New Terminal Building, Billund Airport, Denmark

Kjeld Thomsen, Man. Dir., Hilmer Jung Larsen, Assoc., Helge Skov Pedersen, Assoc., Bjarne Ibsen, Assoc.,
ISC Consulting Engineers A/S, Copenhagen, Denmark

Introduction

Billund Airport located in Jutland, is the second largest commercial airport in Denmark. The airport was established in 1964 in collaboration between a Danish toy manufacturer – and the county, town and parish councils. Steady growth in traffic from 50000 passengers in 1965 to around 1.6 million in 1995 has been met by many extensions of the existing passenger and cargo facilities south of the single runway (Fig. 1).

In the mid-1990’s the Management decided to establish a new passenger terminal north of the runway and in 1997 five teams of Danish and international architects and engineers were selected to submit their proposal for the new terminal, based on the Owner’s detailed requirements.

In the competition phase, a number of alterations to the Owner’s tender programme were introduced in order to improve the logistics in the passenger handling and in the baggage handling.

The design presented in this article met all the fundamental requirements of the Owner.

The detail design phase started in January 1999, the construction on site started in October 1999 and the inauguration was in May 2002.

Master Plan

The new terminal building is situated north of the existing runway, which is oriented strictly east-west. The area for the airport and its future extension is just west of the frontier formed by the inland ice during the last glacial age resulting in a soft sloping moor with scattered plantations of mainly pine and fir alternating with cultivated fields surrounded by live windbreakers.

The full extension of the master plan implies a second runway north of and parallel to the existing runway with a U-shaped apron and corresponding U-shaped terminal complex between the two runways.

The central axis in the “U” forms the future transportation corridor for both the main road connecting Billund Airport to the motorway system and for a possible train connection to the main railway system.

The concourse of the first phase of the terminal building forms a straight line for the first 10 aircraft stands and lounges. Hereafter the concourse for the subsequent stands and lounges describes the start of the semicircle defined by the position of the future second runway and the future terminal buildings.

The central area is reserved for parking – on ground as well as in a multi storey parking complex – and a future railway station with easy access to both passenger terminal areas.

The area west of the U-shaped central area is reserved for a variety of primarily technical activities related to the airport such as maintenance and general aviation services.

The first phase of the extension of the airport is designed for 3.5 million passengers annually and comprises a terminal building with an area of approx. 16000 m² and a total floor area of 43000 m² and an apron of approx. 100000 m².

Architectural Design

The architectural design (Fig. 2) is characterised by logic clearness obtained by:
- few levels
- a strict but flexible plan layout
- a plain section.

The main elements of the architectural design are:

The Wall, forming the noise reducing backbone of the concourse and lounges and separating landside from airside. The Wall ends in the two buildings forming the gables of the terminal building. It is made of concrete elements and absorbs the difference between the levels in the dividing line between landside and airside.

The Anchor, which is a number of in-situ concrete structures at the entrance front fixating the roof structure.

The Plinth, being the main floor of the terminal building in level with the entrance landside but one level up relative to the apron making the most of the slope of the landscape. The Plinth is tiled with marble reaching from the landside entrance to the concourse and lounges in level 1. It is the base level for the lower hinge link of the columns supporting the roof structure.

Fig. 1: Aerial view of terminal building
The Rafts are the inserted balconies in two levels in the central hall. The Rafts form the floors of a number of the terminal's functions and appear as homogeneous structures floating in space.

The Shield, being the large single-curved roof structure that in one snatch spans the entire terminal area. The Shield is designed with skylights alongside the main steel girders thus illuminating the structures, giving general daylight in the central hall and offers the possibility of views to the sky, the clouds and the aircrafts. On the inside the Shield appears as corrugated steel sheeting. In areas with mechanical installations and over the Rafts and the building structures at the gables, plane acoustic ceilings are suspended below the steel sheeting.

The Gateway, the space between the Wall and the Shield forming the visual and functional link between the moor and the airport - between landscape and airside. The Gateway as a theme underlines the terminal as a building where the change between two ways of transportation is made with as few stops as possible.

