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**Autor:** Grob, Josef

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## Cable-Suspended Pipeline Crossing a Glacier in the Alps

Conduite suspendue au dessus d'un glacier dans les Alpes

Hängeleitung über einen Gletscher in den Alpen

**Josef GROB**  
Civil Engineer  
Universal Eng. Corp. (UEC)  
Basle, Switzerland



Josef Grob, born in 1945, obtained his civil engineering and his doctorate degrees at the Swiss Federal Institute of Technology in Zurich (ETHZ). He has been working as a senior designer with the consultants Schneller, Schmidhalter and Ritz, Brig, Switzerland. At present he is a division manager in structural and civil engineering with UEC.

### SUMMARY

A four stage pump installation supplies water to a site at Felskinn above Saas-Fee, Switzerland, from 1830 to 2987 m above msl. At the top stage the water pipeline is suspended across a glacier by a free hanging cable system with a main free span of more than 600 m. It was necessary to erect an intermediate pylon on the glacier, due to the unfavourable characteristics of the topography. This pylon moves about 15 to 20 m per year as a result of the creep of the glacier.

### RESUME

Un système d'approvisionnement en eau, équipé de 4 stations de pompage, alimente un chantier situé à Felskinn, au-dessus de Saas-Fee en Suisse, soit entre les altitudes de 1830 et 2987 m. La section supérieure de cette conduite d'eau traverse un glacier et est suspendue sur une portée principale de plus de 600 m, grâce à un système de câbles. La topographie défavorable a contraint la mise en place d'un mât intermédiaire dont le déplacement annuel atteint entre 15 et 20 m par an à la suite du mouvement du glacier.

### ZUSAMMENFASSUNG

Zur Versorgung einer Baustelle auf Felskinn oberhalb Saas-Fee in der Schweiz transportiert eine vierstufige Pumpförderanlage Wasser von 1830 auf 2987 m.ü.M. Die Förderleitung überquert im obersten Abschnitt einen Gletscher an einer Freileitung mit einer Hauptspannweite von über 600 m. Wegen des ungünstigen Längenprofils musste auf dem Gletscher eine Mittelstütze angeordnet werden, die sich infolge der Kriechbewegungen des Gletschers um 15 bis 20 m pro Jahr verschiebt.



## 1. INTRODUCTION

The cable-suspended pipeline, Fig. 1, is part of a pumping installation for the supply of water to the site of the construction of an underground cable-car "Metro-Alpin" at Saas-Fee, Switzerland. The pipeline supplies water from a point 1830 m above msl to Felskinn at an altitude of 2987 m.

The "Metro-Alpin" is the biggest construction project of the company Luftseilbahnen Saas-Fee AG and was started on 1st September 1981. The cable-hauled cars running on rail in the tunnel provide access to a large glacial tourist area above Saas-Fee. This system was chosen instead of a suspended cable-car for ease of maintenance and operation and from environmental considerations. The cars run in an inclined tunnel 1447 m long to provide a connection from Felskinn which is reached by a suspended cable-car built in 1969 to the Mittelallalin shoulder at 3456 m above msl.

The inclined cable-car gallery runs partially under glacier with a minimum rock cover of 10 to 15 m. For this reason careful excavation methods by mechanical means were chosen, in spite of the bigger logistical problems. Conventional drill and blast methods would hardly have been feasible. The tunnel profile has a diameter of 420 cm and was driven by a Robbins tunnelling machine type 136-204. This machine was transported in several parts of not more than 12 t weight to the tunnel starting point at Felskinn using the existing suspended cable-car.

The client arranged to supply the site with a maximum daily water quantity of 100 m<sup>3</sup> for the free use of the contractor. The contractor had to re-cycle the water several times due to the limited quantity available. Economic considerations for the design of the 100 m<sup>3</sup>/day (~1.25 l/sec) pumping installation led to a layout of four pumps in series. At the top stage the pressure head reaches 327 m consisting of 302.6 m level difference and 24.4 m friction losses.

