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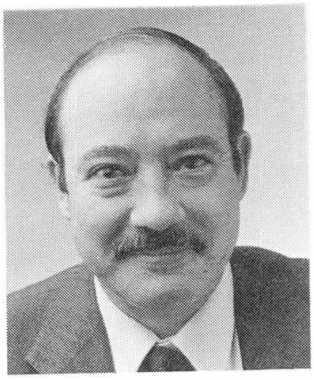
# Undersea Cable Tunnel, Singapore

## Tunnel de câbles sous-marin, Singapour

## Unterwasser-Kabeltunnel, Singapur

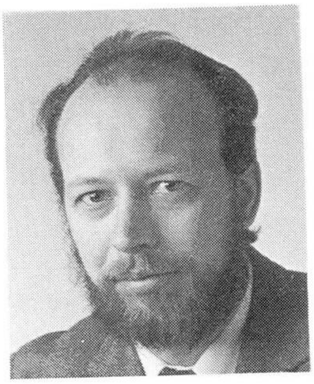
**Nestor S. RASMUSSEN**
Civil Engineer
Christiani & Nielsen A/S
Copenhagen, Denmark

Nestor Rasmussen, born 1931, obtained his M.Sc. Degree from the Technical University in Copenhagen. For more than 30 years he has been involved in design and construction of subaquaous tunnels. Nestor Rasmussen was overall coordinator of the planning and subsequently in charge of the sinking of this tunnel.



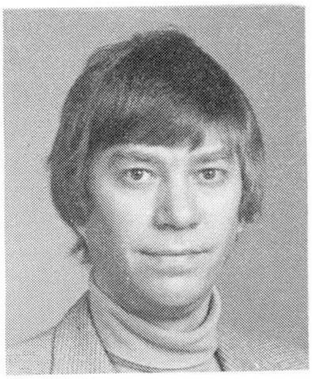
**O.P. JENSEN**
Civil Engineer
Christiani & Nielsen A/S
Copenhagen, Denmark

O.P. Jensen, born 1947, obtained his M.Sc. Degree from the Technical University in Copenhagen. He has specialized in immersed tunnel and off-shore design and participated both in studies and detailed design. O.P. Jensen was in charge of the prestressing and soil-structure modelling for this tunnel.



**Steen JORGENSEN**
Civil Engineer
Christiani & Nielsen A/S
Copenhagen, Denmark

Steen Jorgensen, born 1949, obtained his M.Sc. Degree from the Technical University in Copenhagen. He has been involved in design, site supervision and management.
Steen Jorgensen was overall coordinator of the design and preparation of working drawings for the immersed tunnel section.



## SUMMARY

In 1986 the contractors delivered a 2.6 km long undersea cable tunnel to the Public Utilities Board in Singapore. The contract comprised detailed design and construction. The tunnel is an immersed, reinforced concrete tunnel. The very short time available for construction, 10 months, required a close coordination of design and construction methods and the use of a series of unconventional construction techniques.

## RÉSUMÉ

En 1986 l'entrepreneur a livré au Public Utilities Board, Singapour, un tunnel de câbles sous-marin d'une longueur de 2,6 km. Le mandat comportait le projet détaillé et la réalisation de l'ouvrage. Le tunnel est construit comme un tunnel immergé en béton armé. La période très courte disponible pour la construction – 10 mois – a exigé une coordination étroite entre l'établissement du projet et les méthodes d'exécution des travaux ainsi que l'utilisation d'un grand nombre de procédés d'exécution particuliers.

## ZUSAMMENFASSUNG

Im Jahr 1986 hat die Bauunternehmung an die Public Utilities Board in Singapur einen 2.6 km langen Senktunnel aus Stahlbeton geliefert. Der Auftrag umfasste die Projektierung und Ausführung des Tunnels. Die sehr kurze Bauzeit von 10 Monaten, welche für die Bauarbeiten zur Verfügung stand, erforderte eine enge Koordination von Projektierung und Ausführung. Dabei kamen auch aussergewöhnliche Bautechniken zur Anwendung.

