Cambridge International Examinations
Cambridge Pre-U Certificate

PHYSICS (PRINCIPAL) **9792/02**

Paper 2 Part A Written Paper **May/June 2015**

INSERT

The question in Section B of this paper will relate to the subject matter in this Insert. You will have received a copy of this booklet in advance of the examination.

The extracts on the following pages are taken from a variety of sources.
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You should draw on all your knowledge of Physics when answering the questions.

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This document consists of **10** printed pages and **2** blank pages.

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Extract 1: Archimedes' Principle

Buoyancy and Archimedes' Principle

The equation for the pressure beneath the surface of a fluid shows that the pressure increases with the depth of the fluid. If, therefore, an object is submerged in a fluid, the pressure at the bottom of the object is greater than the pressure at the top.

Fig. E1.1 shows a submerged submarine. On the submarine forces which cause the water pressure are shown acting at right angles to the surface of the submarine. Sideways forces cancel out, but because there are larger upward forces on the bottom than there are downwards forces on the top, the resultant of all of these forces is an upward force. The resultant force due to the pressure of the fluid surrounding it is called the **buoyancy force** or **upthrust**. The same reasoning would show that as a result of the air surrounding a person, everybody has a buoyancy force acting **upwards** on them due to the pressure of the air. The force due to air pressure acting downwards on your head is less than the upward force on your feet because of the higher air pressure near the ground. The buoyancy force on a person is small. Someone with a weight of 800 N usually has a buoyancy force of about 1 N.

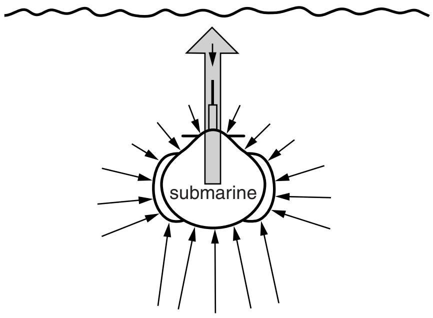

Fig. E1.1

To calculate the value of the buoyancy force, consider an object with uniform cross-sectional area A, and with a horizontal top and bottom. It has a length l and is placed so that its top is a distance d beneath the surface of a liquid of uniform density ρ, see Fig. E1.2.

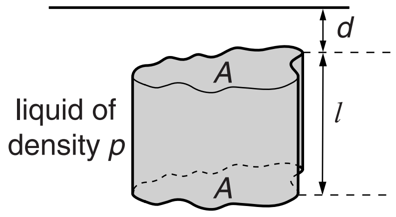

Fig. E1.2

pressure on top $= d\rho g$
force downwards on top $= d\rho g A$
pressure on bottom $= (d + l)\rho g$
force upwards on bottom $= (d + l)\rho g A$
buoyancy force $= (d + l)\rho g A - d\rho g A = l\rho g A$

Since lA is the volume of the object, $lA\rho$ is the mass of the fluid which the object displaces and $l\rho g A$ is the weight of fluid displaced. This is a deduction of **Archimedes' Principle** which states that for an object immersed in a fluid the buoyancy force is equal to the weight of the fluid displaced. It can be applied generally and not just when the object has a regular shape.

If an object floats, it does so because the buoyancy force acting on it is equal and opposite to its weight. An object which sinks has a buoyancy force acting on it which is less than its weight. The shape of any piece of material is bound to have an effect on the weight of fluid which it displaces. A steel boat can float because the steel is shaped to displace a large volume of water; the volume displaced is clearly much larger than the volume of the steel itself, see Fig. E1.3.

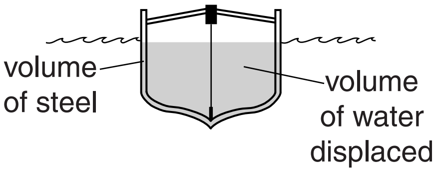

Fig. E1.3

Fig. E1.4 The oil tanker Norrisia has a total mass of approximately 150 000 tonnes when fully laden. It therefore needs to displace 150 000 tonnes of water in order to float.

From: Physics by Robert Hutchings ISBN 0-333-46515-6

Extract 2: Submerged floating tunnels

A tunnel is a tunnel, is a tunnel – right? Well not so fast. A recent symposium in Norway explained why tunnels for strait crossings are special. Deep mined rock tunnels; TBM bored tunnels; immersed tubes; and submerged floating tunnels, all have one thing in common; they are under or through the sea, but each is specific in its own right and, as a collection, different in so many ways from tunnels on land. Bridge alternatives and ferries for strait crossings were also considered at the Strait Crossings symposium; one of the rare occasions when bridges, tunnels and ferries are discussed at the same forum.