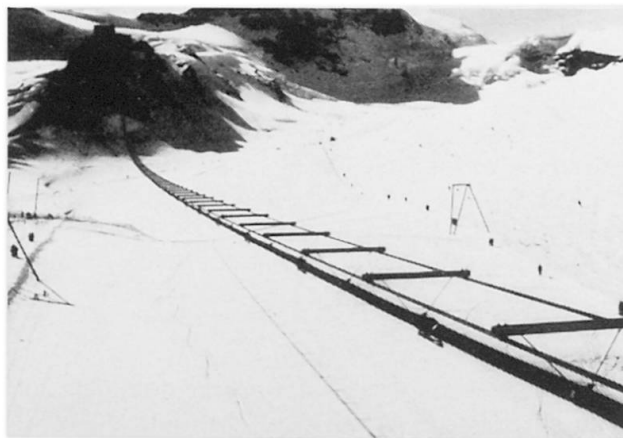


Fig. 1 Cable-suspended pipeline

The siting of the pipeline and the intermediate reservoirs was determined by geotechnical and topographical conditions and potential avalanche areas also had to be avoided. For the lower stage the pipeline lies in soft ground having some vegetation. Above 2100 m there is no vegetation in the glacial moraine zone and finally the pipeline crosses a glacier between reservoir No. 4 and Felskinn. This glacier creeps between 15 and 20 m per year and obviously the pipeline cannot be embedded in such a movement zone. Therefore the pipeline crossing the glacier is suspended on a free-hanging cable system, Fig. 1.

The costs for the pumping installation of total length 3950 m and elevation of 1160 m are about 1.6 m SFr. of which about 50 % forms the cost for the 910 m long suspended section.

## 2. SUSPENDED PIPELINE SECTION

The suspended pipeline section has no stiffening leg. The water pipeline is encased in an outside hard polyethylene pipe of 125 mm diameter which is suspended from two cables each 36 mm diameter. The suspension cables are fixed at both ends, at the bottom end on a steel tripod 12.5 m high and at the top end to a concrete bollard giving a means to adjust the cable tension if required. The tripod is placed at Reservoir No. 4 on a moraine layer of 12 m depth lying on old stationary ice. It is anchored into the moraine layer with 4 x 40 t ground anchors to provide stability against overturning. The moraine layer is a permafrost zone except for the surface. At the top end the cables are fixed to a concrete bollard which is anchored with 2 x 40 t ground anchors into the serpentine rock which is also a permafrost zone.

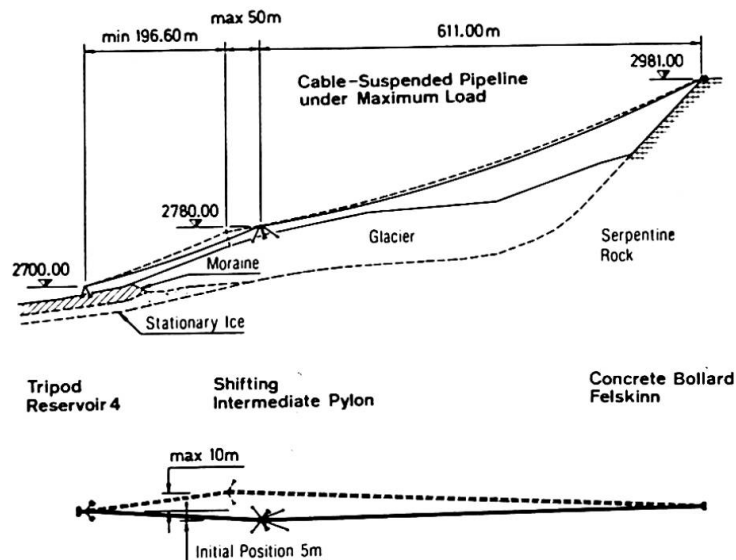


Fig. 2 Suspended pipeline section

Due to the unfavourable surface profile of the glacier and the levels of the anchorage points, see Fig. 2, an intermediate pylon was necessary. The head of this 35 m high pylon is restrained by four cable stays anchored in the glacier. This intermediate pylon is moving downhill with the glacier resulting in a relative displacement from the supported cables which move through saddles at the head of the pylon. The surface creep of the glacier is about 15 to 20 m per year and the system allows a maximum displacement of the intermediate pylon of 50 m longitudinally and  $\pm 10$  m in the transverse direction. With this arrangement an uninterrupted water supply to the construction site is possible. The total time of construction of the "Metro-Alpin" is 3 years to completion for the 1984-85 winter season. The initial position for the pylon transversally was given by the actual direction of creep and by the position of a crevasse.