The terminal building itself is designed logically and easy-to-perceive for all categories of passengers enabling them to choose between a direct - and hence fast - route through the terminal or to spend time in the variety of different shopping facilities or to relax in the restaurants.

The interior as well as the exterior appears in modern Scandinavian style in light colours with an extensive use of wood and glass.

Superstructure

The structural system has been adapted to suit rectangular plane shape of the terminal core as well as the flight wing shape of the cross section. The core has a total length of 150 m consisting of 7 modules of 21 m and cantilevered ends (Fig. 3).

The main girders in the roof structure consist of twin steel plate girders in mutual distance of 3 m. The distance between the twin girders is 21 m centre to centre. The building has a maximum width of 90 m. The structure is divided in a 72 m span with intermediate columns in distances of 18 m and "flaps" of a width of 18 m lowered approximately 5 m towards the apron.

The twin main girders have a circular shape with a radius of 238.6 m and are supported by radial positioned columns with footing in a mutual distance of 18 m. The twin plate girders have a constant depth of 1.3 m in the whole length, except for the 4.5 m cantilevered parts where the height is reduced from 1.3 m to 0.5 m towards the edge of the building. The web thickness is 10–12 mm and the flange width is 300 mm and 20 mm thickness. The girders are interconnected with diaphragms above the column supports.

The roof cover consists of aluminium sheets supported on insulated corrugated steel sheets. The sheets are rolled in full width of the building without any transverse joints. The corrugated steel sheets are supported on 18 m long laminated timber purlins with a depth of 1 m and a width of 180–220 mm.

The horizontal stability of the sections between the purlins and the main girders is provided through diaphragm action in the roof cover.

Two lattice girders have been arranged in the roof plane between neighbouring main girders with mutual distance of 18 m from façade to façade. These lattice girders consist of crossing diagonals in tubular members and the main girders as flanges. The lattice girders are located in the second module from the gables.

The roof's main girder sections are stabilised horizontally by means of support to the two roof trusses through the diaphragm connections above the columns and intermediate tubular connections midway between the diaphragms (Figs. 4 and 5).

Horizontal load on the gables is transferred through the roof plane to the concrete foundations providing vertical and horizontal support for the main girders at the entrance facade and to the concrete buildings located at the gables inside the terminal building.

Tubular V-shaped twin columns with a diameter each of 323.9 mm and 12 mm thickness provide the support for the main girders. The columns are provided with plate cross footings tapered towards the bearing at the base. They are connected to the same base socket on a common pin and at the top of the column bolted with a butt joint to the bottom flange of the main girders.

Fig. 3: Cross-section in terminal building system
the floors of the two storey building and partly of fire insulation of the individual elements meeting the fire code requirements.

The main columns have F60 fire paint cover whereas the floor beams and the columns in the two storey buildings are insulated by fireboards to F60 respectively.

All 10 lounges are provided with a 14 m long fixed bridge part and a moveable part to allow direct access to the aircraft. The bridges are designed as simple supported lattice box girders with a depth of 3 m and width of 2.5 m.

The apron tower located in the centre front of the concourse façade is designed as a braced frame steel structure.

**Substructure**

The substructures for the new terminal building consist of 7500 m² in-situ cast concrete and 15,000 t of precast concrete elements. All foundations for the substructures are founded directly on the soil.

In general, the main substructure of the terminal building consists of precast concrete element structures, comprising 10,000 m² pre-cast hollow concrete deck elements with a thickness of 270 mm in a 9 m span. The deck structure is split up into three separate diaphragms making the entrance floor (the Plinth) in the terminal building. The concrete deck elements are supported on 870 mm high precast and prestressed concrete beams in a 10.5 m span supported on corbels on precast concrete columns. The column has a square cross section with dimension of 480 x 480 mm and compression strength of 45 MPa. The precast square columns further support the V-shaped twin steel columns carrying the superstructure for the interior decks.

The horizontal stability is provided by the eight in-situ cast concrete cores (the Anchors) and through diaphragm action to the anchors in the precast hollow concrete deck.

