During recent years, the Tyrol has become more and more important as a cross road center in the Alps, due to the construction of important north-south road links. The Brenner and Reschenpass are the lowest, and during winter, safest crossings in the Alps.

With construction of the motorway from Kufstein via Innsbruck to the Brenner, the most important Alpine cross road has been completed.

The road from Ulm, in Germany, to Milan, via the Fern- and Reschenpass, will not only serve as an important European Trans Alpine north-south link, it will also create an equilibrium between areas which are more economically developed than others.

In addition to these north-south links, the most important crossing in the east-west direction in the Austrian Alps will be the Arlberg Tunnel. It will link the two provinces of Tyrol and Vorarlberg, up to now separated by the natural barrier of the Arlberg.

Apart from its enormous importance for the entire Austrian economy, it will be an outstanding part of the Trans-European road network (picture 1).

Ninety years after the inauguration of the Arlberg Rail Tunnel, on the fifth of July, 1974, work has been started on the Arlberg Road Tunnel. It is about 14 kms long and has its eastern entrance in St.Anton and its western in Langen. The
pict. 1: Trans European road network

pict. 2: Location of the Arlberg Road Tunnel
construction of the second largest road tunnel in Europe thus has been started. The link through the Arlberg consists, in fact, of 2 tunnels. The bypass tunnel for St. Anton, 3.6 kms, and the main tunnel, 10.5 kms, cutting through the main massiv of the Arlberg.

It will be equipped with two vertical ventilation shafts and all the necessary caverns. The Maienwasen shaft has a diameter of 9.12 m and will be 230 m deep. The Albona shaft will be driven 748 m deep and has a diameter of 8.37 m. Thus, it will be the most remarkable shaft construction for ventilation of a road tunnel in Europe.

**Location of the Tunnel**

To achieve the optimum conditions for construction and its final use, most extensive studies, concerning various different projects, had to be considered. The research included the geology and topography of the pass area and ecological problems in the important tourist area of the Arlberg (picture 2).

The axis of the tunnel, due to geological reasons and from the operational point of view, is not straight.

In the first phase of the construction, only the southern tube, designed for two-car lanes, is being built. The northern tube, phase 2, is planned in such a way that its construction will not disturb traffic through the first tube.

The bridging of the Rosanna Valley, between the bypass and the main tunnel, will be affected by a closed tube to keep off unfavorable weather conditions, and to avoid interruption of the ventilation system.

**Standard Profile**

The diameter of the tunnel depends on space necessary for the
moving traffic, the ventilation, the canals for various other installations, and water drainage. Apart from all this, the design and size of the profile depends on the conditions of rock to be expected.

On the photograph, you can see the two types of profiles for solid and for pressure exerting rock (picture 3). The cross section of excavation varies between 90.6 and 95 m². The rock is supported by sprayed concrete, anchors, steel mesh and steel ribs following the system of the New Austrian Tunneling Method, in short NATM. The sprayed concrete arch is being water proofed where necessary.

The inner ring, which has no structural functions with respect to the rock within the NATM, carries the partition deck and all other installations. The partition deck is being attached by anchors placed in the partition wall. Arch, partition deck, and wall, are being constructed separately, each in 12 m sections by pumped concrete.

Above the partition Deck are the ventilation ducts for fresh and used air. In the borderstone, the pipes for the drainage of the driveway will be installed. Somewhat apart of the tunnel axis is the main drainage.

**GEOLOGY**

Two basic geological entities meet in the Arlberg area: the younger paleozoic and mesozoic sediments of the northern limestone Alps, and the crystalline rock of the Silvretta massive in the South. These both tectonically formed large entities meet at a very morphologic seam. In the Arlberg area, the very wide East-West zone of disturbances stand vertically to steep. The precambric, metamorphic complex of the Silvretta includes, from North to South, shale-gneis to gneis-phyllit, mica schist, granitverous muscovit and felsite gneis (picture 4).
ARLBERG TUNNEL

ARLBERG - STRASSENTUNNEL
REGELPROFIL

pict. 3: Standard Profile of the Arlberg Road Tunnel

pict. 4: Geology Arlberg area
For the purpose of the prognosis of the geological and rock movement conditions, extensive field surveys have been carried out; several core drillings for subsurface exploration in the portal areas and at the surface points of the air shafts. The most important results were obtained from old engineering documentations, dating back during the construction of the railway tunnel in the years 1880 until 1883.

