Structures Subjected to Extreme Natural and Man-made Hazards: an Introduction

On the 1st of November 1755, a terrible earthquake destroyed almost totally the town of Lisbon and killed 60,000 people. In his celebrated Cándido (Translation from the French by Robert Bruce Boswell – Chapter VI), Voltaire evokes this disaster as follows:

After the earthquake, which had destroyed three quarters of Lisbon, the wise men of the country had found no means more effectual for obviating total ruin than that of giving the people a fine auto-da-fe; it was decided by the university of Coimbra that the spectacle of a few people roasted at a slow fire, with grand ceremonies, is an infallible specific for preventing earthquakes.

Fortunately, such ways of thinking have progressively disappeared and been replaced by more effectual means for avoiding disasters since this auto-da-fe, which took place on the 27th of June 1756, about 250 years ago.

Though it will always be impossible to prevent extreme natural hazards from occurring, earthquakes, hurricanes, strong waves, floods, ice storms, landslides, avalanches, environmental changes and the like are now carefully studied and monitored, giving Engineers the feedback necessary to design structures able to resist these events as much as possible.

Despite the remarkable progress achieved in the last decades with the development of powerful tools to perform sophisticated dynamic structural analyses and the dissemination of voluminous specific building codes, design philosophy must be further developed in order to better gauge feasibility and acceptable damages.

In addition, recent events have shown that man-made disasters can be as unpredictable as natural disasters; fire, explosions, impacts and shocks, nuclear power plant accidents, not to mention human errors in the design of temporary or permanent structural stages, must be taken into account if we are to progress.

In this context the structural Engineer is no longer just a Designer; rather, the structural Engineer must anticipate all risks, recommend the right structure in the right place and imagine the most convenient construction methods and devices for total confidence and safety.

The papers included in this issue of SEI are related to some recently completed structures, conceived and constructed using various means to prevent human damage and loss should one of the risks mentioned above occur. In 2005, the LABSE symposium will take place in Lisbon from September 14 to 16 to discuss the theme "Structures and Extreme Events". As Chairman of the Scientific Committee, I invite all of you to participate and contribute your experience, that we may join forces to anticipate the unthinkable.

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North River Bridge, Thule, Greenland

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Introduction

The new North River Bridge is supposedly the most northerly built road bridge of its size at the latitude of 77° N. The North River is located in a high rocky arctic environment and runs parallel with the runway in Thule Airbase, Greenland. The Airbase is divided by a canyon running parallel to the runway over a distance of about 400 m to 600 m called the North River. The canyon is water-filled in the short summer period and has a low, frozen water level in the long winter season running from October to June. The bridge replaces a shorter 23 m span truss bridge.
which was destroyed in August 2001 when heavy rain and melt water from the ice cap caused sudden flooding of the river. It eroded the backfill at the abutments of the existing bridge and left an existing lattice girder of 23 m span half way tilted and unstable in the riverbed. A study showed that it was not feasible to repair the deformed two-lane bridge structure not least because safety considerations indicated that the natural riverbed profile should be restored in the bridge line. This required a total bridge length of about 60 m including removal of the 20 m long embankments to restore the original shape of the river cross section. It was therefore decided to construct a two-lane road bridge with 60 m span (Fig. 1). The construction season in the arctic region is only 4 months from June to mid-September, while completion work can take place from mid-September to October. Snow storms and temperatures below -20°C can already be expected in October.

The bridge structure consists of two 5 m tall Warren-type trusses carrying the 8.4 m wide bridge deck. No lattice bracing is arranged between the top flanges due to client requirements, leaving the 54 m top flange length unsupported apart from elastic supports provided by restraints from the transverse floor beams. The bridge deck consists of timber oak beams transversely prestressed together by means of bars forming a homogeneous slab. The timber deck is particularly suitable in a dry and cool climate (Figs. 2 and 3).

Only one or two ships arrive from Denmark at Thule every summer and all construction elements had to be shipped in 12.2 m containers. The system was therefore designed with connections for fast assembly on site, thereby avoiding welding in low temperatures.

The ship arrival season to Thule is limited to 6–8 weeks in the summer season (July, August) and left only 1 to 2 months to assemble and erect the new bridge. These facts influenced the selection of the structural concept for the bridge. Speedy assembly and installation was a mandatory requirement, which means that site welding had to be avoided. Therefore, an all bolted steel lattice girder solution with a stress laminated wood bridge deck fulfilling American Association of State Highway & Transportation Officials (AASHTO) Specification was proposed as the most feasible and adequate solution.

The detail design phase was carried out in January/February 2002. The construction contracts were entered into in May. Construction of abutments started in June and the bridge was opened for traffic in the beginning of October 2002.

Conditions in Arctic Climate

The climatic conditions in the North of Greenland have had a dominating influence on the selection of a structural concept for the bridge, selection of material and selection of assembly and mounting procedures.

