tory, when completed Water Tunnel No. 3 will improve water distribution to major sections of the city, which currently uses some 5.7 million m^3 of water daily.

Stage 2 of this project involves driving an 8km section of the 25.6km tunnel running through hard, jointed rock formations of varying types, including biotite-hornblende gneiss intermixed with granite gneiss, amphibolite, pegmatite and biotite schist some 200m under NYC. One section of rhyolite schist has an unconfined compressive strength of 275MPa.

To carry out this demanding work Markham of the UK with Atlas Copco Robbins custom designed and built a special 580 tonne Model 235-282 TBM in ten months, shipping it to the US in mid-June to the contractor working on this section of the project, a JV of Grow, Perini and Skanska (*T&T, June '96, p16*).

Designed to bore tunnel diameters from 6.5m to 8.5m, the machine is equipped with ten 315kW electric motors to turn the cutterhead at 8 rev/min and deliver a maximum torque of 3.62MNm. The TBM's large (4.6m diameter) three-axis main bearing can sustain high thrust loads up 15.6MN. The machine also has built into it the largest gripper thrust cylinders made for a Robbins design, with a cylinder diaof 1m and an operating pressure of 345 bar.

The TBM's cutterhead has 50 Robbins heavy-duty Series 19 disc cutters, each 483mm in diameter and rated for loads up to 312kN. Two Atlas Copco COP 1238 roof drills are mounted on the machine to enable installation of 2.5m rockbolts radially from crown to springline. Another COP 1238 drill is included for probe drilling and can rotate through a full circle around the main beam. It will also drill 30m ahead of the TBM at an angle of 6° to 10° or directly through the cutterhead.

On this job, the machine has to negotiate both right and left turns of as little as 250m radius. A two-conveyor muck removal system is therefore used, made up of a 15m long conveyor from the TBM feeding a 2.4m long transfer conveyor and a continuous conveyor hopper.

Stage 1 of the NYC Water Tunnel, which is 21.6km long, has been completed, while Stage 2, currently under construction, will serve the boroughs of Brooklyn, Queens and Manhattan. Stages 3 and 4 are still being planned.

Caribbean and Latin America

Puerto Rico

In July this year, invitations were issued by the Puerto Rican authorities to bid for the 1.5km line and station forming the Rio Piedras Contract for Phase 1 of the Tren Urbano Rail Transit System in San Juan. This section of the new San Juan Metropolitan Region Rapid Transit System will be double tracked and constructed by cut-and-cover and mining methods and will pass below an urban area.

Underground structures include 626m of 5.8m diameter twin-bore tunnels, two portals, a junction to a future line, a 138m centre platform station with a shaft at each end and a midline ventilation shaft, and cut-and-cover trackways. A 126m section of the station will be driven under buildings. Work will include: final design and

Age of the mega-projects

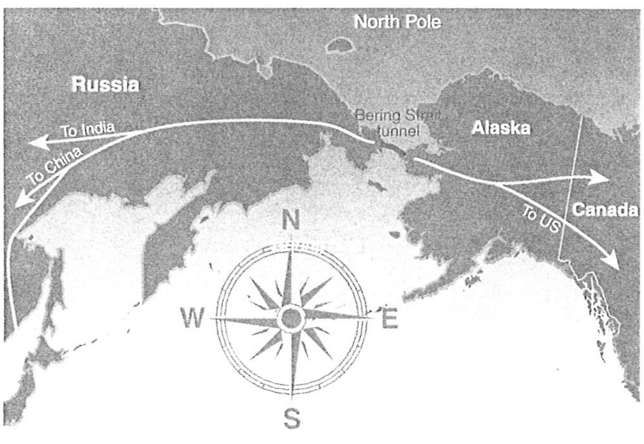
At the international conference entitled North American Tunnelling 96 held in Washington DC in April the latest thinking emerged on a number of large tunnelling projects which at one time were thought to be 'pie in the sky'. A selection follows, plus others which are equally startling in concept.

Bering Strait Link

If Russian and US engineers reach agreement on their plans to drive a series of rail tunnels between Alaska and Siberia under the Bering Strait, timetables for the first rail route to cross the International Date Line should prove interesting.

For more than nine years, Engineering Technology Inc has been working to make this 170-year-old dream a reality. The Interhemispheric Bering Strait Tunnel & Railway Group (IBSTRG) has been working on the same subject for the past four years The Russian Tunnelling Association and allied Russian organisations have been carrying out similarly detailed feasibility studies . These has led to two papers outlining current thinking on this project - one from the Americans, the other from the Russians.

