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# DISCRETE SUPPORTS IN SUBMERGED TUNNELS.

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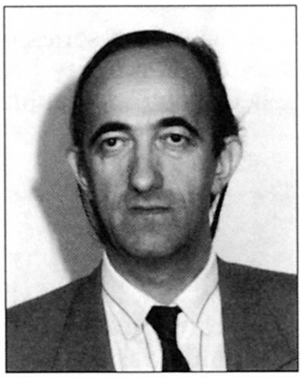

Joseramón Madinaveitia, born 1943, obtained his civil engineering degree in 1968 and his history degree in 1985, in charge of the Bilbao Metro project since 1991.

**Summary**

The Bilbao metro's underriver crossing at Olabeaga was executed using the immersed tunnel technique. The elements of the tunnel were prefabricated in a provisional dry dock which formed part of the future land tunnel. The presence of competent rock at bed level enabled sand injections to be replaced by discrete concrete supports, acting as keelblocks. Microconcrete-injected sacking bags were used to make the required bed adjustments. River traffic immediately above the tunnel, including vessels up to 10,000 DWT, remained uninterrupted throughout the operations.

## 1. Background

When the Basque Government decided, in 1989, to begin work on the Bilbao Subway, one of the major technical challenges involved was how to overcome the barrier of the river at Olabeaga, used by vessels of more than 10,000 DWT.

The engineering company which produced the project analysed a number of possibilities, including modifying the route to pass under the bed and boring the entire tunnel in rock. This solution was discarded because it meant that the nearest stations would have needed to be much deeper underground, which was felt to be a negative move as far as attracting passengers was concerned.

The submerged tunnel solution was retained and to develop this method, new in Spain, the engineering company sought advice and support from an English consultant, working on the Conwy project at the time. The design included the habitual technique of sand injections under the structures once they had been put into place in their final position.

When the winning construction firm started work, it sought the advice of a Danish firm with long experience in sand injection processes under submerged tunnels.

## 2. The Concept of Discrete Supports

However, the geotechnical campaigns carried out prior to the design phase detected the presence of the rock ceiling at levels similar to those planned for the submerged tunnel supports.

With the quality of the rock confirmed, after dredging the fragmented, decomposed metre at the top, the need to rethink the support system became clear.

The idea was to transmit work loads to the rock via a series of discrete supports in concrete to replace the layer of injected sand. This way the continuity between the rigidity of the concrete structure of the tunnel units and the rock bed would be maintained without the need to insert a looser element like injected sand.

## 3. Construction Area.

The river Nervión, which runs through Bilbao, has a long tradition of shipbuilding, and a major effort was made to make the section of the submerged tunnel units compatible with one of the existing dry docks. However, analysis showed this was not a viable solution. (Fig. 1)