The motorway tunnel is located 90 to 250 m south of the railway tunnel and is parallel to it. The hydrogeological conditions and the deformations, as well as readjustments of the tunnel supports, have been investigated. Through these investigations, conclusions could be drawn for the rock movements in the new tunnel.

Construction Method

The drive, securing and support of the rock is carried out according to the NATM. This method has been developed in the course of a long range of experience, the oldest dating back to almost half a century. Its actual rules, with regard to the rock movement, are based on mining experience for many centuries. On one hand, through the use of modern stabilizing materials, and in the other hand, through measuring in situ, which includes the influence of the time factor and the use of the rock movement experience, one can follow the interplay of forces in the surroundings of the excavation and find out the beginning of the equilibrium. The surrounding rock will be transformed from a loading into a carrying body.

The reason for the world-wide success of the method is its development by practice. The means of stabilizing being used with NATM are in general: sprayed concrete, anchoring and light steel ribs.

Steel laggins and grout injections for consolidation are being used to assist the drive, or as means of stabilization as required.
The most important means of stabilization have to render the following functions:

A) Sprayed concrete is much older than the NATM. By its outstanding performance, solidity, stability, adaptability, and yield capacity, it continues to be one of the most essential means of support with this method. It is particularly useful for immediate sealing of bare rock. Another very important advantage is that within a very short time, relatively high hardness can be achieved, which is an important feature in modern tunneling. To apply sprayed concrete successfully, it must include a waterproofing and quick setting admixture for early high strength of the concrete, which also reduces considerably the rebound. At this point, I would like to mention that due to the importance of the sprayed concrete in the NATM and the complexity of its use, the spraying equipment, including the metering and the admixtures, ought to be entrusted for delivery and servicing to one and the same firm for obvious reasons.

Sprayed concrete, in cavity construction, has several functions:

1) As a seal against atmospheric weathering, thus stopping chemical change and deterioration of the rock.

2) Linings of cavities to avoid a build-up of stress concentrations at the border zone.

3) If sprayed concrete is being applied in thicker layers, as for surface sealing, it also takes the function of an arch.

In all three cases, the close bond and adhesion with the rock is of major importance. The sprayed concrete forms a load-bearing structural unit with the surrounding rock. As the properties of the concrete, to a great extent, allow it to absorb radial deformations, it meets the requirements of
a semi-stiff support. Only in case of very substantial deformation of the border zone, will sprayed concrete be liable to break. Reinforced by steel mesh, sheared off parts of sprayed concrete do not cause any immediate danger to the workmen.

B) More important than sprayed concrete, which rather serves as an upgrading of the rock surface, is the stabilizing effect of anchoring. Anchoring being applied systematically speeds up the development of a carrying rock arch. The functions of anchors is to hinder radial distortion resulting in a directed and controlled deformation, thus preserving the geometrical form of the excavation to a great extent.

The various types of anchors, for instance, expansion anchors or grouted anchors, have to be used with respect to the various types of rock. One ought to prefer grouted anchors as through their adhesion to the rock, they allow the formation of the secondary arches between the anchors. Expansion bolts should be used mainly as local safety measures in solid rock and grouted anchors as systematic anchoring in friable rock up to pressure exerting rock.

Under difficult condition, as in the Arlberg tunnel, anchoring is the most important means of stabilization. Therefore, the determination of the length and density of the anchoring is of extreme importance. This determination, in extremly difficult situations, can be estimated only by using deformation measurements in situ. In extreme cases on the Arlberg, we used grouted pre-stressed anchors 6 to 12 m long.

On the basis of the geological and rock movement calculations, the rock has been classified into 6 types (picture 5), which again corresponds with described rock classes. For various rock quality classes, typical support measures have
pict. 5: Rock classes for excavating and supporting

pict. 6: Rock - movement after excavating roof and bench I and II
been established. According to the determined specifications, and the geological conditions, the support resistance has been established.

