Many of the newer applications of reinforced and prestressed concrete require high concentrations of transverse reinforcement to resist out-of-plane shear and to provide ductility under overload. Peripheral walls of offshore concrete structures for the Arctic and sub-Arctic must withstand intense punching shears from the impact of sea ice and icebergs. In more temperate zones, the shafts of offshore platforms must withstand the impact of boats and barges, and the base slab of a gravity base platform may have to withstand high shears from concentrated soil reactions. On land, protective and containment structures may have to resist earthquakes, explosions, or the impact of tornado-driven or falling objects. Required percentages of transverse steel may reach 1.5 to 2.5%

The use of conventional stirrups in the form of bent bars presents many problems when the required transverse steel percentages are high. Firstly, the size of the bars are limited by the allowable radius of bend: thus when high transverse steel percentages are required, the only solution may be to bundle the bars in groups of 2 or more. Secondly, to provide the maximum ductility, the tails must be tucked back into the core, since otherwise, failure may occur prematurely by the stirrup opening up with spalling of the cover. Thirdly, the failure mode of a stirrup is limited by crushing under the bend, hence stirrup bars typically develop only 70% of yield at failure. Fourthly, the bent stirrups are difficult and time-consuming to place. Finally, the congestion of bars makes it difficult to place and vibrate the concrete.

Test specimen with I00% of ultimate capacity and a deflection ductility factor of over 40

All these factors and considerations point up the need to develop a more efficient and effective form of transverse and confining reinforcement. To address this need, Ben C. Gerwick, Inc. initiated work on the development of the T-headed stirrup.

The first proposed application of T-headed bars was for offshore ice-resistant concrete platforms, which are subjected to high punching shear forces. In order to determine the effectiveness of T-headed bars for such an application, they were included in an extensive testing and analysis program. Large scale physical tests for these studies were conducted using the 4 million lb test machine at the University of California at Berkeley.

A 1 to 3.5 scale reinforced concrete beam specimen was tested in flexure/punching shear. This test specimen had a deflection ductility factor of over 40 at the end of test, while retaining essentially 1 00% of its ultimate capacity.

A non-linear finite-element analysis predicted an approximately one-eighth higher capacity for the specimen with T-headed stirrups, due to the superior ductility of the confined concrete. The specimen developed a large post-ultimate capacity due to catenary action from draping of the reinforcing steel. -It is the catenary behavior that accounts for the very high deflection ductility factor of over 40. This results in a large amount of energy absorption that can dissipate energy from impacting objects, or earthquakes. The development of load carrying mechanisms for such members can go progressively from flexural beam action, to arch or dome action, to catenary action.
News/91Apr/91aprphotoc

T-Heads of Stirrups used in Testing Program

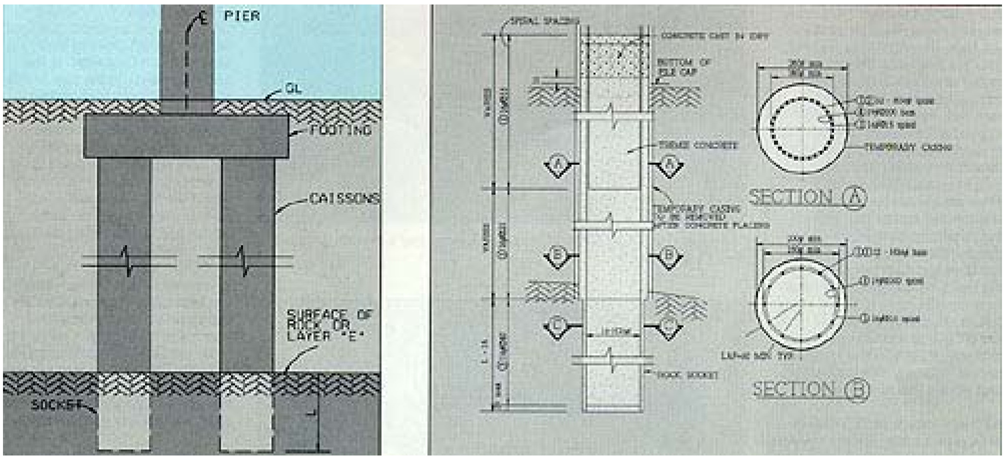
Some 80,000 T-headed bars were used on Gullfaks C in the following ways: in the tops of the shafts, in order to relieve steel congestion; in the top of the sludge tank, in order to develop shorter development lengths in ordinary reinforcement and to simplify the removal of slipforms; and in the top of the surfactant tank, in order to provide better anchorage for projecting concrete and to inhibit spalling.
The material cost of the T-headed bar appears to be approximately the same as for the equivalent number of bent stirrups, since the latter have longer tails or legs and are only 70% efficient. However, the labor cost of placing one Theaded bar compared with 6 stirrups makes them very attractive.