Both suggested that the crossing should make use of the two small islands located in the middle of the strait: Little Diomede (or Krusenstern) Island, which belongs to the US, and Big Diomede (or Ratmanov) Island, which is Russian territory. These islands divide the over water distance between the continents into three sections - 22 miles between Alaska and Little Diomede, 2.5 miles between Little Diomede and Big Diomede, and a further 22 miles between Big Diomede and the Asian mainland.



Location of the proposed Bering Strait rail tunnel.

The Russian and US tunnel concepts call for two parallel railway tunnels: a southern one which links both islands directly and uses each for vertical shaft connections to the tunnel; and a northern one which just passes the north of Big Diomede Island.

According to the Russians, water depth in the Bering Strait reaches 60m and the tunnel alignment is determined by the requirement that rock cover should not be less than 50m. Standard 1.3 and 0.3 per cent gradients must be adopted for the bank and sea sections of the tunnels. Taking into account the fact that trains will be travelling at speeds exceeding 160km/h, large radius curves are proposed of not less than 2500m horizontally and 10 000m vertically. The tunnelwill pass through heavily faulted Pre-Cambrian metamorphic rock and Palaeozoic limestone containing granitic intrusions, whose physical and mechanical properties are under investigation.

However, it is considered that some 75 per cent of the 113km long tunnel will be driven through formations presenting no unusual problems. Even so, some 15 per cent of its length must pass through zones adjacent to discontinuities and through weathered zones of badly fissured water saturated rock.

Both concepts call for excavation of a service tunnel below the two main rail tunnels, which must be able to accommodate

Cutterhead on the Markham/Atlas Copco Robbins TBM for the NYC water tunnel.

construction of a station; construction of utilities, and street and surface restoration where necessary. Completion is scheduled for 2001 (*World News, June '96, p9*).

Chile road building

A massive road building scheme with much tunnelling work was announced at the beginning of 1996 by the Chilean government. Currently out to tender, this $2bn project will involve construction and operation by the private sector and is intended to improve Chile's Pacific ports' links. This is the second phase of Chilean road expansion this century, and bids are invited for 12 road projects in three sectors:

- Highway 5 - the Pan-American High way -worth $1.4bn;
- urban concessions in the Santiago region - worth $350m; and
- an intercity concession worth $300m between Santiago, the seaport of Valparaiso and the resort of Vina del Mar.

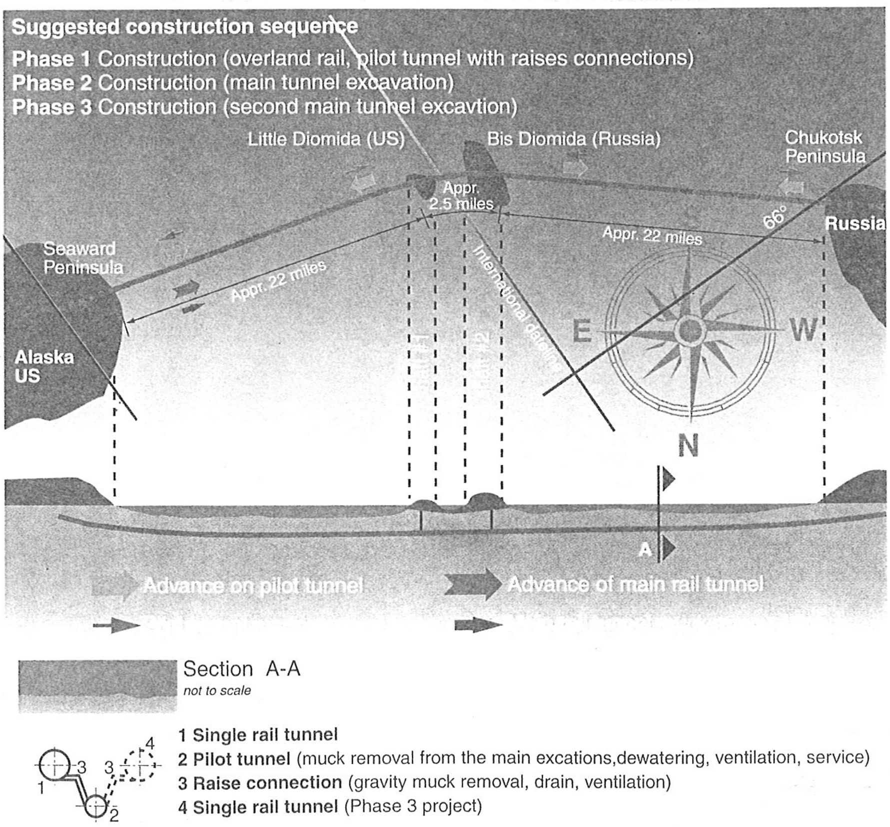
Highway 5 will include a 3.2km long tunnel through the La Dormida Ridge.

