPower
Renewables Value:	circa. £42M
Principle Contractor:	Farrans
Designer:	Grontmij
Environmental Consultant:	McCloy Consulting
Wind turbines:	Vestas V90-3.0MW
Number of turbines/foundations:	60
Concrete Supplier:	Barr Limited
Concrete Volume:	circa. 21,500m³
Admixtures:	Glenium® 126 Masterkure® 181 Pozzolith® 100 XR



Intelligent solutions from BASF Construction Chemicals

Whatever your construction problem, whatever the structure you are building, BASF Construction Chemicals has an intelligent solution to help you be more successful.

Our market leading brands offer the widest range of proven technologies to help you build a better world.

Emaco[®] - Concrete Repair Systems

MBrace[®] - Composite Strengthening Systems

Masterflow[®] - Precision and Structural Grouts

Masterflex[®] - Joint Sealants

Masterseal[®] - Coatings and Waterproofing

Concresive[®] - Crack Injection Resins

Conideck[®] - Hand and Spray applied Waterproof Membrane Systems

Coniroof[®] - PU Based Roofing Systems

Mastertop[®] - Decorative and Industrial Flooring Solutions

Ucrete[®] - Flooring Solutions for Harsh Environments

Glenium[®] - Superplasticizers

RheoFIT[®] - Waterproofing Admixtures

Masterkure[®] - Curing Compounds

Rheofinish[®] - Release Agents

MEYCO[®] - Shotcrete and Spraying Equipment

Micro-Air[®] - Air-entraining Agents

PCI[®] - Tile Fixing, Cement Underlays and Waterproofing Systems

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About BASF

BASF is the world's leading chemical company: The Chemical Company. Its portfolio ranges from chemicals, plastics, performance products and agricultural products to oil and gas. As a reliable partner BASF creates chemistry to help its customers in virtually all industries to be more successful. With its high-value products and intelligent solutions, BASF plays an important role in finding answers to global challenges such as climate protection, energy efficiency, nutrition and mobility. BASF posted sales of about 63.9 billion in 2010 and had approximately 109,000 employees as of the end of the year. BASF shares are traded on the stock exchanges in Frankfurt (BAS), London (BFA) and Zurich (AN). Further information on BASF is available on the Internet at www.basf.com or in its Social Media Newsroom at newsroom.basf.com.

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