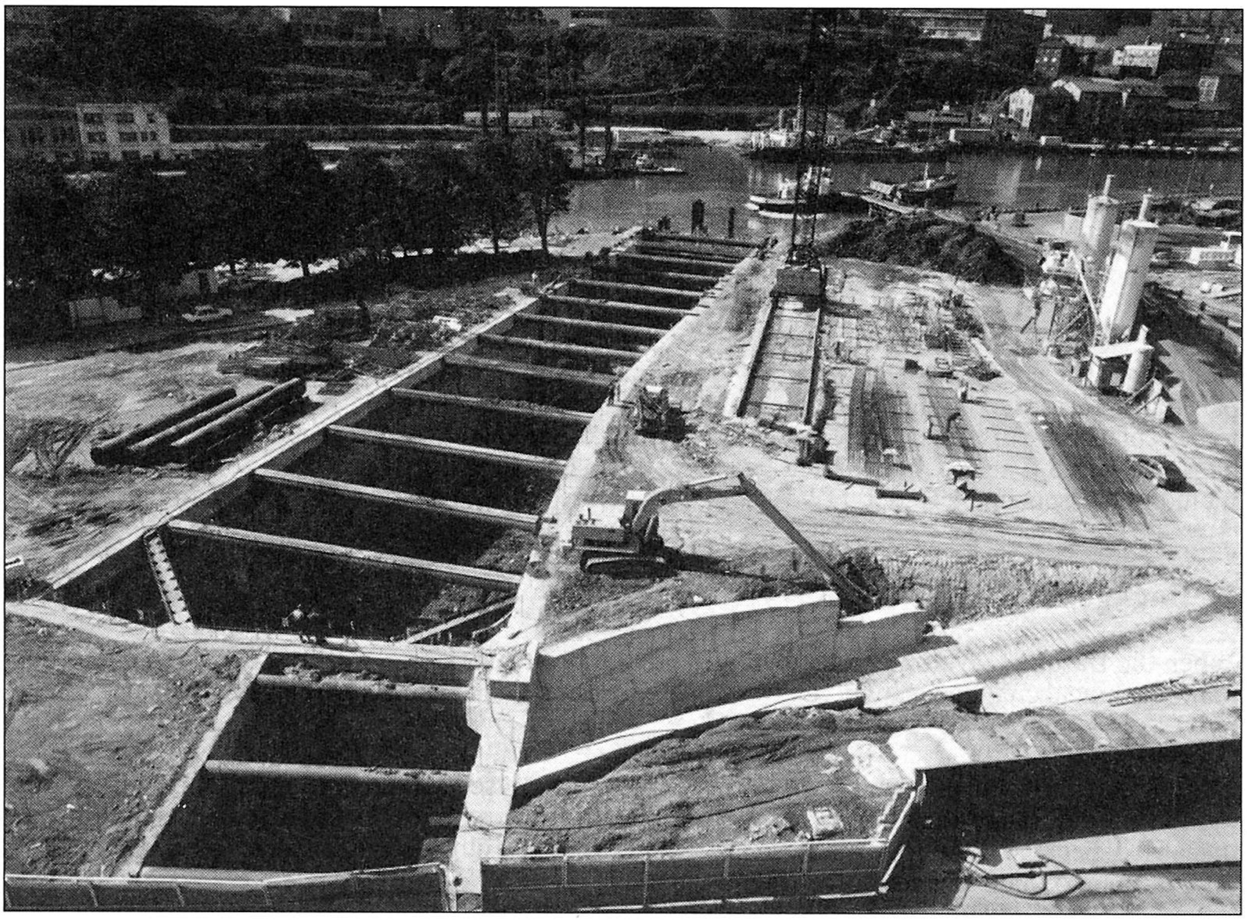

*Fig.1 Construction Site*

Instead, the decision was taken to prepare a provisional dry dock where the different modules of the submerged tunnels could be built. The area chosen corresponded exactly to the route of the tunnel on the right bank. That way, a large part of the structure required for the provisional dry dock could be used to shape the definitive section of the subway tunnel.

The floor of the dry dock would be the roof of the tunnel and the dock walls, in cocrete diaphragm walls, would be the side walls of the definitive tunnel.

The diaphragn walls were embedded in rock at lower levels using trench cutter equipment. As the between-diaphragmwalls excavation progressed to shape the dock, head support struts were installed.

Highly liquid mud in the surrounding earth put the diaphragm walls under great pressure, so a jet-grouted slab at tunnel crown level was performed before excavation.

The slab acted as a strut from the beginning and prevented screen wall deformation and negative effects on nearby buildings while excavation went ahead.

The construction area was 100 x 15 metres and 12 metres deep. It was separated from the river by a metal gate removable by crane. The gate was prepared to withstand differential thrusts in both directions. On one side and with the dry dock, the thrust from the current and the tidal range; on the other side, during the test period on the structures in the dock, the water could reach anything up to 5 metres higher than the river level.

## 4. Submerged Tunnels

The submerged tunnels measured 11.60 x 7.30 metres and were each 85.35 metres long. (Fig. 2).