Mexico

Ingenieros Civiles Asociados (ICA) has almost completed the Acapulco Tunnel in Acapulco, western Mexico. The 3km long, three-lane road tunnel is being constructed to improve links between the old and modern quarters of town, reducing travelling from 40 minutes to ten. The tunnels will be 12m wide by 9m high.Originally, it had been intended to build twin tunnels using four Tamrock Maximatic 305 T three-boom drilling jumbos, but because of Mexico's economic plight, it was decided to begin work on only one tunnel using two jumbos.

The upper portion of the tunnel has been blasted in either two or three vertical sections depending upon rock conditions, which is mainly metamorphic gneiss with intrusions of granite and diorite. The jumbos are performing a combination of drifting, benching and bolting.

"To excavate the first section, we drilled a 1.5m deep, 48mm diameter hole in the centre of the upper section and blasted a 1m diameter hole," explained Octavio Coria Ochoa of ICA. "Blasting then continued to the full pattern." Subsequent sections have been excavated in 1.5m cuts. Advance rates have varied from 1.5m/12h to



It is planned to excavate a service tunnel below two main rail tunnels under the Bering Strait.

nearly all existing rolling stock configurations. In the first phase of construction, only the southern main tunnel would be excavated, plus a 1400m length of northern tunnel to allow trains to pass each other.

The US concept envisages that the service tunnel be excavated first to provide a means of ventilation, spoil removal (via belt conveyor) and tunnel maintenance, plus access to the other tunnels.

Gibraltar Strait Tunnel

In March this year the Spanish and Moroccan governments announced their approval for work to start late next year on the construction of a rail tunnel under the Strait of Gibraltar (*T&T, Mar '96, p7*).

Agreement over the scheme had been reached the previous month at the Spanish-Moroccan summit conference held in Rabat, Morocco, and announced by the Spanish minister of public works, Senor Borrell.

The 28km tunnel will be driven from Tarifa in Spain to Tangiers in Morocco. It will run 100m beneath the seabed at a maximum of 400m below sea level. Completion is anticipated by 2010. Estimated cost is around $4bn. The Spanish government considers that the rate of return is adequate to make private investment attractive, possibly on a Build-Operate-Transfer (BOT) basis.

Borrell also announced that a pilot tunnel would be under construction in less than two years. However, because of the timing of the announcement, made on March 3 during the run-up to the Spanish general election, and the general lack of earmarked funds, there is some concern that the scheme will still take a long time to get off the ground. Both governments have yet to approach the EU for funding.

Messina Strait Project

The design/proposal by the ENI consortium for a Messina Strait fixed link between Calabria and Sicily, submitted to the Italian government in 1993, is still under review. The proposal envisages a twin-track, 5.3km long rail tunnel and two separate two-lane road tunnels, 6.6km and 6.9km long respectively. Each of the three crossings will comprise 4.5km of submerged floating tunnels, the remainder being immersed tube tunnels and landfall (bored) tunnels. The crossings will take place at a depth of some 40m below sea level, in a channel where maximum water depth is about 350m. This channel is tra-

3.5m/8h, depending upon rock quality. Shotcrete and systematic rockbolting has been applied as initial support, while for the first 150m from each portal and in poor quality rock, 254mm x 146mm steel arches have been installed at 1m intervals.

ICA is using two methods of excavation for the lower section: the first is to excavate a central section followed by two side sections; the second is to excavate a heading and bench. The tunnel is being lined with hydraulic concrete at the portals and in poor quality rock, and with 80mm thick shotcrete over the remainder of its length.

South East Asia

Thailand

In May this year, Bangkok's Rapid Transit Authority signed a contract with a JV comprising Mott MacDonald of the UK, US-based De Leuw Cather and four local companies to project manage development of the city's $3bn metro scheme. The scheme will include some 20km of twin tunnels plus 20 stations and is scheduled for completion in 2003. The 5.7m diameter concrete lined tunnel will be located 15-25m below ground in stiff clay and will probably be driven by EPBMs. Construction will start early in 1997 and will be undertaken as five packages: the southern 5km; the northern 5km; the depot; lifts and escalators; and trackwork.