Norway is a natural choice of a country in which to hold a discussion about providing links across water divides. With thousands of miles of coastline and communities on different islands and opposite sides of long fjords, Norway is the world's leader in building and operating strait crossings. As well as hundreds of ferries in service, and many bridges of different types and size, Norway has 26 undersea road tunnels with another three in construction and several more in planning and design. As one of the most interesting, topic-specific gatherings of the year, professionals and engineers gathered in Trondheim to discuss all facets of building, owning, and operating strait crossing bridges, ferries and tunnels.

Submerged floating tunnels

The concept of the submerged floating tunnel (SFT) has been long appreciated but the idea that it is still a far off, futuristic novelty is wrong. Two full sessions and a three-hour workshop at the symposium were devoted to the concentrated work progressing in different countries and by different teams around the world to bring this concept to reality.

Despite a British patent dating back more than 100 years, it is Norwegian engineers who have invested more in developing the technology in recent times. For Norway, the concept provides the best option for providing fixed links across the country's deep fjords, at locations where the divide is either too deep for deep-mined rock tunnels or too wide or exposed for long, high bridges or floating bridges.

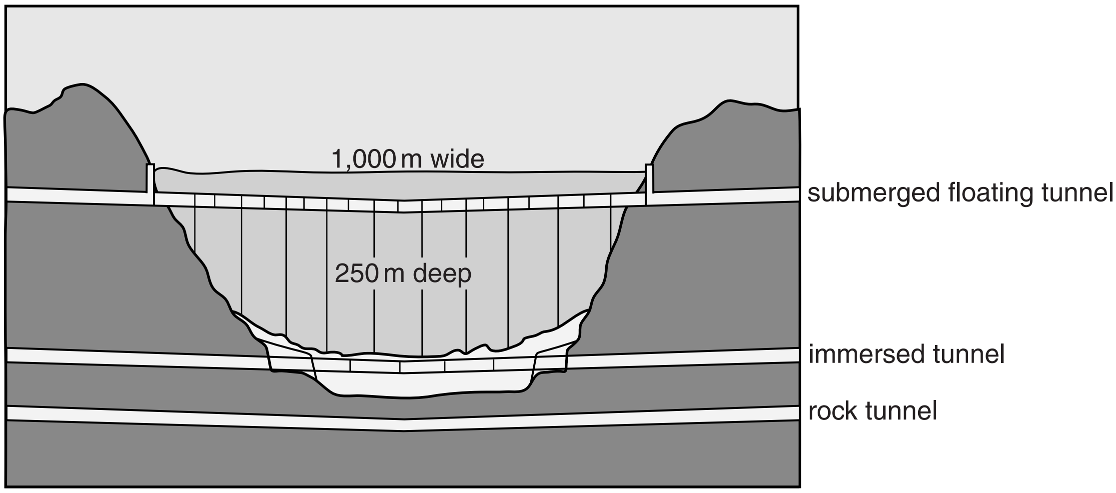

Fig. E2.1 Tunnel options.

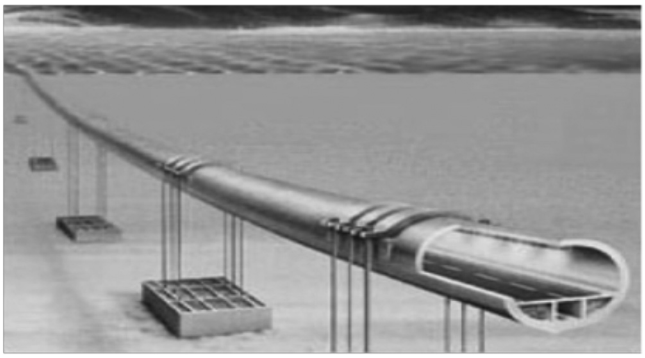

Fig. E2.2

Comparisons of lengths and illustration of an SFT

Set at about 25–30 m below the surface, connected to short landfall tunnels at either side, and tethered in some way to counteract buoyancy and the movement of tides, currents and waves, an SFT would:

- be much shorter than a deep mined rock tunnel or a high level suspension bridge;
- be less expensive to build than the deep mined rock tunnel or high level bridge option;
- consume less materials than the alternatives;
- take less time to construct.