The determination of the rock classes at the tunnel face and the determination of support measures, which do not always correspond to the general planning, are being established on site by the representatives of client, together with the contractor.

An integrating part of this method are the geotechnical measurements. The deformations of points of the border zone of the cavity are being controlled by convergency measurements (picture 6) and the differential deformation of the rock by multiextensometers. They allow the determination of strain in various stages of depth. Tensions are being registered by pressure pads measuring the radial tension between rock and outer arch, and also the tangential tensions of the latter. This set up serves as control of the ring tension of the inner arch.

Any activity influences the rock movement, especially the type of support, removal of benches, closing of the invert and so on. Where activities, which can not be monitored satisfactorily with computation models, the measurements form the only reliable control regarding the real development. In the case of longer tunnels, the possibility for comparison between the observed behavior of the rock and support offers the immediate use of the experience in practice. With the help of the measuring observation in situ, stabilization can be adapted and modified in due course.

Operation for Arlberg Tunneling

Our joint venture has been awarded with the construction of the eastern part of the tunnel, that is the 3.6 kms by-pass tunnel
pict. 7: Electrohydraulic drilling equipment on ATE by Atlas Copco

pict. 8: Mucking by a Broyt-excavator and loading on a Kiruna Truck K 250
and about 5 kms of the main tunnel. We had therefore the possibility to attack the job from various points. On the basis of the local situation, we decided to run the site without rails in the tunnel.

Already six weeks after we received the firm order, we started with the excavation of the bypass tunnel, from the east in its full profile in two or three floors, according to the quality of the rock. The constant, and often sudden, changes between the different classes of rock to be expected led to the decision to excavate even in better rock about 60 m² of the top part of the profile.

Immediate adaption, in case of excavation of high pressure exerting rock, by using a second bench and thus reducing the first attack in the top to 30 m², enabled us to meet the necessity of a smooth drive, quick securing and supporting.

In line with the specifications of the rock movements and the deformations, the speed of drive can be adjusted accordingly. By avoiding rails in the tunnel, it is easy to surmount differences in height and other obstacles. If geotechnical measurements prove that additional supporting is necessary, these supports can be installed without hindering the driving activities. For the first time in Austria, in the main excavation area, electro hydraulic drilling equipment, by Atlas Copco, is being used (picture 7). In the roof, there are 4 booms and in the bench 3 booms (But ER 14). The equipment is mounted on a 40 ton truck. At rounds from 0,75 m up to 4.0 m, between 20 and 240 m³ rocks are being loosened by each round, and are then loaded by an electric powered Broyt excavator X 4 with 2.7 m³ loading shovel on Kiruna Trucks K 250 (picture 8).

In high rock classes 4 and 5, a mechanical shovel transports the excavated material to a Broyt excavator.

The dry mix for the sprayed concrete is being hauled by
pict. 9: Central crashing and mixing plant on ATE

pict. 10: Storage hopper with spraying machines by Wallco
concrete mixers from a central plant (picture 9) to the various working stations and filled into a storage hopper on wheels.

Via conveyor belts, with mounted meterings for the correct addition of the quick setting admixture, the mix is fed into the spraying machines and there off transported through 65 mm hoses by compressed air to the nozzles (picture 10). Performances from 6-8 m³ per machine per hour guarantee a rapid sealing of the bare rock. A proper choice of the ratio of material, cement and admixture results in a strength of the sprayed concrete of over approximately 7,840 psi after 28 days. The steel mesh is being fixed by short bolts to avoid the large quantities of the comparatively expensive sprayed concrete to fill excess profiles. They can be filled in by pumped concrete.

It is very important to close the floor in the loose material near the entrances resulting out of mud flows and so on (picture 11). High moisture causes, in general, immediate pressure at all exposed surfaces. The time of the closure has to be coordinated exactly with the measuring of deformation (picture 12). By cutting through the above mentioned loose material at the entrances for a length of about 120 m, we found remnants of huge Larch trees which had been covered about 10,000 years ago by mud flows.

As a consequence, because of water saturation, this material partly lost any solidity. We could stop the deformation by intensive system-anchoring, sprayed concrete, steel mesh and steel ribs but we did not have to use steel laggings.