Indonesia

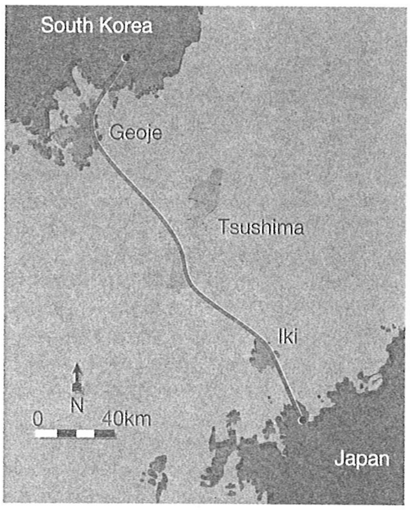
In a JV with Hyundai Engineering and PT Mercu Buana Raya of Indonesia, Jin Ro Construction is working on construction of two headrace tunnels for the Renun Hydroelectric Scheme in Sumatra, the company's first project outside Korea (*T&T, Jan '96, p8*). Two Atlas Copco/Robbins TBMs are being used on the project.The tunnels are being driven through ground that includes consolidated dacitic tuffs with unconfined compressive strengths of 100 -500kg/cm^2. Core samples tested showed values of 300kg/cm^2.

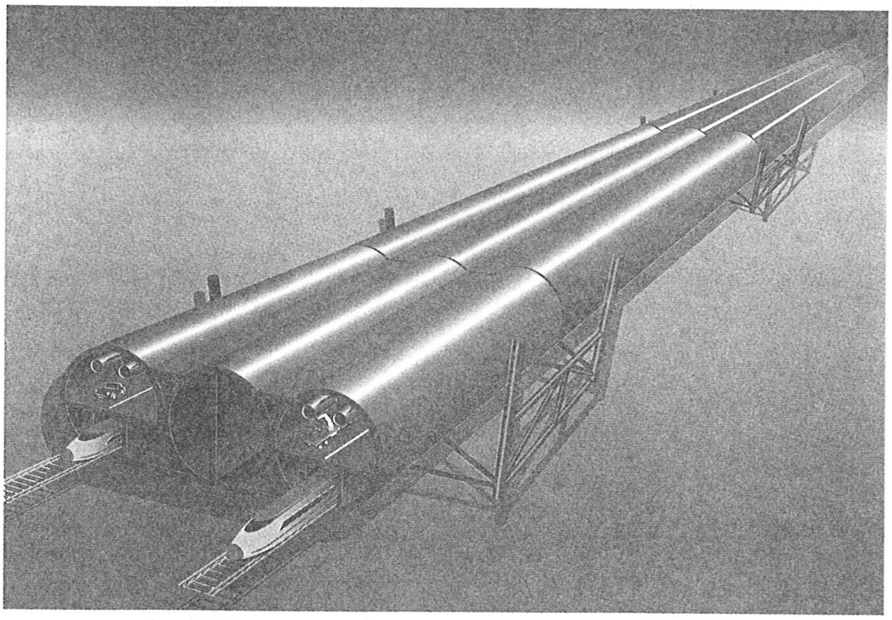
The TBMs will drive the 8.5km long upstream headrace tunnel on Lot 1 of the project, with excavation proceeding on a 1:9 gradient from the regulating pond to the intake under 50-60m of cover. Blocky ground and water inflows were expected in a 2km section near the regulating pond where eight rivers meet above the tunnel.

Lot 2 work includes the downstream headrace tunnel bored using a No. 1114-262 TBM upgraded with a Robbins 3.92/3.97 diameter modification kit. This TBM is being used to drive 10.3km from the surge tank to the regulating pond at a gradient of 1:1000 in hard dacitic tuffs some 260m below the surface.

Malaysian projects

At the beginning of the year, three EPB machines were delivered to central Kuala Lumpur for driving the first urban rail tunnel project in Malaysia. Japanese contractor Hazama is excavating 1.5km of the city centre's 5km long twin 4.9m diameter tunnel for the city's light railway under a $39.2m design+construct contract. The 35km light railway scheme will stretch





Above. Projected road and rail tunnels linking Japan and Korea.
Right. The tunnel comprises three steel immersed tubes.

versed by a number of geologically active faults and past experience suggests that earthquakes up to 7.5 on the Richter Scale can occur locally, accompanied by ground accelerations of 0.36-0.63 of gravity.