Below the entrance floor, the concrete substructure comprises an approximately 5 m high cellar under the entire terminal building, containing installations for building services and the baggage handling system. A 5 m deep and 6 m wide ventilation tunnel, with a total length of 150 m, absorbs the 5 m level difference between airside and landside. Internal deck diaphragms in the tunnel structure transmit the earth pressure to the eight in-situ cast concrete blocks.

The in-situ cast concrete anchors are cast out with mass concrete below the entrance level in order to provide a sufficient anchoring against overturning and sliding. Each anchor structure has a total concrete mass of 450 t founded on 800 mm thick rectangular concrete base plates with the side lengths of 7.1 m x 10.5 m.

Inside the terminal building two three-storey prefabricated concrete buildings are forming the east and west gables. These buildings have a width of 12 m and a total length of 80 m.

Outside, the gables in the terminal building and the substructures for the concourses continue east and west, comprising the concrete structures for the access from airside apron to the bus lounges in the cellar level. A 5 m tall retaining wall absorbs the difference in levels between the apron airside and the landside.

In-situ cast concrete structures which make up the decks, beams and columns, provide the substructure for lounges at cellar level and supports the superstructures for these lounges.

All foundations are cast in-situ and are founded directly on the existing soil or on improved soil consisting of compacted gravel. Due to the presence of fat clay in some areas below the foundations 30,000 m² have been excavated and replaced with compacted gravel in varying thickness up to 5 m in order to minimise the difference in settlements.

**Fabrication**

The superstructures for the new terminal building have a material consumption of 1500 t of structural steel, 6400 m² lightweight concrete element deck, 550 m² laminated timber purlins and 17,500 m² corrugated steel sheets.

The steel structures are generally built up of transportable sections joined by means of bolted joints. The fabrication of all steel structures took place in a workshop in Poland. The structural elements were delivered from the shop on trucks just in time for erection, corrosion protected with final paint system inclusive fire paint protection for selected elements. All primary structures, main roof girders, tubular columns and the two internal floor structures are fabricated in steel S235.
except bearing parts which are in steel S355. Bracing and secondary structures are mild steel S235.

The fabrication of primary steel structures started in April 2000 and was finished in September 2000.

The lightweight concrete decks are built up by 1.2 x 4.4 m prefabricated 180 mm thick slab sections joined to establish overall diaphragm action in the floors.

The laminated timber purlins 180–220 x 1000 mm, 18 m long were fabricated in Denmark. They were delivered to the site with predrilled holes for the joints and camber from 80 mm to 120 mm.

The load carrying part of the roof cover consists of 127 mm deep corrugated steel sheets fixed to timber purlins. The top cover of aluminium sheets 0.7 mm thick was rolled on site in continuous length corresponding to the width of the building.

**Construction**

The terminal building was erected using three tower cranes. One rail-running tower crane along the northern facade, one rail-running tower crane along the southern facade and one fixed tower crane located at the centre in a provisional hole in the deck structure above the cellar.

The mounting started with the three-storey concrete buildings along the terminal gables. The steel superstructure was mounted from the gables towards the centre where an expansion joint is provided transverse to the building.

The first two rows of columns were erected and fixed provisionally by steel wires until the two plate girders with laminated timber purlins and wind-bracing were brought in place and fixed to the concrete anchor blocks. The two rows of columns and girders outside the concrete buildings were erected and connected to the braced structures by the laminated timber purlins. The roof cover mounting was started while the erection of the columns, girders and laminated timber purlins above the central hall continued towards the centre.

The erection of the primary steel structures began in June 2000 and the steel structure was completed in November 2000. The complete terminal structure was ready for interior installation works in February 2001.

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**SEI Data Block**

**Owner:**
Billund Airport Ltd, Billund, Denmark

**Architect:**
KHR A/S Architects, Virum, Denmark

**Consulting engineer:**
ISC Consulting Engineers A/S, Copenhagen, Denmark

**Contractor:**
MT Hoejgaard A/S, Denmark (civil works), Copenhagen, Denmark

**Subcontractor:**
J. Bladt A/S (steel structures), Aalborg, Denmark

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