By thorough filling of all cavities along the drive with sprayed concrete, we succeeded in avoiding uncontrolled loosening behind the outer ring.

The electricity is being supplied, up to about 300 m behind the heading, by a voltage of 10 KV via cables to a mobile transformer station mounted on a truck. The various equipment
pict. 11: Loose material near the entrance of the bypass tunnel

pict. 12: Measuring of the deformation
and installations are being supplied via low voltage cables from this truck.

50 m³ air compressors, equally mounted on trucks, equipped with special coolers and their own transformers, are being placed as near as possible to the various points of application, thus avoiding loss of air at pipe couplings and by friction in long pipes.

We succeeded in reducing construction time by about 7 months for the 3.6 km bypass tunnel by starting a pilot tunnel from the west.

After the middle of the bypass tunnel, the crosscut of the full profile drive from the east and the reduced profile drive from the west, we are able to start a very successful system of widening to full profile. The complete supply with construction materials, sprayed concrete, and anchors for the securing and supporting of the rock, was fed from the west. The excavated material was transported by wheel shovels eastward until it is finally transported by Kiruna Trucks. We succeeded according to the rock quality in a performance of between 12 m to 22 m per day in 24 hours. The low height in both working sides, especially for the installations of securing, the much simpler air ventilation system, and the two independently operating working parties, are the reason for the high speed of drive in shale gneiss and mica shale, which requires a complete securing and supporting after each round.

We started work on the main east tunnel with a pilot tunnel, which was located at the base of the tunnel profile (16-20 m²) without any equipment on rails (picture 15).

One of the reasons for this pilot tunnel was to get more information regarding the rock. Due to information obtained, we were able to save money in the provision of support.

We could partly install the final floor, which gave us good
pict. 13: Shotcreting on ATE maintunnel

pict. 14: Shotcreting on ATE - bypass tunnel
traffic conditions. Furthermore, we wanted to reach the point of the ventilation cavern at the foot of the 230 m deep Maienwosen shaft situated about 1100 m from the entrance as soon as possible.

This way we could start to drive a pilot shaft with 4 m² from bottom to top, and so, we could transport the material resulting from the widening of the shaft to full profile through the pilot tunnel.

Parallel with the further drive of the pilot tunnel towards the west, the entire drive, securing, and concrete jobs in the shaft could be finished within 10 months.

In general, we used the same system as described for the bypass tunnel heading the pilot tunnel. As of station 1700 m, we arrived at gneiss and phyllitic mica shale in thin layers, with strong mylonit traces, both under tectonical stress, creating heavy pressure and deformations. To immediately achieve the final securing and support, steel ribs, sprayed concrete, steel mesh and system anchoring, we elevated the floor bench over a length of 30 m to 4 meters under the top of the main profile and drove and secured the final roof over a length of 100 m. Because of the most disagreeable rock and deviation to the prognosis, and on the other hand the direction of our client to save time, we had to apply a very intensive drive.

The first measure was to start widening the pilot tunnel to a profile of 60 m² in the top, as of station 1100 m, till the already completed roof, as of station 1700 m and driving on with 60 m² to station 2600 m. The complete supply with materials was being fed through the 1100 m pilot tunnel. The transport of the excavation material was being done also by Kiruna Truck K 250 through this pilot with a profile of about 16 m².

Subsequently a double-widening followed, requiring pre-planning
plot 16: Entrainment of the by-pass tunnel in the Rosana Valley

plot 15: Operation system in the mountainous Alps
of organization, with one drive from the shaft outward to the east and another drive simultaneously from the Rosanna Valley to west. Employees and construction material were being transported through the pilot tunnel, material for sprayed concrete, electricity, pressurized air and water, were being fed through the shaft. The ventilation, in either case, was to come from a ventilator mounted on the top of the already finished Maienwasen shaft. The excavation material was temporarily being disposed of near station 2000 m. The crosscut of this 1100 m long part of tunnel succeeded on 90 days (picture 15).

Since this time, the crew is driving from station 2600 m to the est, and another crew is excavating the necessary caverns on the bottom of the shaft for the ventilation equipment.

A third crew is removing the second bench. Between the first and last drive, we have to transport the materials on a rough floor on bench 2 for about two thousand meters.