## 1. INTRODUCTION

In late April 1985, the Public Utilities Board of Singapore awarded to Christiani & Nielsen A/S a contract for the design and construction of an immersed cable tunnel from Pulau Seraya across the Jurong Strait to Mainland Singapore

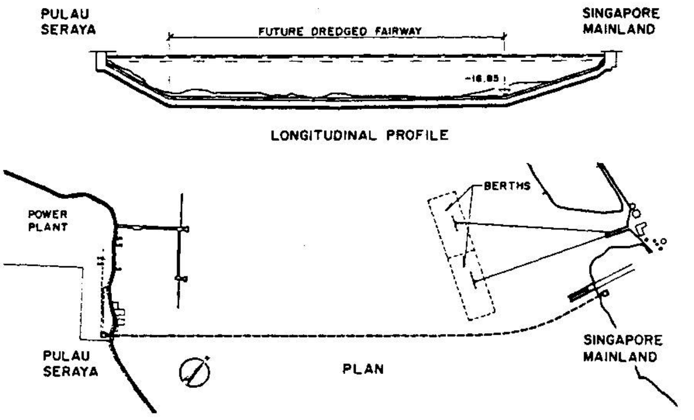


Fig. 1 Plan and longitudinal profile of tunnel

At the time of the award, a new 750 MW power station was under construction on Pulau Seraya. This station has been commissioned and started supplying electrical power to Singapore from January 1987.

The overall economy gained by the use of conventional land power cables instead of sea cables and the requirement for uninterupted passage of the ships through the busy Jurong Strait made the Owner choose a cable tunnel for the crossing.

The contract was awarded after international tendering based on an outline design and specifications prepared by Mott, Hay & Anderson Asia Pte. The tender documents described an Engineer's Preferred Scheme, a reinforced concrete tunnel of rectangular cross section built by use of the immersed tube technique, but the tender documents also had a bored tunnel option. In addition to the tunnel, the contract included two terminal buildings and mechanical and electrical installations in the tunnel for lighting, ventilation, cooling of power cables, fire protection etc.

The cable tunnel in Singapore is remarkable for a number of reasons:

(i) the length of the tunnel, 2.6 km of which 1.8 km has floor level 23 m or more below Main Sea level.

(ii) the extent to which the permanent civil works and the mechanical/electrical installations were completed prior to the tunnel elements being launched.

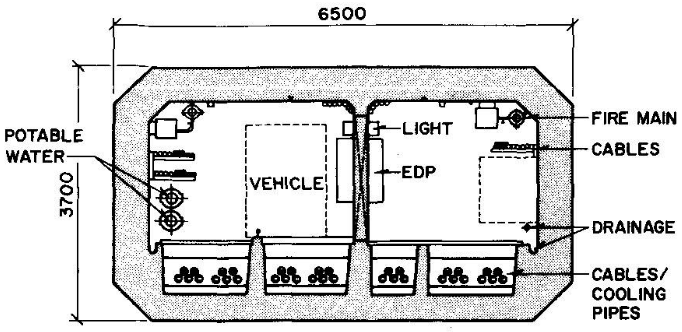
(iii) the very short time available for the design and construction and, as a consequence, the unconventional construction techniques used.

The contract value was of the order of 80 million Singapore Dollars, with the electrical and mechanical installations representing approximately 25% thereof.

| SECTION | EXCAVATION CU.M. | REINFORCED CONCRETE CU.M. | SAND FOUNDATION CU.M. | BACKFILLING CU.M. | ARMOUR ROCK CU.M. |
|---|---|---|---|---|---|
| TERMINAL BUILDING MAINLAND SINGAPORE | 18,000 | 6,400 | — | — | — |
| UNDERSEA TUNNEL | 463,000 | 27,500 | 50,000 | 90,000 | 75,000 |
| TERMINAL BUILDING PULAU SERAYA | 19,000 | 6,900 | — | — | — |
| TOTAL | 500,000 | 40,800 | 50,000 | 90,000 | 75,000 |

Table 1 Main quantities - civil works

As shown in Table 1, the terminal buildings represented only a minor part of the works. These buildings are conventional reinforced concrete structures which through their basements provide access to the tunnel and house a series of mechanical and electrical service installations.



The subsoil varied from rock to soft clays. The clay formations were typically encountered at the shore ends and the terminal buildings were thus founded on piles.

Fig. 2 Cross-section of cable tunnel

## 2. GENERAL ORGANIZATION OF DESIGN AND CONSTRUCTION TASKS

In order to meet the time schedule a close coordination of the design and construction methods was required, in particular for the immersed tunnel section. The detailed design of this section and the planning of the construction methods were consequently done within the main contractor's organization while Ove Arup and Partners, London were engaged for the design of the terminal buildings and the mechanical/electrical installations.