Norway came closest to building the world's first floating tube in the 1980s when a two-lane SFT road connection was adopted for a crossing of the Høgsfjord toward the city of Stavanger. Conceptual and preliminary design was complete; planning permission and construction permits had been granted; the financing structure was being finalised; four concepts for design and construction had been prequalified; and the procurement of a construction contract for the selected option was advancing. It was at the eleventh hour that the local county council decided that an undersea mined tunnel at a different location would be the fixed link, and not the Høgsfjord SFT as promoted by the country's Public Roads Administration.

Although the opportunity at Høgsfjord was missed, it is often forgotten that it was a political decision that defeated the possibility and not the technical feasibility. The four prequalified SFT concepts had drawn together the expertise of tunnellers, bridge builders, materials engineers, university research resources, and the engineering skill of experts advancing the cutting edge design of fixed and floating deep sea platforms needed at the time for Norway's oil and natural gas reserves in the North Sea and the North Atlantic Ocean.

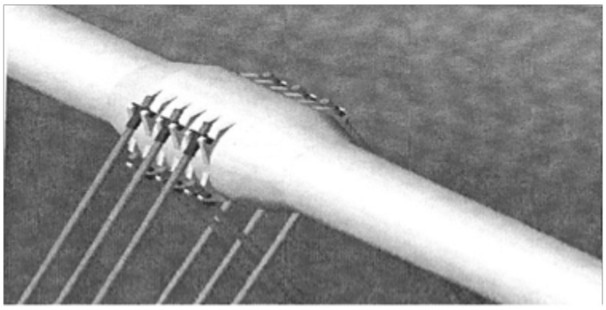

Fig. E2.3

Illustration of tethering systems

The technical challenges of building an SFT are not underestimated. The most paramount of these as discussed at the symposium sessions and workshop are listed here in no particular order:

1. The need to prevent resonance vibrations and movements being induced into the hollow tube as well as into the anchoring tethers under different hydraulic and dynamic load conditions.

2. The practicalities of fabricating and placing of the tube elements, installing the anchor systems, and realising the landfalls at either end.

3. Maintenance and repair of the submerged infrastructure.

4. Addressing the highly improbable, but perhaps possible, event of a submarine or a sinking ship colliding with the suspended tube – not a small worry in the minds of the public and potential owners.

5. Public perception and operational safety. How to gain the confidence of the public and assure the safety of the infrastructure to clients and the insurance industry? It was suggested that the concept be built first at a theme park like Disneyland to provide a 'soft' introduction to the public.

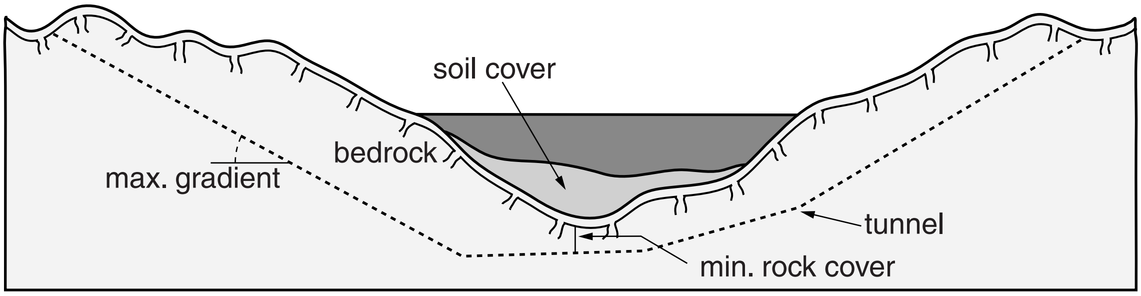

Fig. E2.4 Typical alignment of a subsea road tunnel.

Typical section of a deep rock subsea road tunnel

All these issues are being considered and addressed by different teams around the world and the locations of possible SFTs continue to be identified. Of several candidates for the first SFT in Norway, the most promising is a crossing of the 4,200 m wide, 450 m deep Storfjord between the towns of Hareid and Sula near the city of Ålesund. Compared to a deep-mined rock tunnel or a long high-level bridge, an SFT would be a third of the length, consume a third of the materials, and offer convincing traffic management advantages. The first demonstration project may well be the 100 m long SFT in Qiandao Lake in China's eastern province of Zhejiang.