The capacity of the pumping installation will only be used partially after the end of the construction of the underground cable-car for the supply of drinking water. Therefore at this time an interruption in the water supply is



acceptable due to the lower water demand and the removal of the intermediate pylon and its re-erection in the initial position can be accommodated. This will be the case after reaching a longitudinal displacement of 50 m or a transverse displacement of 10 m. The two free spans thus vary from: lower span 246.6 m to 196.6 m  
upper span 611.0 m to 661.0 m

The problem of freezing in the pipeline is solved by keeping the water moving all the time and emptying the pipeline whenever pumping is stopped. This is guaranteed by a minimum slope of the pipeline of 10 ‰. Additionally at the outlet from Reservoir No. 4 below the most exposed suspended section, the water may be heated using a 25 kW heater to raise the temperature 5 °C. In practice it is found that even with very low temperatures the water normally requires no supplementary heating due to the solar energy absorbed by the black hard polyethylene pipe.

### 3. SUSPENDED SYSTEM

#### 3.1 Construction

The main load bearing elements of the suspended system consist of two 36 mm diameter "Seale" multi-tendon cables with a fibre core. The guaranteed tensile strength of each cable is 810 kN.

At 254 cm centres a rectangular steel pipe section, 60 mm x 40 mm, is fixed across the two cables which are 100 cm apart. From this is hung the hard polyethylene pipe with two steel cables, Fig. 3.

The main steel cables and the polyethylene pipe have very different longitudinal deformations. In order to avoid forces in the polyethylene pipe the 501 cm long sections are not fixed together at the spigot and socket-type joints. On the assumption that the friction at the joints will vary a sliding clamp arrangement, see Fig. 3, is provided at each joint to prevent the pipe sections pulling apart. This consists of two clamps joined by a slotted steel strap to allow 160 mm of movement.

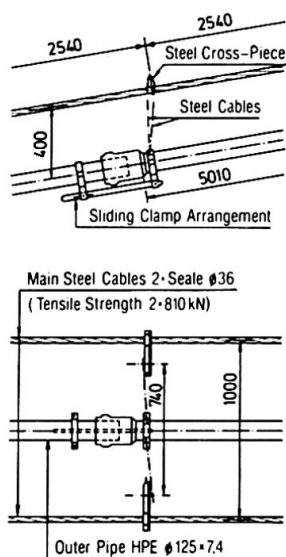


Fig. 3 Suspended system

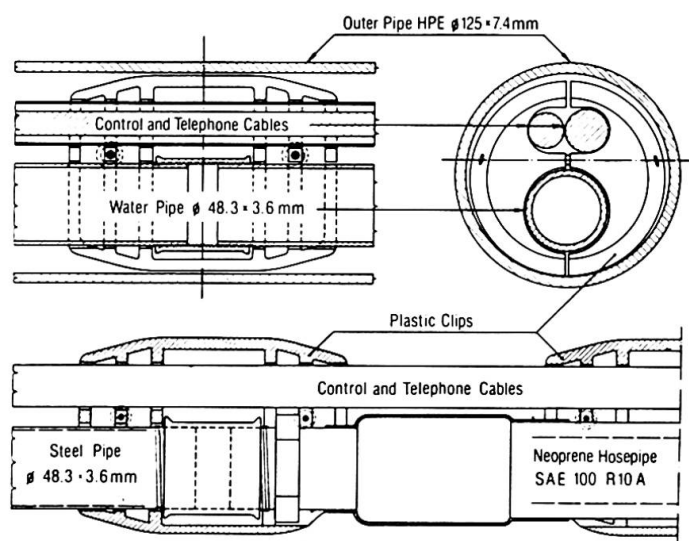


Fig. 4 Internal pipe and cable bundle

The outer polyethylene pipe protects the water pipe and also carries one telephone and one control cable, Fig. 4. This pipe minimises the ice load due to its smooth surface and provides an internal air space which gives good temperature insulation. Polyethylene material is used because of its ductility and because the added carbon black gives good resistance to ultra-violet light.