The production rate required for the construction of the immersed tube section was 100 m of tunnel per week and this was achieved by:

(i) precasting some 754, 3.5 m long, tunnel segments in a casting yard on Mainland Singapore.

(ii) Assembling 29 of these segments at a time on a marine lift next to the casting yard, to form 100 m long tunnel elements, and mounting up to 80% of the mechanical and electrical installations in the element. (Two marine lifts were operated providing 14 working days per tunnel element).

(iii) Launching these tunnel elements by means of the marine lifts at a rate of one element per week.

(iv) Sinking, joining, founding and backfilling the tunnel elements at a rate of one element per week.

The bulk of the tunnel trench had been dredged prior to the start of sinking but hard rock was encountered over a length of approx. 850 m. Drilling and blasting of this rock was required prior to completion of the dredging.

For the construction it was necessary to run five work sites simultaneously, as shown in Table 2.

a work site for the Terminal Building on Mainland Singapore.

a casting yard for the fabrication of tunnel segments

two marine lifts for assembling and launching of tunnel elements

a marine tunnel sinking and founding section

a work site for the Terminal Building on Pulau Seraya

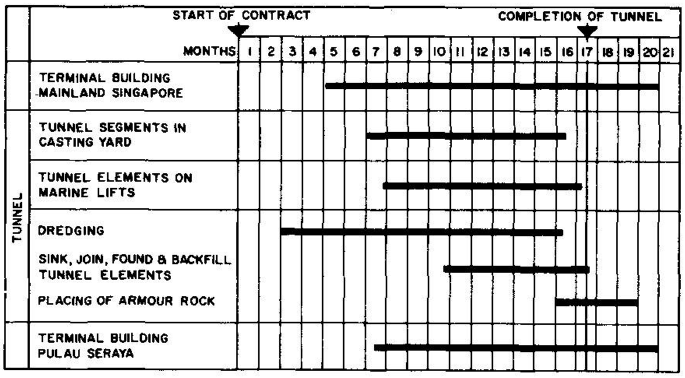


Table 2 Overall construction programme

## 3. DETAIL DESIGN

The design was carried out in accordance with British Standards.

In the longitudinal direction the bending moments and shear forces were calculated by use of a soil-structure interaction model and from this the number of tendons were determined. The prestressing fulfils the stress requirements outlined in the following conditions (negative signs represent compression):

(i) Normal operation condition : Stress requirement -2.0 to -16.0 MPa

(ii) Extreme operation condition : Stress requirement 0.0 to -16.0 MPa

(iii) Accidental condition : Stress requirement 2.3 to -16.0 MPa

The condition (ii) was a combination of (i) and a load from sunken ship of $50\ kN/m^2$ over a length of 20 m anywhere along the tunnel, or a dragging anchor load of 4000 kN acting perpendicular to the tunnel at roof level. The condition (iii) consisted of (ii) and flooding of the tunnel. The number of tendons were governed by the conditions (i) and (ii) and varied from 19 to 37 depending on the subsoil conditions along the tunnel.

As reports on these conditions were available, from observations during dredging and from supplementary geotechnical investigations carried out during the construction period, the required minimum number of tendons was determined and a corresponding economy achieved.

## 4. CONSTRUCTION OF TUNNEL

### 4.1 Casting yard operations

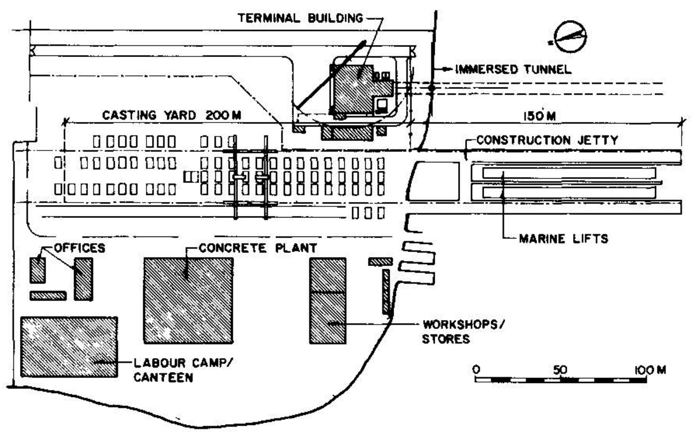


Fig. 3 Lay-out of work site

The tunnel segments which weighed between 92 and 98 tons were cast in vertical position in rigidly held steel forms.