In North America, an SFT has been proposed as a fixed link to Vancouver Island on the west coast of Canada across the 26 km wide, 365 m deep Georgia Strait, and in Washington State in the USA, an SFT is a considered option for fixed links across Lake Washington east of Seattle. Asia, Indonesia, Japan and Korea have expressed interest the SFT fixed link concept for quite ambitious projects, but it might well be China that builds the first SFT in the world. Back in Norway, the brightest brains in the engineering fraternity are investigating the best solution for a crossing of the Sognefjord, which is 4,000 m (12,000 ft) wide and some 1,350 m (4,000 ft) deep.

For development of the SFT concept there was a sense that the engineers engaged are spinning their wheels, that the need to actually build one was needed to cut through the often passionate discourse about laboratory and engineering studies in which the different groups are engaged. Long strings of complex equations were used to argue one point against another and left some, if not most, in the audience on the sideline.

Adapted from: http://www.tunneltalk.com/Strait-Crossings-Jan10-Conference-report.php

Extract 3: Advantages and construction

Basic principle of SFT

SFT is a buoyant structure which moves in water. The relation between buoyancy and weight is very important, since it controls the static behaviour of the tunnel and, to some extent, the response to dynamic forces. Minimum internal dimensions often result in a near optimum design. There are two ways in which SFT can be floated: positive buoyancy and negative buoyancy.

Positive buoyancy: In this, the SFT is fixed in position by anchoring either by means of tension legs to the bottom or by means of pontoons on the surface. Here the SFT is mainly 30 metres below the water surface.

Negative buoyancy: Here the foundations are piers or columns fixed to the sea or lake. This method is limited to 100 metres water depth.

SFT must be designed to withstand forces from earthquakes and waves and be corrosion-resistant. Transverse stiffness is provided by bottom anchoring.

Optimal shape of SFT

The shape of the SFT in Fig. E3.1 has been chosen because when the vertical curvature is concentrated in the middle of the SFT, it is easier to shorten the concrete tube during installation, and variations in the buoyancy in the middle of the tunnel introduce little bending in the tunnel. Similarly, an unusual amount of water in the middle of the tunnel gives little bending and axial force.

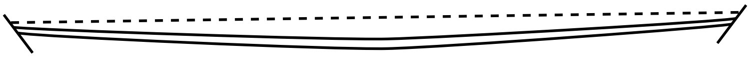

Fig. E3.1

Construction

The concept of submerged floating tunnels is based on well-known technology applied to floating bridges and offshore structures. The construction is similar to that of immersed tunnels. One way is to build the tube in sections in a dry dock, then float these to the construction site and sink them into place, while sealed. When the sections are fixed to each other, the seals are then broken.

Another possibility is to build the sections unsealed, and after welding them together, pump the water out. The ballast used is calculated so that the structure has approximate hydrostatic equilibrium (that is, the tunnel is roughly the same overall density as water), whereas immersed tube tunnels are ballasted more to weight them down to the sea bed. This, of course, means that a submerged floating tunnel must be anchored to the ground or to the water surface to keep it in place (depending on the equilibrium point).

From: http://www.engineeringcivil.com/submerged-floating-tunnel.html

Extract 4: Types of submerged floating tunnels

There are basically four types of submerged floating tunnels (SFT).

SFT with pontoons
This is independent of water depth, is sensitive to wind, waves, currents and possible ship collision. Design should be such that if one pontoon is lost, the structure will survive.