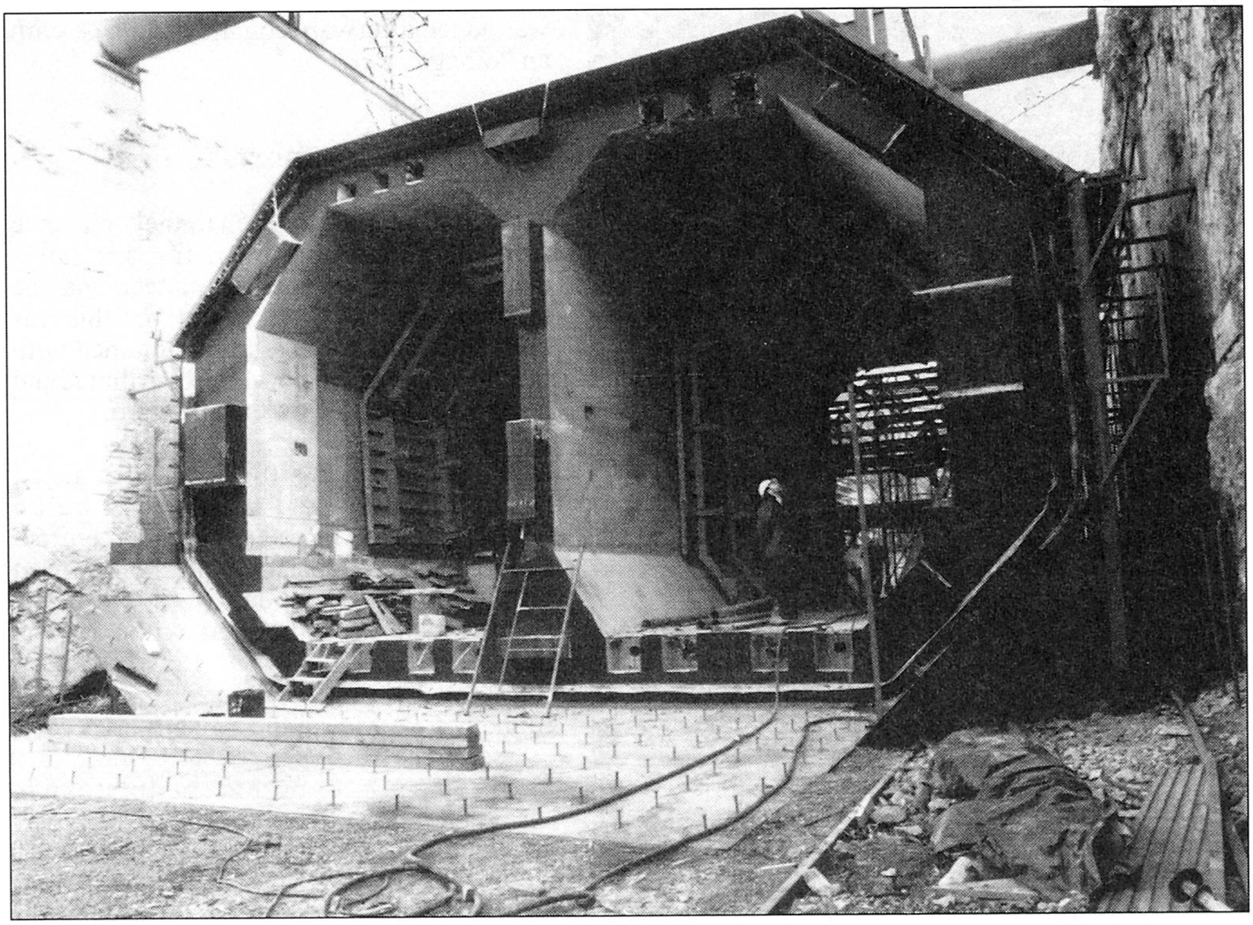

*Fig. 2 Tunnel units. Cross Section.*

Each unit was divided into two compartments, one for each direction, by a continuous 0.40 metre thick concrete wall. The outer walls were 0.80 m. thick at the base and sides and 0.70 m. thick at the top with chamfered corners.

They were built in modules to be integrated via post-tensioning, a technique used only temporarily to guarantee performance in flotation and initial support worst-case hypotheses at adjustment points.

Re-usable metal gates closed off the end compartments during floating and controlled sinking operations. A metal chimney tube enabled access during floating and sinking and also facilitated ventilation and energy supply.

## 5. Positioning and Adjustment

Vertical and horizontal jacks (8 Ud. in all) were fitted at either end of each unit for adjustments. The jacks moved the unit vertically and horizontally until correctly positioned, with errors of less than 10 mm.

However, in one of the operations, vertical mobility was limited by unusual deposits in the support zone. The structure was lifted slightly with the aid of the positioning catamaran and the area hosed out with water at high-pressure to shift the deposits brought by a recent high tide.

One important function of positioning is to give the joint between the structure and the receiving work on land continuous perimetral support, thereby ensuring initial watertightness and enabling the submerged structure's connection with land to be kept open. (Fig. 3)