The reinforced cages with the required number of ducts for the prestressing cables were preassembled.

The concrete was produced on site and pumped into the forms.

The forms were stripped after minimum 12 hours and the segments were cured another 4 days before they were transported to a storage area and transposed into a horizontal position.

The casting of the tunnel segments in a vertical position without any construction joints between floor, walls and roof, contributed to a reinforced concrete of high quality and absolute watertightness.

### 4.2 Marine Lift operations

Two marine lifts were constructed in front of the casting yard and two 50 t gantry cranes, working in tandem, brought the tunnel segments out on the marine lift platforms. These platforms were 120 m long and 10 m wide and each marine lift was suspended in 12 steel cables and hydraulic jacks of a capacity of 3500 kN. The platforms could be lowered and raised 8 m at a speed of 2 m per hour.

Access to the marine lifts and supplementary working area was provided by two 150 m long, 8 m wide, jetties.

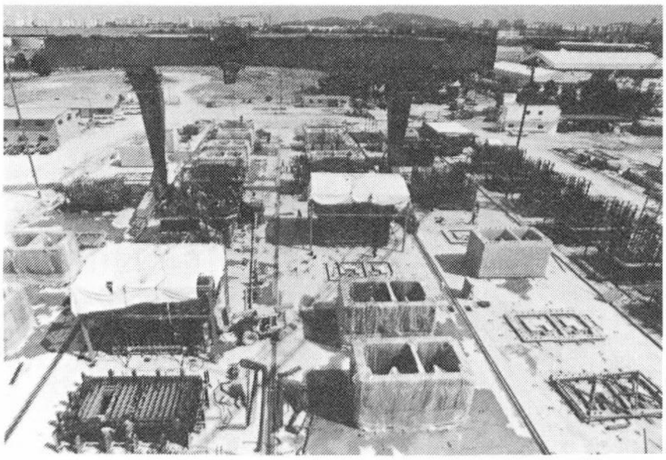


Photo 1 View of casting yard

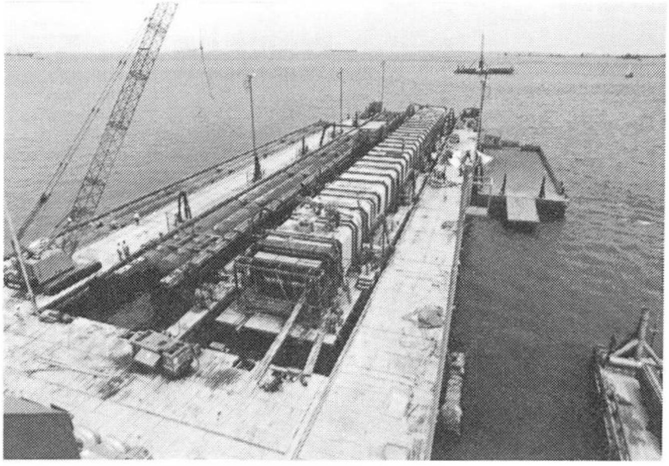


Photo 2 View of marine lift area

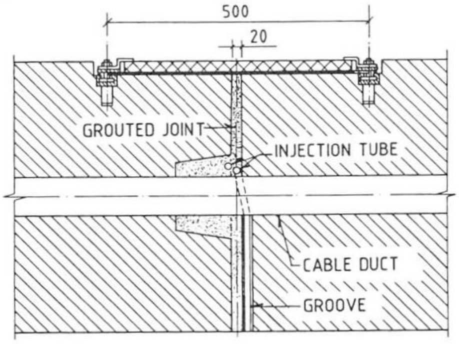


Fig. 4 Segment joint

After having been grit blasted at the end faces, the tunnel segments were lined-up on the marine lifts leaving a 20 mm wide space between the segments. These spaces were grouted by means of an expanding cementitious grout. The grouted joints were covered, at the external faces, by a narrow double membrane protected by a band of 20 mm plywood.

In order to prevent ingress of grout into the cable ducts, an inflatable Ductube was used in each duct. An injecting tube system to enable epoxy resin injection at a later stage, if required, was installed along the joint perimeter. All joints have, however, proved watertight without injection.

Premade tendons were pulled through the cable ducts as soon as the joints had been completed, and stressing of these tendons was started 12 hours after the last joint had been grouted using 2500 kN jacks at each end of the tunnel element.