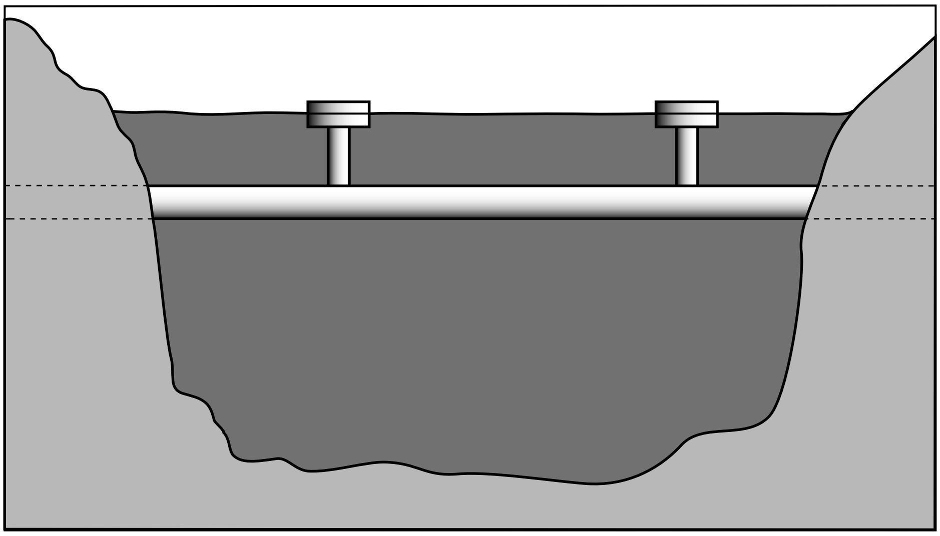

Fig. E4.1 SFT with pontoons

SFT supported on columns
This is an "underwater bridge" with foundations on the bottom. In principle the columns are in compression but they may also be a tension type alternative. Water depth will play an important role in this case and a few hundred metres depth is considered the limit at the present time. However, much deeper foundations are at present under investigation.

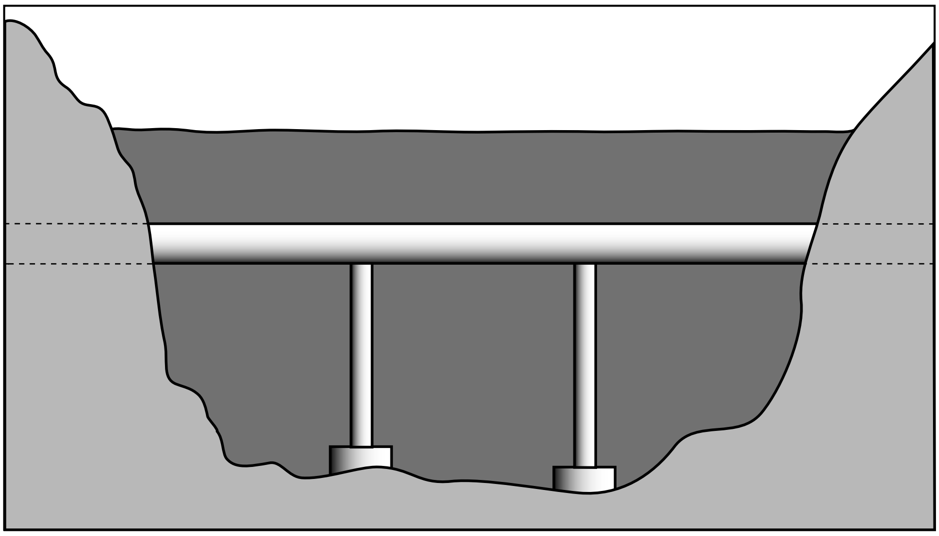

Fig. E4.2 SFT supported on columns

SFT with tethers to the bottom

This is based on tethers being in tension in all future situations; no slack in these tethers may be accepted in any future load cases. The present practical depths for this type of crossing may be several hundred metres, whether the tethers are vertical or a combination of vertical and inclined.

