

Three production halls for Fehmarnbelt Tunnel Factory

Denmark's largest infrastructure project and the longest immersed tunnel in the world.

We designed and build three production halls in close cooperation

Three production halls, totaling 76,800 m2 were constructed at the construction site in Rødbyhavn. The factory comprises a total of six production lines spread across these three halls:

The Rebar Hall, The Casting Hall, and the Curing Hall. Here, FLC will reinforce, form, pour, and cure the segments for the tunnel.

The tunnel element factory commenced production of the first elements at the beginning of 2023. The tunnel of the Fehmarnbelt connection is expected to be completed in 2029, shortening the travel time between Scandinavia and the rest of Europe.

Give Steel A/S built the production halls for FLC*, who supplies the production buildings for project owner Femern A/S.

In addition to the steel construction, which comprises more than 10,000 tons of steel, Give Steel has delivered and installed approx. 146,000 m2 facade and roof structures.

In 2020, **KI Rådgivende Ingeniører** entered into an agreement with Give Steel to develop the structural design for the new tunnel element factory halls.

KI has been involved from the very beginning and, in close collaboration with Give Steel, developed the structural system and the bidding model for the tender.

THE PROJECT

Danish state-owned Femern A/S is the project owner of the Fehmarnbelt tunnel.

Construction year:	2021-2023					
Project owner:	FLC, who builds for Femern A/S					
Project:	3 production halls					
Location:	Rødbyhavn, Lolland, Denmark					
Construction company: Give Steel A/S						
Structural Engineering: KI Rådgivende Ingeniører Ap						

* Femern Link Contractors (FLC) is a Joint Venture company which is responsible for the design and construction of the production halls for the Fehmarnbelt Tunnel.

The Femern Link Contractors (FLC) consortium is comprised of VINCI Constructions Grands Projects (France), Aarsleff (Denmark), Max Bögl Stiftung & CO KG (Germany), BAM Infra B.V (the Netherlands), BAM International B.V (the Netherlands), Wayss & Freytag Ingenieurbau AG (Germany), Solétanche-Bachy International S.A.S (France), CFE SA (Belgium) and Dredging International NV (Belgium).



From concept to reality



- Re-bar area
- Casting area
- Curing area





From concept to reality





From concept to reality



From concept to reality

- 3 Steel halls
- Tender design
- Winner strategy: Simple design!



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Engineering

Why is that important?

- The structure is (essentially) simple
- Loaded by few basic loads, but <u>many</u> combinations
- Easy to lose the overview in a large global model
- Excessive calculation time
- Difficult to manage changes and understand the basic structural load path.