The end tunnel segments were provided with steel shrouds fitting the end of the segment walls, with a steel bulkhead with a watertight door and with shear dowel/pockets, the bulkhead being a temporary feature while the shear keys form part of the permanent element joint.

Steel plates were welded onto the steel shrouds at the element ends and a rubber gasket was mounted at one end of the tunnel element.

Finally most of the mechanical and electrical installations were mounted in the tunnel element thus minimizing the work to be done within the tunnel after the elements were in place. As a consequence, the first high-voltage cable could be pulled through the tunnel only 3 weeks after the sinking of the last tunnel element.

The optimum utilization of the tunnel cross-section for permanent use and the degree to which the tunnel elements were prefabricated made the tunnel element come out with practically the permanent weight, i.e. a buoyancy aid was needed in order to make the tunnel elements float temporarily during their transport from the marine lift area to the final place in the tunnel trench. This buoyancy aid consisted of a buoyancy tank unit weighing 350 tons which was floated in on top of the tunnel element while this was temporarily lowered by means of the marine lift.

### 4.3 Sinking and founding operations

While the tunnel element/buoyancy tank assembly was interconnected and the last preparation of the element was being done, the tunnel trench section was cleaned for any accumulated silt, and a lay-barge, see photo No. 4, was warped 100 m forward along the tunnel line.

The tunnel element/buoyancy tank assemblies were towed from the marine lift area to the lay-barge at the turn of the tide and, after ballasting with water, lowered into the tunnel trench by means of two standard cranes.

The assemblies were landed on temporary steel supports, joined to the previously placed tunnel elements, and brought into specified line and elevation by operation of hydrulic jacks in the temporary steel supports.

The permanent support of the tunnel was a sand foundation hydraulically placed by use of the Christiani & Nielsen Method. The sand/water mixing took place on the lay-barge.

The backfilling except for a 1 m thick armour rock protection was also placed by means of equipment on the lay-barge.

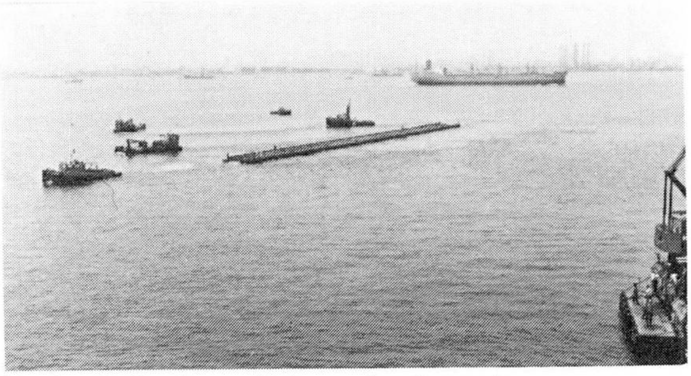


Photo 3 Towing of tunnel element

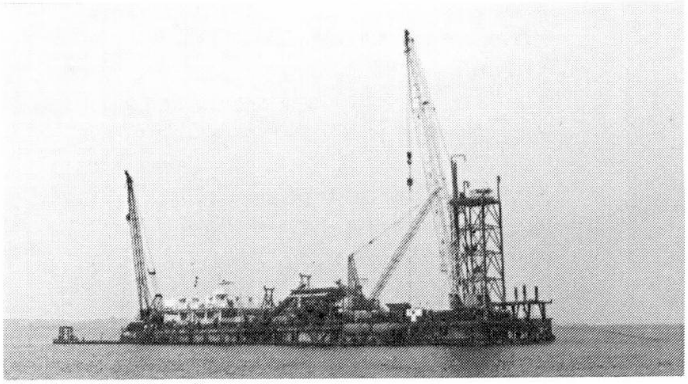


Photo 4 Lay-barge

The 26 tunnel elements were placed and backfilled in 27 weeks from March to September 1986.

## 5. QUALITY AND ECONOMY

The casting method used for the tunnel segments and the assembling method used for the tunnel elements ensured a high quality, reinforced concrete structure which is absolutely watertight requiring no waterproofing membrane.

The close coordination of design and construction allowed an optimization of the number of longitudinal prestressing tendons in the elements.

The carefully planned towing and lowering of the tunnel elements at the turn of the tide meant a saving on tugs and that no horizontal mooring of the tunnel element was required.

A detailed planning of all operations from precasting of tunnel segments to placing of backfill, and a disciplined and well organized staff and labour force made it possible to build the 2.6 km long tunnel in 10 months and deliver the works on time.