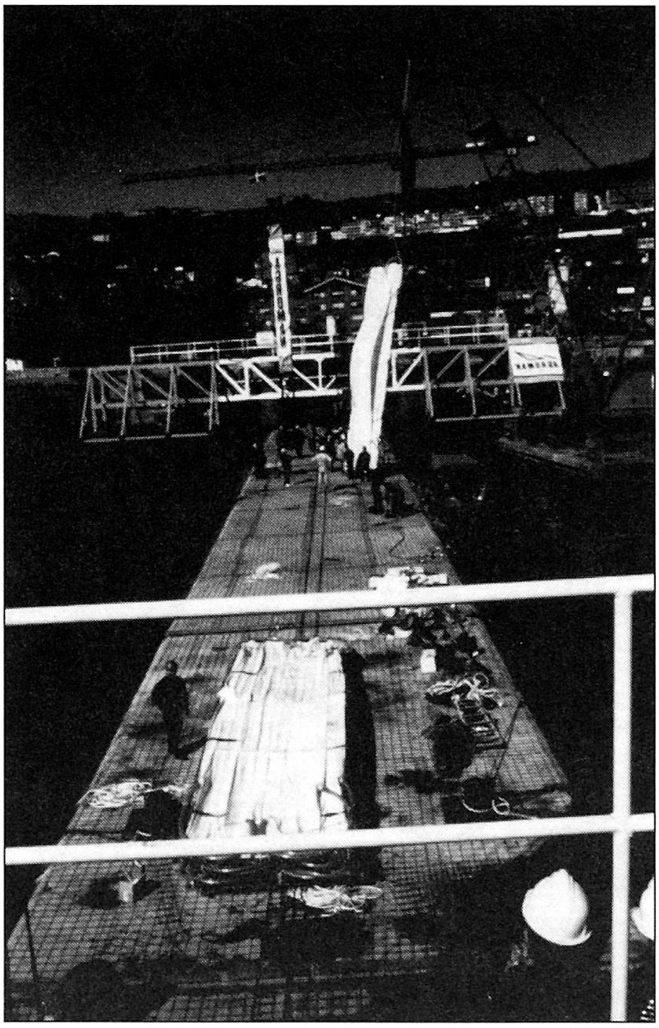

*Fig. 3 Tunnel Positioning*

A "gina" joint was used and a second seal was added afterwards on the inner side with an "omega" joint.

## 6. Discrete Supports

The initial support for each tunnel unit, once in place at the bottom of the specially-excavated trench, was guaranteed via the jacks at the four corners. However, this was only a temporary situation maintained with the aid of water ballast which distributed and minimised stresses on the structure.

In the definitive situation, with fixed concrete ballasts and variable rail traffic loads, almost continual support is required. Besides, the post-tensioning technique used on the modules was temporary and better support was also needed when it was released.

In the Bilbao Metro, the novelty involved:

a) preparing concrete bedplates as keelblock on the river bed, the top part of which were to be a metre below the definitive bed level for the structure. These bedplates were built using an external metal mould subsequently filled with submerged concrete. The plates would be adjusted to the right levels in a second phase. (Fig. 4)