T-headed bars were also employed for transverse reinforcement on the Ekofisk Barrier Wall. They proved efficient, and the contractor for the Ekofisk Barrier Wall used the T-headed concept for inplane reinforcement as well, to replace hooks where there was need for development of anchorage in a short length. Currently, T-headed bars are being employed on the Sleipner A platform.

The new Bih-Tan Bridge across the Shin-Dan River in northern Taipei will consist of a double 3-span continuous concrete arch bridge with a maximum main span of 160 meters.

Each of the two spans are 16 meters wide and constructed with concrete segmental box girders in the form of arches. The arch configuration was chosen to blend in with the local environment and terrain.

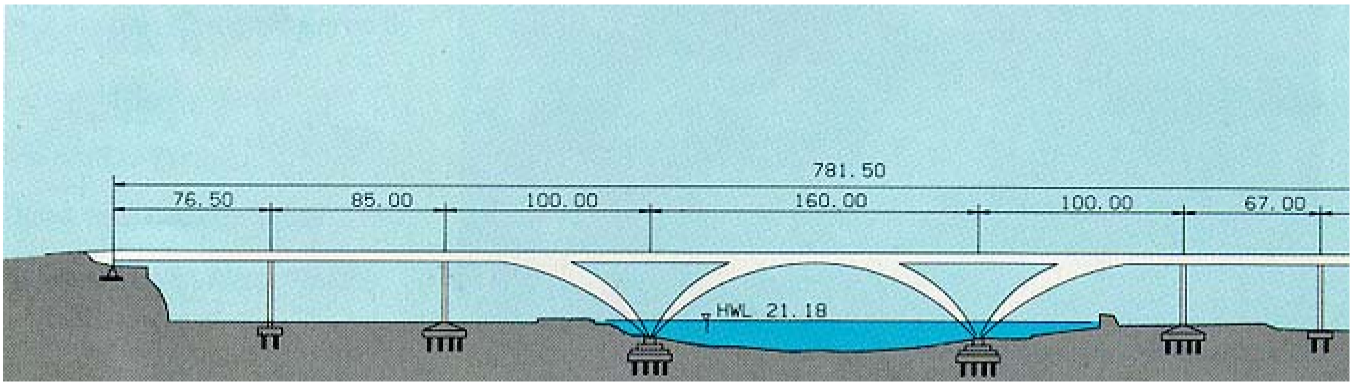
Foundations for the bridge consist of drilled in caissons having a diameter of 2.0 meters. These caissons are installed through the upper sands, gravel and cobble layers to bedrock where a 1.80 meter rock socket is drilled. After drilling, and cleaning, a reinforcing cage is installed and tremie concrete placed in the caisson and rock socket.



Foundation Elevation -----------------------Typical Caisson Details

To facilitate construction, the Contractor will use a temporary heavy wall steel caisson to reach the rock. The permanent caisson will be formed inside the temporary caisson using a corrugated steel pipe designed to take concrete pressures. After concreting, the space between the permanent caisson and temporary casing is filled with grout while the casing is extracted for use on a subsequent pile.

There are 206 caissons to be installed for foundations of the main portion of the bridge. Ben C. Gerwick, Inc. developed the design concept for the foundation for T.Y. Lin International, design consultants for the bridge.