	<u>Sir</u>	Simple Load Cases					
		Case	Label	Case name	Description		
Deadlaad		101	Gk.sup	Gk.sup	Selfweight - Sup		
Dead load —		102	Gk.inf	Gk.inf	Selfweight - Inf		
(2 pcs.)		201	W0k.s1	W0k.s1	Wind North - Suction - Case 1		
		202	W0k.s2	W0k.s2	Wind North - Suction - Case 2		
		203	W90k.s1	W90k.s1	Wind North - Compression - Case 1		
		204	W90k.s2	W90k.s2	Wind North - Compression - Case 2		
		205	W180k.s1	W180k.s1	Wind East - Suction - Case 1		
		206	W180k.s2	W180k.s2	Wind East - Suction - Case 2		
		207	W270k.s1	W270k.s1	Wind East - Compression - Case 1		
Wind load		208	W270k.s2	W270k.s2	Wind East - Compression - Case 2		
		209	W0k.c1	W0k.c1	Wind South - Suction - Case 1		
(16 pcs.)		210	W0k.c2	W0k.c2	Wind South - Suction - Case 2		
		211	W90k.c1	W90k.c1	Wind South - Compression - Case 1		
		212	W90k.c2	W90k.c2	Wind South - Compression - Case 2		
		213	W180k.c1	W180k.c1	Wind West - Suction - Case 1		
		214	W180k.c2	W180k.c2	Wind West - Suction - Case 2		
		215	W270k.c1	W270k.c1	Wind West - Compression - Case 1		
		216	W270k.c2	W270k.c2	Wind West - Compression - Case 2		
		301	Sk.undrifted	Sk.undrifted	Snow - Undrifted		
Snow load		302	Sk.drifted	Sk.drifted	Snow - Drifted		
		303	Sk.unbal.left	Sk.unbal.left	Snow - Unbalanced left		
(4 pcs.)		304	Sk.unbal.right	Sk.unbal.right	Snow - Unbalanced right		
		51	T1_LC1	Crane1_LC1	Crane Type 1 - Case 1		
		52	T1_LC2	Crane1_LC2	Crane Type 1 - Case 2		
		61	T2_LC1	Crane2_LC1	Crane Type 2 - Case 1		
		62	T2_LC2	Crane2_LC2	Crane Type 2 - Case 2		
		71	T3_LC1	Crane3_LC1	Crane Type 3 - Case 1		
	•	72	T3_LC2	Crane3_LC2	Crane Type 3 - Case 2		
Crane loads		81	T4A_LC1	Crane4A_LC1	Crane Type 4A - Case 1		
(14 pcs.)		82	T4A_LC2	Crane4A_LC2	Crane Type 4A - Case 2		
		83	T4A_LC3	Crane4A_LC3	Crane Type 4A - Case 3		
		84	T4A_LC4	Crane4A_LC4	Crane Type 4A - Case 4		
		91	T4B_LC1	Crane4B_LC1	Crane Type 4B - Cas		
		92	T4B_LC2	Crane4B_LC2	Crane Type 4B - Case		
		93	T4B_LC3	Crane4B_LC3	Crane Type 4B - Case 3		
		94	T4B_LC4	Crane4B_LC4	Crane Type 4B - Case 4		
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Basic concept



Simplicity is the key

Simplicity requires discipline

- The building is designed as a series of 2D trusses and frames!
- Global 3D FE-model to verify structural design
 Not dictate the design
- When the 3D model deviates from the 2D design -> explanation





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Give Steel



Simplicity is the key

Main trusses

- Designed as 2D frames
- Moment stiff corners
- Clamped at the base
- Maximize frame stiffness without vertical bracing



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Main columns

- Initially designed as "airport" columns.
- Instability (torsional and flexural / LTB) led to uneconomical design
- Welded RHS columns
- <u>Clamped at the base !</u>



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Simplicity is the key

Crane girders

- Designed as 3D truss elements to enhance the "out-of-plane" stiffness
- Output (reactions) as input (loads) to structural model (global 3D model)



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2x Type 3 Simultaneous lift

12

1x Type 4

1x Type 4

3-2-

3x Type 2 Simultaneous lift

3x Type 2 Simultaneous lift 3x Type 1 Simultaneous lift







Final design





Engineering and fabrication

Devil in the detail

- Many considerations regarding details
- Coordination between design, fabrication, management and erection
- How to detail +10,000 t. structure and satisfy all stakeholders?
- Structure, discipline and committed involvement
- Simple flowchart for detail design





Engineering and fabrication

Devil in the detail

Activity	Phase	Deliverable
Connection design for review	Concept	Design meetings
Final concept drawing submit for approval	Concept	DWG drawing (FI - date) / printed sketch (FI - date)
Feedback from production and erection team	Feedback	Annotated sketches
Concept design frozen	Feedback	Design meetings
Connection design for review	For construction	DWG drawing / RxA Printed sketches / RxA
Internal QC of connection	For construction	QC comments
QC comments implemented "for construction"	For construction	DWG drawing / Rxx Printed sketches / Rxx
Calculation note for connection	For documentation	Report / RxA
All connections gather in report	For documentation	

Trusses









The Fehmarn project is Give Steel's biggest mega structure to date, with a delivery of 180 tons of steel structures every week in 2022.







BIM technology



Construction and lifecycle





CDE Platforms "Single source of truth"

CDE Platforms, BIM technology, construction and lifecycle

Give Steel was not only the steel supplier, but also the General Contractor of the production halls.

The responsibility for other branches led us to use the **CDE Platform** which was crucial for storing all the documentation in one place.

Each of the platforms have specific options that are required at various stages of the project.