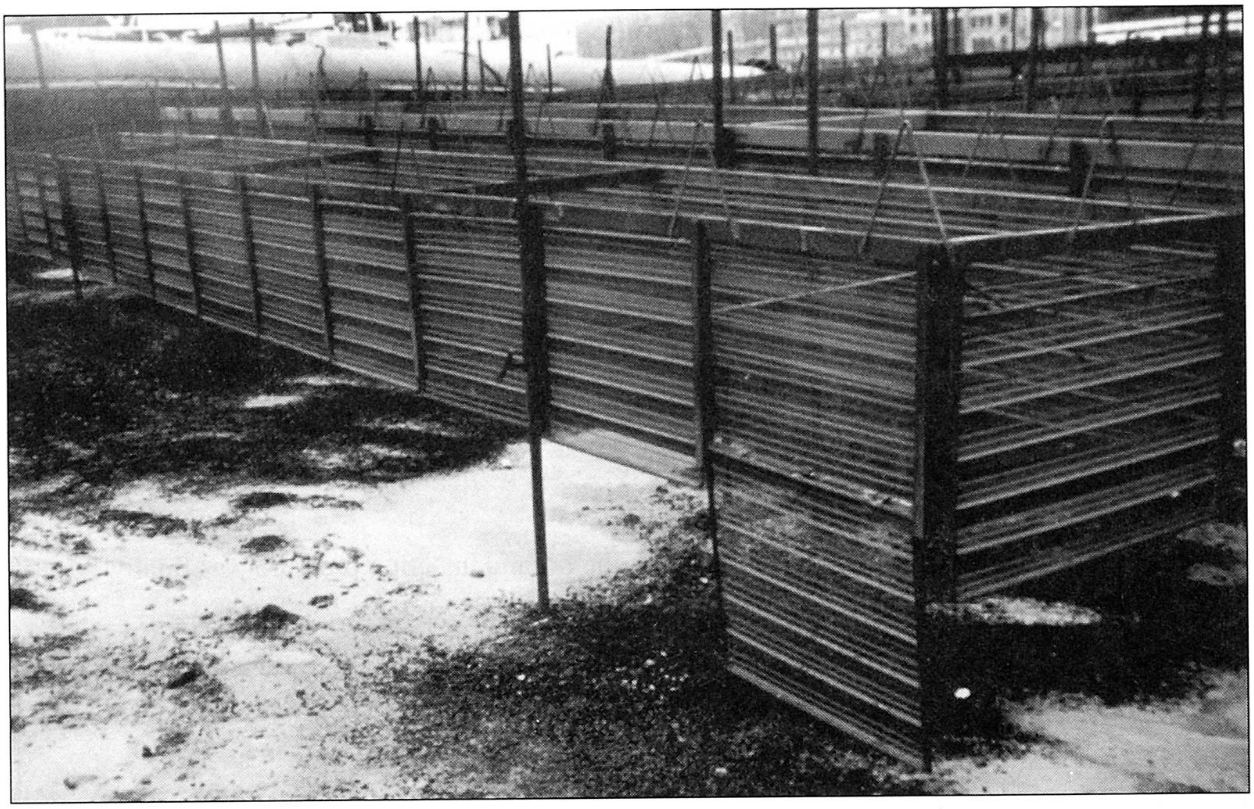

*Fig. 4 Metal mould for keelblocks*

b) placing empty sacks—9.40 m long and 0.80 diameter when filled—on these plates. The first time, divers were used to place the sacks in position after the structure had been positioned, but in later manoeuvres the sacks—three per plate—were placed before controlled sinking was performed. (Fig. 5)

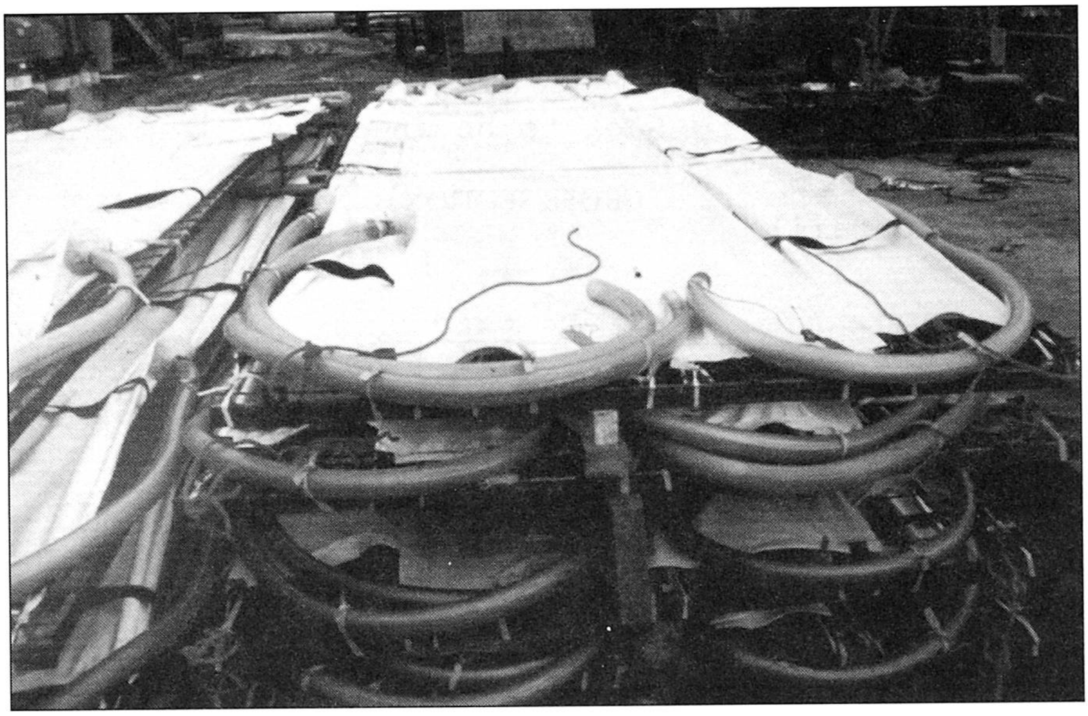

*Fig. 5 Sacks before injection*

The sacks were made of a synthetic, Bullflex-type material which enabled microconcrete to be injected as the water and air was pushed out through the material, thus ensuring a perfect fill.

Supports were separated by 3 or 5 metres depending on the areas. Given the relative lack of experience with this method, and the fact that the work had to be done blind at a depth of more than 20 metres, a number of test runs were carried out.