From the end of September to the end of May the temperature is normally below 0°C. Snow usually starts in October and the Thule area is covered with snow until mid June. Seaway traffic is only possible in July and August as the Melville Bay is frozen up. Only one or two cargo vessels arrive from Denmark to Thule in August, a period during which the sea is free from ice.

The soil consisting primarily of weathered rock and gravel is permanently frozen which means that foundations are built on subsoil in permafrost conditions. Excavation is usually done by blasting.

The water level in the North River can be high in the summer season but is usually low and frozen from September to June.

Concrete casting can only be carried out in June, July and August.

Concrete and aggregates have to be available in June, which means that they need to be shipped the year before application. The steel material for fatigue loaded welded structures needs to have sufficient ductility at -60°C and consequently be normalised, steel of quality class:

- S355J2G3, EN10025, (ASTM A572 Gr 50) for plate thickness ≤ 30 mm and
- S355NL, EN10113, (ASTM A572 Gr 50) for plate thickness ≥ 30 mm

with supplementary requirements regarding Charpy V-notch testing down to -20°C and -40°C respectively for American Society for Testing and Materials (ASTM) specified steel.

All structural components for the superstructure had to be prefabricated to maximum 12 m lengths corresponding to the size of a 12.2 m container, and had to be loaded onto the same ship arriving in August.

The short construction season means that time consuming welding needs to be avoided.

A steel bridge concept requires limited maintenance because the humidity is generally below 40%. The speed of corrosion is therefore very slow and paint protection of steel has a long life.

Hydraulic Considerations

The natural cross section of the North River bed was reduced in width by the old bridge with embankments on both
sides of approximately 20 m length. The water flow in the river and the current speed is mostly acceptable even for the narrowed cross section. No severe erosion problems were experienced in more than 40 years. However, a sudden high melt water volume flowed out from under the ice cap in August 2002 with the water level in the North River reaching the deck level of the bridge. The strong current eroded the embankments and the backfill of the abutments resulting in a partial downfall and torsional deformation of the steel bridge superstructure. The evaluation of the accident resulted in a decision to improve the hydraulic flow by removal of the embankments abutting the bridge in order to achieve a long term and reliable solution. The bridge length consequently had to be extended to about 60 m.

Steel Bridge Superstructure

The 60.95 m long free span of the bridge superstructure consists of two 5 m high Warren type regular trusses supporting the 8,433 m wide bridge deck.

Welded I-shaped bridge floor beams connect the lattice nodes in the bottom flanges by means of rigid High Strength Friction Grip (HSFG) bolted connection, thereby forming semi rigid frames at intervals of 6.1 m. The open channel shaped cross section of the bridge is made possible due to the elastic horizontal support of the topflange provided by the half frames. A K-lattice bracing in tubular sections of 193.3 mm × 6.3 mm connects the bottom flanges below the bridge floor to a lattice girder carrying the horizontal loads to the abutments (Fig. 4).

The top and the bottom flanges of the Warren type trusses as well as the diagonals are welded H-sections with web depth 406 mm, 508 mm and 355 mm respectively. The flange width is constant at 406 mm. The flange thickness varies between 25 mm and 50 mm. Brackets for support of a fuel pipeline from the tank farm to the airport side of the river and supports for electrical power cables are cantilevered outside the trusses next to every bottom flange node.

The structure is bolted with HSFG class 10.9 bolts corresponding to ASTM 12.4 m connections. These are arranged close to the shop welded nodes thus keeping the maximum transport section length under 12.2 m.

A fixed bearing transferring only horizontal load is provided in the centre at one end of the bridge and a similar bearing carrying only horizontal load transverse to the bridge axis at the other end. Spherical sliding bearings are provided below the outer truss nodes for vertical support of the trusses on the concrete abutments.

Precamber of 150 mm was provided at the centre of the trusses corresponding to the dead load deflection and half the applied distributed load.

An interesting feature was observed following the analyses of the stability and bearing capacity of the horizontally elastic supported top flange of the truss girders. Taking into account the elastic torsional restraint in the top flange nodes as provided by the bending rigidity of the diagonals the load bearing capacity was increased by approximately 50%.

Bridge Deck

The bridge deck consists of German oak timber beams with depth 250-300 mm and width 50 mm connected transversely to a solid slab by means of 26 mm diameter bars arranged pr. 1.15 m. The transverse prestress is 0.7 Mpa on the gross section. The wood slab is bolted to the cross girders in the bridge floor arranged at a distance of 2,032 m. The wood deck was designed according to the AASHTO bridge specifications. The timber is especially suitable for this application compared to an orthotropic steel deck, partly due to the cold and dry climate and partly because of time consuming welding which is avoided. A timber deck is a durable solution as proven by the service life of more than 50 years in the old bridge.