The suspended system has large deformations under wind and ice loads and temperature differences. The internal pipe and cable bundle is free to move along the whole length of the suspended section. This avoids forces due to these deformations and to the temperature difference usually existing between the water pipe and the suspension cables. The internal bundle is clamped only at the top end. The maximum relative displacement between the outer pipe and the bundle is reached at the lower tripod end and is compensated by a special articulated sliding construction.

The water pipe and cable bundle is held together every 2.5 to 3 m with specially designed plastic clips, Fig. 4, which locate the steel pipe and cables in the designated position and facilitate the pulling process in the erection phase. This solution also gives a better temperature insulation of the water pipe because there is no direct contact between the water pipe and the external pipe.

A steel pipe with screwed joints, 48.3 mm external diameter, 3.6 mm wall thickness, is used for most of the water line. In sections of tight curvature flexible high pressure neoprene hosepipe type SAE 100R 10A is chosen. This was the case near both anchorage points and at the intermediate pylon. The neoprene hose at the top end is reinforced with a special tension member consisting of two small steel cables to provide additional tensile strength for the holding force of 20 kN at this point.

### 3.2 Design

The load assumptions were basically taken from the Swiss Code SIA 160 (1970) and adapted to the local conditions.

The total design loads on the suspended system are:

Dead load including water	0.21 kN/m
Quasi-static wind load	0.25 kN/m
Ice load	0.26 kN/m

The calculation of the tensile forces and cable deformations was carried out for the above loads in a temperature range of  $-30^{\circ}\text{C}$  to  $20^{\circ}\text{C}$ . The elasticity theory 3rd order was used for the computation for the final state as well as for the different construction stages.

The friction effects at the cable saddles were calculated by trial and error methods. The Young's modulus of the "Seale" multi-tendon suspension cables with fibre core was assumed to be constant at 90 kN/mm<sup>2</sup> over the occurring stress range. For the case of the maximum shift of the intermediate pylon the statical calculation gave the following values:

Max. vertical load:	max. tensile force:	504 kN/cable
	max. sag:	29.8 m

Dead load and wind:	max. tensile force:	403 kN/cable
	max. sag:	15.8 m
	max. horizontal deformation:	18.8 m

These figures show that the dead load + wind case is not governing the design of the suspended construction. Even considering the dynamic behavior with the lowest frequency of 0.80 Hz in the bigger span the tensile forces in the cables due to dead load + wind are less than the forces due to the maximum vertical load. Thus a minimum theoretical safety factor of  $810 \text{ kN}/504 \text{ kN} = 1.61$  is obtained against failure of the cross-section of the cables.

#### 4. PYLONS

##### 4.1 Intermediate Pylon

The intermediate pylon, Fig. 5, constructed of Fe 360 steel has two legs of 27.02 m and 35.50 m length. The head of this pylon is restrained by steel cable stays anchored in the glacier. Since the creep deformations under the two legs will not be exactly the same the legs are linked at the head with an articulated connection so that the feet can have a maximum displacement relative to each other of  $\pm 3\text{m}$ . The legs are supported on steel plate footings and are articulated in both directions. Timber railway sleepers are placed under the steel baseplates in order to prevent heat conduction into the ice and thus excessive settlement. No other fixing is made, the pylon being held down by the four cable stays and the vertical load on the construction.



Fig. 5 Intermediate pylon



Fig. 6 Head of intermediate pylon

Both legs are rectangular trusses, one  $100 \times 100 \text{ cm}$ , the other  $100 \times 160 \text{ cm}$ . The shorter leg has a greater truss depth in order to carry the horizontal forces from the cable saddles and the resulting bending moments. The assembly carrying the two cable saddles is suspended at the head by four steel cables, Fig. 6. This allows the assembly to be easily raised or lowered together with the suspension cables. The saddles can rotate about two axes and are kept in position laterally by a horizontal support frame.



#### 4.2 Tripod

The tripod at Reservoir No. 4 is a 12.5 m high construction of Fe 360 steel consisting of two compression legs joined to form a triangular truss and a tension leg, Fig. 7. Two steel sections IPE 450 form the compression members of the truss and are 800 cm apart at the bottom and 100 cm at the top. The tension leg consists of two parallel steel sections HEA 220, 100 cm apart, embedded in a concrete footing with a steel cross-piece.