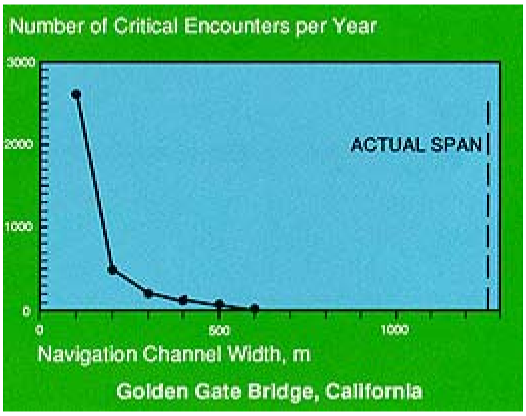


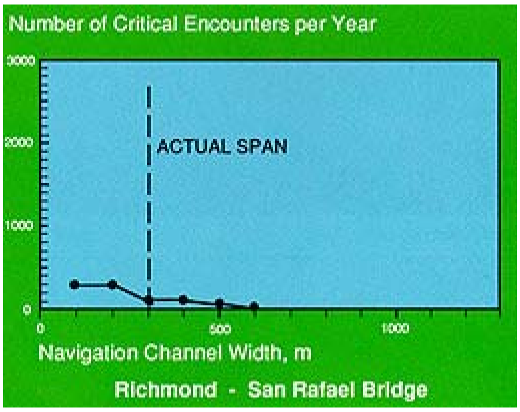
Alternate foundations considered included a sunken concrete caisson alternative and cast in place foundations utilizing full height temporary cofferdams. These other alternatives were eliminated due to higher construction costs and increased risk of construction failure.

The project is underway and foundation construction is expected to start in the Spring of 1991.

The background for this study is the Great Belt Fixed Link Project, Denmark, which includes the construction of a large span suspension bridge, crossing an international shipping route. As part of a comprehensive vessel collision study for the proposed bridge, analyses of vessel collisions at a number of U.S. bridges have been carried out. By use of empirical rules for navigation span opening requirements, based on ship domain theory, it has been possible to utilize vessel collision experience from U.S. bridges with different span openings, vessel traffic flow, navigational conditions and environmental conditions.

The results, achieved through the analyses of these existing U.S. bridges, support the use of the empirical rules to estimate the minimum span opening for the East Bridge of the Great Belt Fixed Link. The results confirmed the need for a very large span as found by computer based maneuvering simulations. The empirical rules are considered to be useful tools, which could be applied to a first step estimation of the minimum navigation span opening of bridges and also as part of the analysis of navigational safety at existing bridges.





The study included development of a method to evaluate the relationship between bridge design and ship traffic by estimation of the number of close encounters in the vicinity of the bridge.

The Great Belt Strait is approximately 17 km wide at the point of crossing and the island of Sprogoe is located approximately in the middle. An international shipping route passes through the Eastern part of the strait and is the only deep water route connecting the Baltic Sea with the North Sea. The traffic flow is approximately 20,000 vessels per year. At the moment there is intensive ferry traffic across the strait (a total of approximately 50,000 movements per year), most of which will disappear after the Fixed Link is installed.

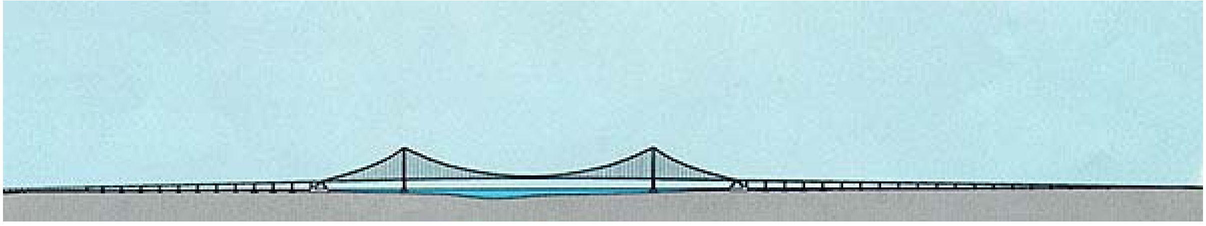
The Fixed Link consists of three parts. The Western part of the link will be a combined rail and road bridge. The Eastern Channel crossing will consist of a bored tunnel for train traffic and a suspension bridge (the East Bridge) for motor vehicles. The East Bridge will have a number of piers located in navigable water and thus be exposed to the risk of vessel collisions.