Abutments and Retaining Walls

The abutments are constructed in reinforced in-situ cast concrete. They consist of two 1 m × 2 m shafts 4.8 m tall each founded on square slabs 4.3 m × 4.3 m and 1 m thick. The shafts support an L-shaped 2 m high concrete beam/retaining wall with wings enclosing the road ballast and providing support for the fixed bearing and the two spherical bearings. The shafts and retaining structure are provided with frost heave protection by means of insulation mats and bituminous felt.

The concrete slabs are founded 1 m below riverbed level and approximately 5 m down in the permafrost zone. Excavation was carried out by means
of drilling/chiselling, a complex and time consuming method. Thawing of the frozen subsoil should be prevented.

The excavated surface was covered with a geotextile net and back filled with compacted non frost susceptible fill.

The scour protection around the abutments consists of a 1.2 m thick filter layer with stone size 200 mm–400 mm and a 1.8 m thick armour layer with stone size 1.0 1–2.5 t. Armour stones and filter stones are produced from non weathered sound basalt rock.

Construction Diary

The excavation for the concrete abutments was carried out in June 2002 and the first concrete casting took place on 10 July. Both concrete abutments and execution of backfill and scour protection was completed by mid August.

The steel superstructure was fabricated in Finland. All the I-sections were fabricated by means of an automatic cutting/welding plant followed by computer aided drilling of bolt holes and lap plates. Accuracy of manufacturing was controlled by a trial assembly of a part of the bridge. The steel sections were sandblasted and coated with a paint system before leaving the workshop.

Fabrication of steel took place during June/July and all steel members, bolts of HSFG class 10,9, and prestressing bars were shipped from Finland to the port of Aalborg in Denmark arriving on 28 July.

The whole bridge structure incl. timber, bearings and bolts left Aalborg on 6 August in 12.2 m flat rack containers. It arrived at Nuuk in the Davis Strait on the west coast of Greenland 7 days later.

In Nuuk, the cargo was unloaded and further loaded onto another ship crossing the Baffin Bay, arriving at Thule in Northwest Greenland on 17 August. The 3 km transfer of the bridge components from the harbour to the site was carried out on trucks. The assembly of the steel structure with approximately 10 000 bolts was completed in 2 weeks on the Southern shore.

The steel bridge superstructure was launched into the final position over two provisional supports located in the frozen riverbed in only one working day. The precalculated camber was met with an accuracy of 2 mm which underlined the workshop fabrication accuracy of the steel elements.

![Fig. 6: View of completed bridge](image)

The timber deck was mounted continuous over the cross girders with lamella length of about 5 m in a way that only one butt joint would occur in any four adjacent beams within 1220 mm distance (Fig. 5). The transverse prestressing was done with 26 mm bars in a distance of 1,14 m. All holes for the bars were predrilled before shipment. The prestressing will be adjusted after one year in service to compensate for transverse creep. The bridge was completed and opened for traffic in the beginning of October, only 8 months after the design had started (Fig. 6).

Arctic Experience

A number of Danish construction companies have a long standing experience in design and construction of buildings and infrastructure in Greenland going back to World War Two.

All material and building components have to be transported to this remote arctic ice covered island. There are only 45 000 inhabitants living along the coastline.

The weather window for casting concrete in the northern region is limited to July and August and all foundations in the Thule region needs to be casted on perma-frozen soil.

The transport of the whole bridge superstructure contained in only one ship required design of a system built up of straight steel members of max 12,2 m length, prepared for easy bolted assembly in temperatures down to −18°C in August, September. Similarly the timber deck was built up of precut and predrilled oak beams. A thorough marking and numbering was mandatory for easy identification and mounting speed on site.

A preassembly in the workshop was also a prime requirement to assure that no site adjustment was needed. Any adjustments would be prohibitive in adhering to the tight construction schedule which was limited to only a few weeks. A detailed logistic planning is mandatory to achieve a successful termination of construction within the time schedule under the conditions.

Conclusion

Successful construction of major structures in remote polar environments calls for consideration of climatic conditions, transportation possibilities, adequate weather windows and knowledge of available site crane equipment already at the design stage. Planning of a schedule for tender, fabrication, preassembly, transport and construction on site must therefore be precise and comprehensive and must adhere to the above mentioned conditions if a successful result is to be achieved. Any error will easily result in one year delay.

The design planning and construction of the Thule Bridge adhered to these basic requirements and the bridge went into service according to schedule.

SEI Data Block

Owner/client: United States Air Force, Greenland

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

Main contractor: Adserbaele and Knudsen, Smørøm, Denmark

Sub contractors: PPTH Kliaivesi, Finland, fabrication of steel structures

MTHøegaard A/S, Denmark, assembly and erection of the bridge

Enemørke og Petersen A/S, Denmark, concrete structures and earthworks

| Steel (t) | 240 |
| Structural bolts | 10 000 |
| In-situ concrete (m³) | 175 |
| German oak timber (t) | 155 |
| Scour protection stones (m³) | 8 500 |

Service date: October 2002