Steel shells of identical diameter are proposed for both the road and rail tunnels. Full transverse ventilation is proposed for all tunnels, space being provided below the roadway for supply air and above the ceiling for exhaust air. Cross passages between the floating, immersed tube and landfall (bored) tunnel sections act as important buffer zones.

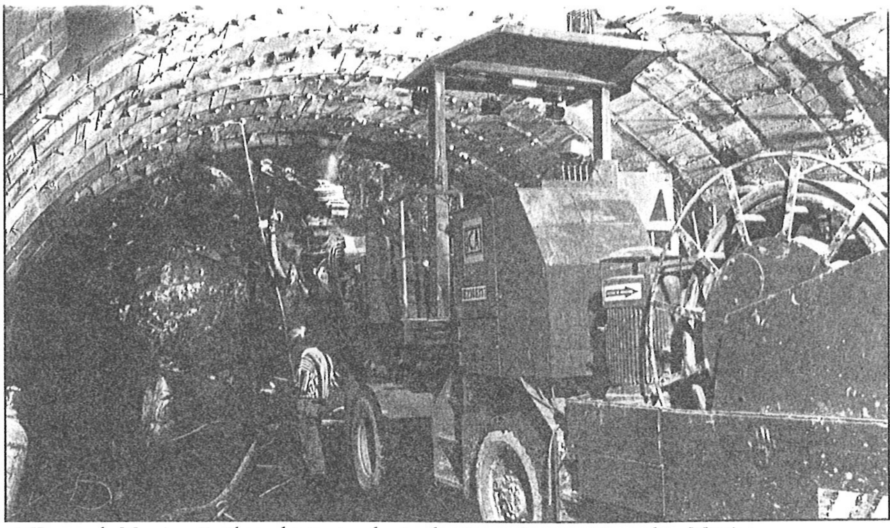
Site conditions and the different constraints imposed by the three tunnel types used for different parts of the crossing dictated the use of two different cross passage tunnels, one between the bored and landfall tunnels and the other between the floating and landfall tunnels.

The floating tunnels are composed of 65 identical 72m long elements. Each has three concentric steel shells, with 1m of air space between the outer and first inner shell and a 0.5m concrete filled annulus between the two inner shells. The innermost tunnel has an i.d. of 13.95m, while the outer have an o.d. of 17.29m. With diaphragm walls every 3m and bulkheads every 12m in the air space, the tunnel is designed to withstand ship collisions by allowing two of the 12m long air compartments to be breached without the inner tunnel being affected.

The basic design envisages two 3.75m wide lanes and one breakdown lane for each roadway tunnel, with two 0.25m wide hard shoulders. The road tunnel is designed to have two 3.5m wide tracks with a 1.8m wide centre gallery between them, plus 1.2m and 1.03m wide safety walks for each track, giving a total width of13.3m.

Each floating tunnel element, which is to be held in place at its centre by four tethers, is designed for 70 tonne/m of positive buoyancy. The tethers, which will extend from above and under each element to anchors on both sides of the tunnel, will consist of steel templates tied down by four pipe piles. These templates are designed to provide suitable locking with the tethers, which must engage them at angles ranging between 45° and 60°.

The landfall tunnels at each end will comprise three distinct elements:



A Tamrock Maximatic three-boom jumbo in the Acapulco road tunnel in Mexico.

from Shan Airport to Gonback and is due for completion in time for the British Commonwealth Games in September 1998.

The NKK manufactured EPBMs have a 5.4m dia. and are more powerful than most usually employed by Hazama. They have been chosen to cope with Malaysia's ground conditions, a mixture of hard rock and limestone. TBV Consult, part of Tarmac, has been working with the Malaysian consultancy Sepakat Setia Perunding to provide quality assurance for the design.

Later in September this year it was announced that Mitsui Construction Co. of Tokyo had won a contract valued at $42.8m from Kuala Lumpur City Centre to Berhad to construct a 450m exit tunnel from a major city centre development. The tunnel will be routed under Lorong Kuda to exit to meet the main Jalan Tun Razak road. Included in the contract is a 25m southbound entrance tunnel. Completion is scheduled for September 1997.

Philippines water tunnel

Also in September Italian JV GLF-SELI, already working in the Philippines on the Umiray-Angat Transbasin Water Project, ordered a 4.9m diameter double-shielded TBM from Atlas Copco Robbins. It which was scheduled for delivery in November and will excavate a 12.1km long tunnel joining the Umiray catchment area to the existing Angat Reservoir through five fault zones. The reservoir is the main source of fresh water for Manila.