The test protocol gave us the following parameters for the best results:

- sack diameter between 0.60 m and 2.50 m.
- injection pressure from 1 to 5 $kg/cm^2$.
- fill time less than an hour, variable according to diameter
- microconcrete with 500 to 1000 kg of cement per cubic metre, with maximum aggregate size limited to 6 mm.

Each sack was fitted with 50 mm valves to check the fill and injection pressure was finally 1.5 $kg/cm^2$. (Fig. 6)

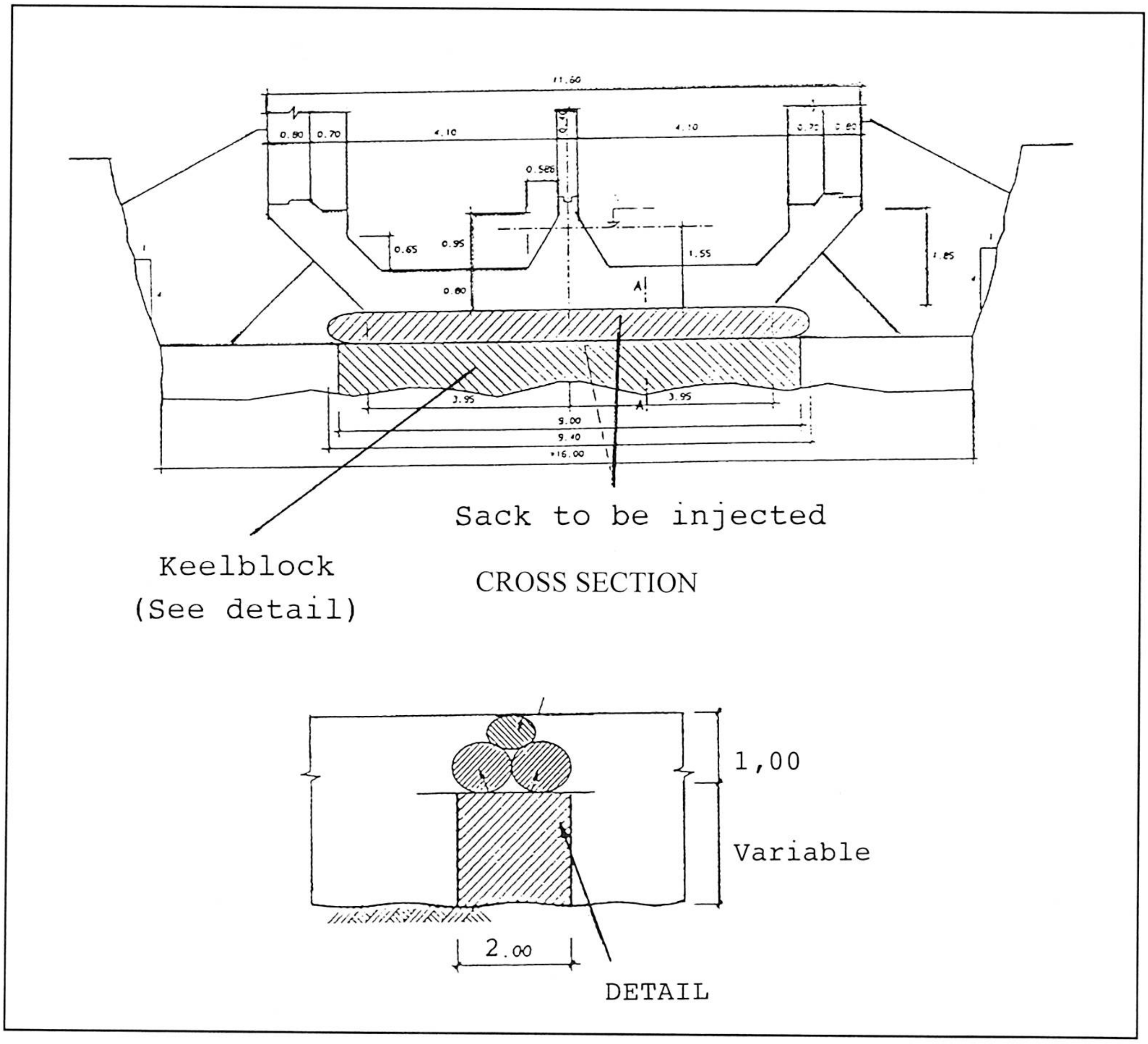


*Fig. 6 Discrete supports*