In 1989 the Great Belt Link Ltd. asked COWiconsult of Denmark to undertake a new comprehensive investigation of the interaction between vessel traffic and the planned bridge structures across the Eastern Channel. The vessel collision study was carried out in cooperation with Ben C. Gerwick, Inc.

The work included collecting data on the existing conditions for the vessel traffic in the Great Belt, forecasting expected traffic development, collecting vessel accident statistics and data on environmental conditions, evaluating the effect of the planned bridge structures on the navigation conditions, and evaluating risks of collisions as well as predicting potential consequences of the possible collisions. The results of the investigation have formed the basis for a new, improved vessel/ bridge collision model.

Methods of reducing the risk of vessel collision have been investigated. A conceptual design of a Vessel Traffic Service system has been made in cooperation with representatives from the Danish Navy and the Danish Maritime Authorities.

The navigation span opening has proved to be one of the most important design parameters for the design of the *bridge. Different methods have been applied to evaluate the effect of the span opening on the navigational conditions. The resulting span opening requirements have led to bridge design alternatives with span openings of 1600 m.*



Great Belt East Bridge, Denmark

A joint venture consisting of the Canadian subsidiary of Morrison Knudsen Corporation and Stena Offshore, Ltd., of Aberdeen, Scotland, recently completed the installation of some 58 miles of pipeline across the straits that separate Vancouver Island from the Canadian mainland. At the deepest point, the 1 0-inch pipeline was placed in water depths of approximately 1400 feet, making it the third deepest pipeline in the world.

The purpose of the pipeline is to convey natural gas from the mainland to scenic Vancouver Island.

During the bidding stages of this notable project, Gerwick engineers assisted Morrison Knudsen in evaluating the feasibility of installing the pipeline with the,,Stena Apache," a reel ship capable of holding some 16 miles of 10inch pipe on an 82-foot-diameter reel. Gerwick engineers also studied means of anchoring support barges in very deep water and worked with a metallurgical consultant to develop welding procedures which would produce welds with sufficient strength and ductility to withstand the severe strains imposed by the reeling and unreeling process.

"Stena Apache" Reeling Pipe

After the successful completion of these studies, Morrison Knudsen and Stena formed a joint venture and submitted the winning bid of about $40 million to Pacific Coast Energy Corporation, of Vancouver.
The joint venture established a yard near Vancouver where the pipe was received in 59-foot lengths. These sections were welded together into 3,700-foot strings which were then reeled onto the,,Stena Apache" and successively

welded together as the operation proceeded. The photograph shows the reeling operation in progress.

After the reel was loaded, the vessel began laying operations by first backing up to a point near the pipeline's landfall. A winch installed on shore then pulled the pipe from the reel to the shore. After the winch stopped pulling, the vessel proceeded forward under its own power, unreeling pipe to the seafloor. When the reel ship arrived near the shore on the other side of the strait, the pipe was cut and a pull-head and cable were attached. The end of the pipe was then lowered into the water with a buoy attached to mark the location. The vessel then backed up to a point near the marker buoy, and with the assistance of another land-based winch, the pipe was pulled from the ship to the shore. This short section of pipe was also cut and lowered to the seafloor and a tie-in barge was then employed to lift the two ends to the surface for welding. When the reel was empty, the ship returned to the yard in Vancouver for a new load and the whole operation was repeated.

The "Stena Apache" completed the laying operation in approximately two months, with only a few days out of operation because of bad weather. This very successful project is a real tribute to the innovative engineers at Morrison Knudsen and Stena Offshore.