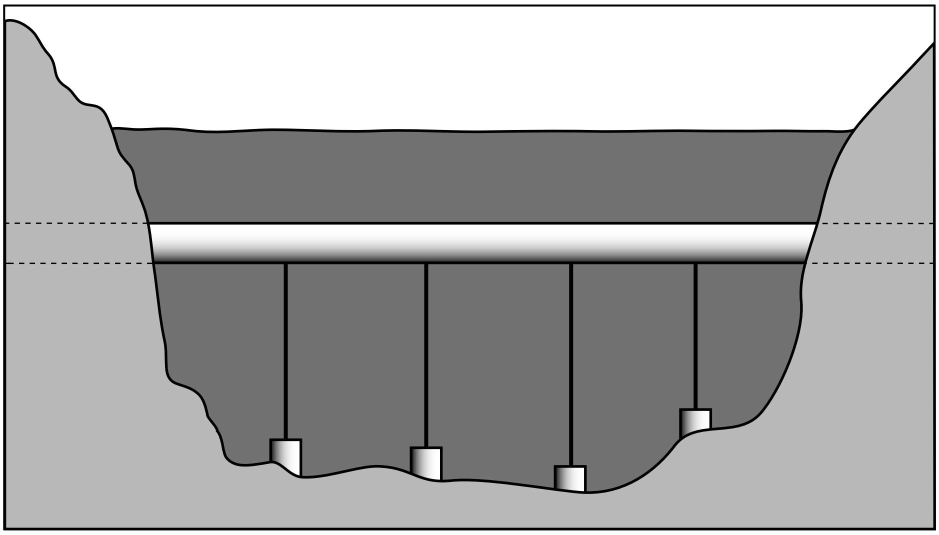

Fig. E4.3 SFT with tethers to the bottom

SFT unanchored

This is interesting as it has no anchoring at all except at landfalls and is then independent of depth. There is obviously a limit to the length but further development may change this. Perhaps an alternative for light traffic should be designed, possibly 100 or 200 metres long.

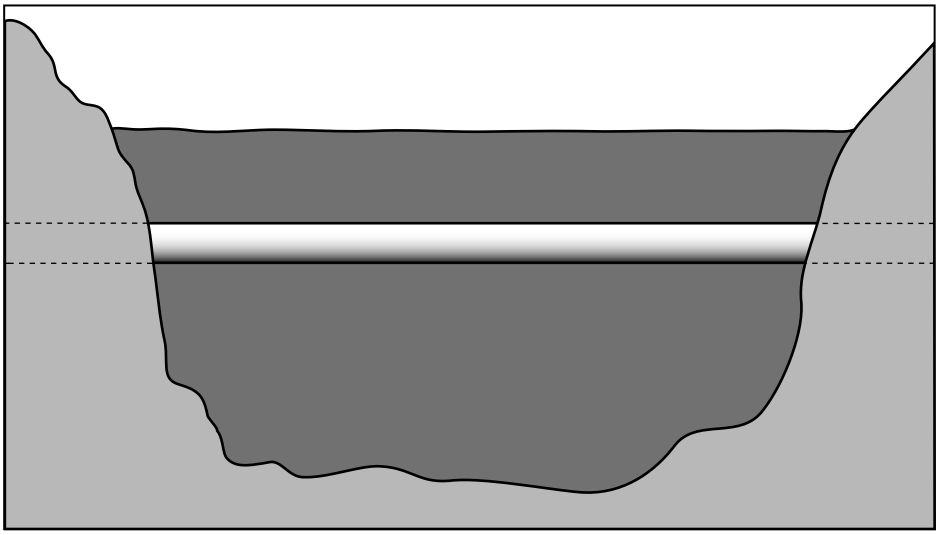

Fig. E4.4 SFT unanchored

From: http://www.engineeringcivil.com/submerged-floating-tunnel.html

Extract 5: New possibilities – floating tunnels

Traditional immersed tunnelling results in a tunnel buried beneath the waterway which it traverses. A new development – the submerged floating tunnel – consists of suspending a tunnel within the waterway, either by tethering a buoyant tunnel section to the bed of the waterway, or by suspending a heavier-than-water tunnel section from pontoons. See Fig. E5.1.

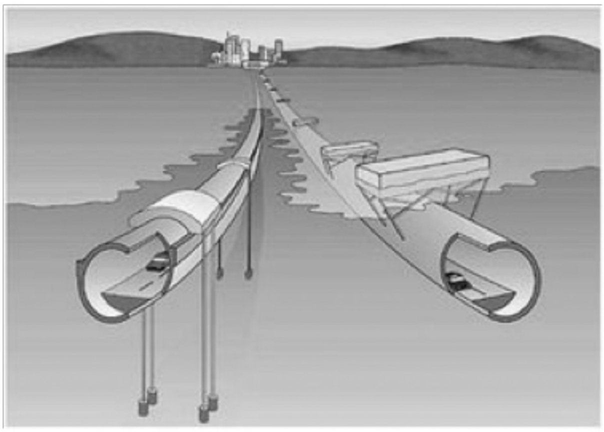

Fig. E5.1

This technique has not yet been realised, but one project, in Norway, is currently in the design phase. The submerged floating tunnel allows construction of a tunnel with a shallow alignment in extremely deep water, where alternatives are technically difficult or prohibitively expensive.

Likely applications include fjords, deep, narrow sea channels, and deep lakes.

From: http://www.ita-aites.org/en/how-to-go-undergound/construction-methods/subaquatic-tunnelling/new-possibilities-floating-tunneling

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