The main reason for choosing this TBM is that it is able to cope with rock formations varying from 30MPa to 200MPa unconfined compressive strength. The machine has been designed with two modes of thrust action, telescopic shield sections and recessed cutters. ■

● The offshore tunnel interface element (OTIE) connecting the landfall tunnels to the floating tunnel. This will be 60m long, supported by six pairs of piles, and will serve as an anchor to the series of landfall elements. It will function as the end anchor of the floating tunnels and for this purpose will contain a specially designed transition module to receive a special joint (Seismic Joint B) designed to prevent seismic vibrations interfering with the integrity of the tunnel at this point.

● The landfall tunnel interface element (LTIE), the last landfall portion of the tunnel, which connects the immersed tube with the bored landfall rock tunnel. The LTIE on the Calabrian side of the Messina Strait contains the construction access shaft for the equipment to be used in interior work for the entire crossing.

● The Intermediate Tunnel Elements (ITE) are the immersed tube tunnels located between the transition elements of OTIE and the LTIE.

The seismic joints are necessary because of the fundamental difference in the support systems of the floating and landfall tunnels, causing them to respond differently to seismic forces, ground motion and to loads attributable to long-term operation. Seismic Joint A consists of a fixed ring and a moveable collar. It will not receive any loads and can move longitudinally by 0.2m or transversely by 0.3m to satisfy environmental and operating requirements.

Seismic Joint B, on the other hand, comprises a fixed collar attached to the landfall side within which the tunnel section on the floating tunnel side can slide longitudinally. During construction, the damping system will relieve the axial pressures present in the temporary joint restrainer, transferring them to the tunnel element shell plates and the foundation. After the restrainer has been removed, the system will be free at the joint, so enabling it to attain its final operating position.

Japan-Korea scheme

It is 15 years since the Reverend Sun Myung Moon proposed construction of a 'great Asian highway' through mainland China, crossing the Korean peninsula from north to south to an underwater tunnel or bridge to Japan and running north through all the Japanese islands. Although politics have slowed down the scheme, plans have developed through the years. Research on a rail tunnel under the Tsushima Strait between Japan and South Korea did in fact begin in 1940 but was abandoned after the Second World War.

Instead, Japan started on the construction of the Seikan undersea tunnel between Aomori and Hakodate, which has been in service since 1988. The undersea section of the Seikan Tunnel is 23.3km long and 140m deep at its deepest point, amply demonstrating the feasibility of such long undersea tunnels in an area periodically subject to severe earthquakes.

The proposed route for the Japan-Korea Tunnel undersea route passes through the islands of Iki and Tsushima at the strait's mid point. The section under the Iki Channel between Iki and Kyushu is 22km long and reaches a maximum depth of 60m. That under the East Channel between Iki and Tsushima reaches 120m and is 49km long. The portion of tunnel under the West Channel between Tsushima and the Korean mainland is also 49km long and reaches a depth of 200m.

Unconsolidated soil, sand and boulders were found to have accumulated to a depth of 500m beneath the seabed underlying the Tsushima Strait, making conventional tunnelling methods impracticable. Therefore, sonic surveys of all the possible routes were carried out, with accompanying boring to depths of 200-500m in sedimentary material in the land approaches to the strait and in the bed of the strait itself. This work led to examination of the immersed tube tunnelling method as one of the construction possibilities.

At the 1995 20th International Conference on the Unity of the Sciences held in Seoul, South Korea, Dr Yoshimaru Murakami, Director of the Japan-Korea Tunnel Research Institute, outlined the philosophy behind the application of the immersed tube method to this project and advocated the Maglev (magnetic levitation) system for transporting the vehicles.

As traffic volume increases, the car/train could be doubled in length to reach 500m. But to maintain tunnel throughput, another tunnel would have to be built to complement the first. This would be achieved by employing in the first instance horseshoe shaped inner sections for the tunnel elements. which could be sunk and placed on the sea bed. Each element would be 250m long and weigh 38 500 tonnes.

About 500 steel shell immersed tube units, each weighing about 4000 tonnes, would be needed. Dr Murakami suggests that these could be manufactured at the large dockyard facilities in Nagasaki or Sasebo. To meet projected completion dates it would be necessary to sink one 250m long tunnel element/week.

As part of the projected East Asian Highway/Rail Link, the Japan-Korea Tunnel, like the rest of the route, requires foreign investment and participation in the form of JVs for it to become a reality. ■