- This type of solution is an integral part of megastructure realizations.
- Drawings, details, 3D models, specifications, and reports were all reviewed and replaced on the server, instead of being sent via email.
- This ensures that all parties always have access to the latest available version of the document.
- This solution is referred to as the "Single source of truth."



BIM and structural design

Planning and 3D modelling

For two years, Give Steel and KI Rådgivende Ingeniører delt with planning, designing, production, and assembly of the Fehmarn Production Halls.

Today's technology and BIM tools offer fantastic possibilities for managing and designing structures.









BIM is much more than a 3D model



Coding the model

For civil engineers, BIM modeling is often associated solely with 3D modeling. However, software that utilizes BIM technology offers many more possibilities for sharing information within 3D elements.

Through a combination of letters and numbers, design and checks assembly become easier and faster.







BIM & Structural Design

Connections and clash checks

Collision or not collision? That is the question...

The greatest advantage of 3D modelling is the ability to perform clash checks on the models.

This step in the design process significantly impacts the improvement in quality and reduces the number of collisions encountered on the construction site.



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Hall A, B and C

The Rebar Hall, The Casting Hall and the Curing Hall

Dimensions

The project comprises two identical halls and one smaller hall.

Roof structure

The roof structure consists of both main and secondary trusses

Mega doors

One of the **main challenges** was designing the support structure for the **mega doors** through which the finished tunnel elements will exit the halls.

Innovative columns have been designed at the gate locations, which will be lifted during the opening process.





Assembling of the structure

or the structure

Digital documentation and QR codes

- Megastructures require special assembly techniques. Give Steel was responsible for the erection of the load-bearing structure.
- During the process, the crew relied on digital documentation as their primary source for connection details, utilizing both drawings and 3D models.
- Furthermore, all elements produced by Give Steel are equipped with a sticker containing a QR code at the very beginning of the production stage.
- Scanners are used on a daily basis to track the production and painting statuses, and they are also employed during transportation and by the installation crew.
- The combination of these two solutions has made the assembly process smooth and straightforward for the installation team.











Main columns and cranes

Trusses

• The column is the load-bearing steel construction in rebar area, which carries the roof structure and the cranes.







Cranes







Our celebration of the last main column was not approved...



The last main column was driven from Give Steel's factory in Brande to Fehmarn's construction site in Rødbyhavn. At Give Steel's production in Brande, the last column was marked with a small Danish flag, to mark the day internally.

53 Main columns Weight: 21 t. Hight: 27,4 m.

Facades

Give Steel delivered approx. 146,000 m2 facade and roof structures

- Give Steel not only produced and installed the large steel structure.
- Give Steel also was responsible for delivering the roof, facades and several other specialist contracts associated with the project.

Stone wool insulated sandwich panels were chosen for several reasons:

- Designed for demanding environments, the smart panel solutions, with their core made of stone wool, deliver optimum thermal performance and fire resistance.
- The modular and dry nature of sandwich panels enabled **rapid construction** at the project's start.
- The insulation will prevent the loss of temperature to optimize the concrete curing process and therefore maximize the tunnel's strength and water seal.



Roof and facades









The three factory halls are covered with sandwich panels up to a height of 30 meters, a roof and facade solution so extensive that it has established the foundation for Give Steel's own facade department.

Social responsibility

The Femern contract creates jobs and apprenticeships for disadvantaged young people in Jutland.

- When you undertake such a large project, it comes with responsibilities. Through this project, we have had the opportunity to make a social impact.
- In connection with the contract, Give Steel has agreed with Lolland Municipality to establish apprenticeships for disadvantaged young people in Lolland Municipality, so that they can receive an education at our factory in Brande.
- A busload of young people from Lolland visited Give Steel in Brande. The visit aimed to show the young people from Lolland the opportunity to pursue a blacksmith apprenticeship.
- Give Steel has had positive experiences in providing young people on the edge of the job market with an opportunity for education – it's part of our DNA.

In the most significant construction contracts with Femern A/S, a specific number of apprentices have been stipulated as a requirement.

This has been implemented through specific targets for apprentices in all relevant bids and contracts.

Each month, the number of hours worked by apprentices and social employments on the project was reported, which was a contractual obligation.