In the suspended section the water pipe and cable bundle slides in the external plastic pipe to give a theoretical relative displacement of up to 330 cm at the tripod under wind and ice loads and temperature differences. From safety considerations the special Z-shaped sliding construction, Fig. 7, allows a displacement of up to 400 cm. It is supported by a secondary steel structure connected to the tripod, Fig. 7. The relative displacement is taken by the curvature of the water pipe and cable bundle at the two corners of the Z-shaped sliding construction without any longitudinal strain. The curvature zones are a 40 cm long section at the top corner and a 530 cm long section at the bottom corner, the latter being protected by a concrete box enclosure. The telephone and control cables are flexible enough for these curves but for the water pipe special flexible "Anaconda" metal hoses with a 39 bar working pressure are used.

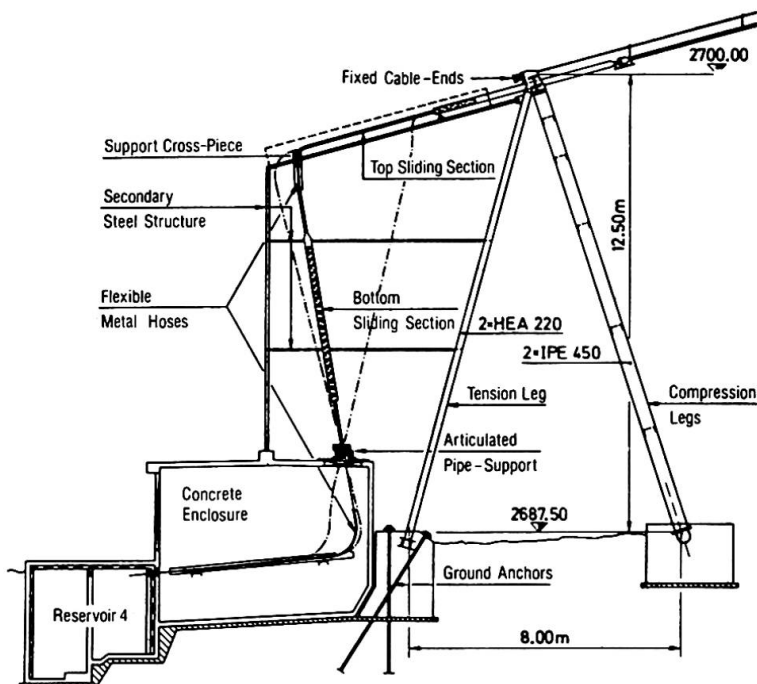


Fig. 7 Tripod at reservoir No. 4

Outside the concrete enclosure the water pipe and cable bundle is protected by specially designed plastic pipe sections as follows:

- sliding sections consisting of two concentric hard polyethylene pipes of diameters 125 mm and 160 mm in the top and vertical legs of the special sliding construction.
- articulated pipe-support on top of the concrete enclosure.
- hinged construction under the top corner taking tensile forces. It is connected to a support cross-piece which slides on both upper steel beams



of the secondary support structure.

## 5. ERECTION

Felskinn is the only site location having access by the existing cable-car. The sites of the intermediate pylon and the lower tripod had to be supplied using helicopters. Therefore the erection of the suspended construction in the following steps was carried out from Felskinn wherever possible:

1. Erection of the lower tripod and intermediate pylon - maximum weight of prefabricated steel sections limited to 750 kg for helicopter transport.
2. Pulling and tensioning of the suspension cables in the half-raised position at the intermediate pylon.
3. Assembly and lowering of the outer plastic pipe and its support members by means of a temporary cable clamped at each suspension point.
4. Assembly of the water pipe and cable bundle and introduction into the outer plastic pipe.
5. Lifting and fixing of the cable saddles into their final position at the intermediate pylon.
6. Tension check and eventual correction of the tensile force in the suspension cables at Felskinn.
7. Assembly of the sliding construction at the tripod.
8. Clamping of the steel cross bars onto the suspension cables and removal of the temporary cable.
9. Sliding check of the water pipe and cable bundle by pulling it back into the initial position and clamping it at the top end.

The Felskinn cable-suspended pipeline had to be erected in winter under sometimes very extreme conditions. The erection took place between October 81 and February 82 with some interruptions due to very bad weather.

## REFERENCE

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