All bottom concrete floors, inner arch, partition deck and wall are following parallel to the excavating of bench 2.

The advantage of this complicated operation is the reducing of construction time by about two years.

The performance in the main drive in a pressure exerting rock, with deformations of about 30 cm in 20 days, are 4 to 8 m; the performances of removing the bench, 10 to 14 m per day.

To reduce more construction time, the costs of financing, and the losses through inflation, we are using a 3 shift working system all year around, interrupted only at Christmas and Easter.

With a total number of 470 blue collar and 30 white collar employees at Arlberg East, we serve three drives and a complete concrete group. On construction of buildings outside
the tunnel, about 40 men are occupied. The aggregate plant and concrete plant employ about 130 men. The serving and maintenance of the entire equipment, with a total of about 25,000 H.P., absorb a staff of about 70 employees.

With this number of employees, we succeeded in keeping in line and most times even surpassing the constructural targets at our contract. These were according to the classification of rock, to construct per day between 1.40 m in high pressure exerting rock, 5.60 m on generally friable rock, up to 11.20 m in solid rock.

A highly qualified team of well-trained engineers and experienced operators, after finishing this job in 1979, will have abolished the last major obstacle within the road link from Vienna to Paris.

Quality control on the East Arlberg Tunnel site.

In order to construct according to the client's specification it is necessary to control the production of the shotcrete and pumped concrete very carefully. This includes the materials; storage and batching; mixing and transport of the concretes.

The aggregates were obtained from a convenient source in a nearby river. The production of aggregates was at the rate of 1500 ton per day with a monthly total of approximately 45,000 tons a month. This material was crushed, washed and graded into 5 sizes thus the sand (0-4 mm) is tested once a day to check for fine content (0 - 0.2 mm).

The moisture content of the sand is constantly checked by a neutronic sund in the storage bin.

The grading of the larger aggregate sizes is checked once a week. The specific gravity and bulk density of each fraction is checked once a month.

Cement is supplied by two production plants who manufacture a
specially controlled product for our tunnel project.

250 tons are required per day. Samples weighing 1 kg are sent each week to our client's material laboratory. The water required for the mixing plant is obtained from the river. The supply was checked by the laboratory before the contract commenced.

The accelerator for the shotcrete is checked once a week using the Vicat needle setting test and a standard cement sand mortar. The timings (0-3 min - 5 min) are repeated five times.

An accelerator sample is sent to the laboratory once a month. The admixture for pumped concrete which is an air entraining, plasticiser, accelerator type, is checked once per month, by the client's laboratory.

**Shotcrete testing**

Every 3000 m³ approximately we make
a) test panels without accelerator
b) three panels with 2% accelerator
c) three panels with 4% accelerator.

From these panels are produced test cores and cubes.

Half of these are tested on site and the other cubes are sent to the client's laboratory.

Every 200 m (approx. 600 ft) of shotcrete lining we drill 3" - 6" cores (150 mm) or 5 cores with 100 mm diameter (4") or 10 cores with 50 mm diameter (2").

These are all tested in the client's laboratory.

Constant supervision of the concrete is maintained by the client's staff together with one member of the contractors staff.

They check the pump concrete regularly for
a) Temperature
b) entrained air
c) fresh density

d) consistency (flow table)

Approximately every 200 m³ they make 6 (200 x 200 x 200 mm) 8" x 8" x 8" cubes. Three of these cubes are tested after 28 days in our own laboratory on site. The other are tested after 56 days. From each 1000 m³ one set of three cubes is tested by the outside laboratory (client's).

From each 500 m³ we make 3 cubes of 1 ft x 1 ft x 8" dimension (300 mm x 300 mm x 200 mm) and these are checked for impermeability and freeze/thaw resistance in the outside laboratory.

The shrinkage of the inner arch is measured every 1000 meters (3000 ft approx.) after 3, 7, 12, 28, 56 and 90 days.

The temperature of the air in the tunnel on many points of the profile and the humidity is recorded each day.

All results are written into a schedule and drawn on a chart.

As you will appreciate from this brief report our quality control is very thorough and an inseperable part of the whole project.

pict. 17: Shotcreting in the roof of the bypass tunnel after the crosscut.