Second International Conference on Geotextiles,
Las Vegas, U.S.A.

LUPTON, T. J.
UCO (UK) Ltd., London, UK

The Advancing Techniques in Flexible Forms
Les techniques progressives dans les coffrages flexibles

The term flexible formwork refers to the various applications of porous textiles in the containment of settable materials such as concrete and the like. In spite of well-documented evidence and the clear commercial success in the United States of flexible formwork in erosion control, little innovative field use has been made of the basic technique outside the interest of specialised concerns. The purpose of this paper is to describe some of the more recent European instances which have highlighted the advances in the flexible formwork technique. Each of the case histories to be discussed includes some unique feature which builds upon the basic principle of the system. They have been selected to illustrate the significance of the textile components in harmony with other engineering materials, thus providing a versatile solution to civil engineering problems. In common with many of the geotextile topics presented at this conference, the market must be reeducated if flexible formwork is to have optimum utilisation. It is hoped that this paper will play its part in stimulating progress towards the inclusion of geotextile technology in all engineering courses.

Le terme coffrage flexible fait référence aux diverses applications de textiles perméables utilisés pour la retenue de matières coagulables telles que le béton, le mortier et autres substances similaires. Malgré de nombreux résultats pratiques et le succès incontestable des coffrages flexibles aux États-Unis dans divers domaines tels que la prévention de l'érosion, il a été fait peu usage de cette technique en dehors des applications connues réalisées par certaines entreprises specialisées. Le but de cet article est de décrire quelques applications récemment faites en Europe qui mettent en évidence les progrès réalises dans les coffrages flexibles. Chacun des cas présentés comprend un élément original en complément de la technique déjà connue. Ils ont été sélectionnes afin de souligner l'importance du choix du composant textile en fonction des autres matériaux utilises. Le tout apportant une solution adaptée à différents problèmes du génie civil. Comme la plupart des autres sujets dans le domaine géotextile en discussion à cette conférence, il faut souligner le besoin d'information du marché dans le domaine des coffrages flexibles afin que cette technique puisse prouver tout son intérêt.

INTRODUCTION

Conventionally, the method of casting insitu structures and shapes in concrete involves the use of formwork fabricated from rigid timber and steel. The essential requirement is that these forms provide an impermeable container holding the fluid concrete throughout the hydration period. The duration of this holding phase depends mainly on the desired concrete strength, the climatic conditions, safety of site personnel and the likely effect of the environmental conditions surrounding the finished structure.

An alternative concreting method is to use flexible formwork. These forms are constructed from permeable woven textiles, having the feature of providing a porous wall to the injected concrete. Essentially, this allows the free passage of excess water to pass out from the filling material.

This porous wall feature is fundamental to the whole concept of flexible formwork, and it will be seen by illustration that, in itself, it provides the solution to many everyday engineering problems.

To examine in more detail its potential and the manner in which it functions, let us consider the first case study.

1 ENGLAND

The main contract was a flood alleviation scheme which involved the widening of a river beneath a railway bridge. The new line of the river's edge was to be sheet piled, and was to pass within 1 metre (3.28 ft) of the bridge piers. The design authority's main concern was that the bridge loadings should not create movement of the sheet piles, resulting in the collapse of the structure.

To overcome this problem, a concrete slab was proposed to be placed on the river bed to act as a strut between the two rows of steel piles.

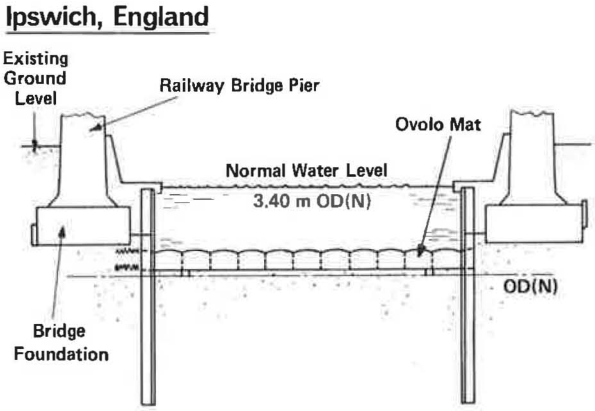

Fig 1: Cross section showing proposed strut

The slab was specified as having a minimum thickness of 0.5 m (1.64 ft), and a strength at 7 days of 21 N/mm² (3045 lbs/in²). It should be homogeneous and in full depth contact with the sheet piles both sides of the river.

Established practices required the construction of a cofferdam, dewatering and a bypass from the river flow.

To examine the suitability of a flexible formwork solution to this application, and to clarify the theory, let us delineate the following possible advantages.

a Porous wall

b Ease of handling

c Adaptability of shape and form

d Scope for alternative filling material

e Cost advantage

1a POROUS WALL

As previously stated, when used in concreting the flexible form is produced from permeable textiles. The fabric is constructed to allow a controlled bleeding of the excess water in the filling material, whilst restraining the loss of its solids.

The water loss produces rapid compaction and results in a dense high strength durable concrete. This can be achieved equally well underwater as in the dry.

It can be seen that there is an immediate advantage in this facility to the situation described, in that the need for a dry working area can be eliminated.

Although not relevant to the situation under discussion, adverse conditions can often affect the porous wall feature, for example, fabric placed in turbulent water will be subjected to buffeting and kneading. This will tend to squeeze out the fine binding particles through the filter wall of the form producing a sandy surface to the finished structure. In turn, this surface will wear and flake under the abrasive action of the water. Although it is interesting to note that, as soon as the finer fractions of the outer layer have passed through the fabric, the coarser part will tend to build up an internal secondary filter inhibiting the further outward migration of particle fines. In this situation, the resultant sandy appearance will only be superficial unless heavy kneading (and hence movement and agitation of the whole mix) has taken place within the fabric formwork.

In cases such as this, more attention must be paid to hydraulic bleeding properties in selecting a suitable fabric. It may also demand further consideration in mix design of the filling material.

1b EASE OF HANDLING

The length of slab section required was 40 m (131.2 ft). Had a cofferdam been used, it would only have been necessary to provide stop end shutters at various intervals lineally along the section, the sheet piles acting as side shutters and normal screeding as the top profile.

The total area of flexible formwork was 520 m² (5335.2 sq ft), and weighed 611 kgs (1345 lbs). It was placed in 10 pieces and joined underwater by the use of continuous chain zip. Mechanical equipment was not required and installation was performed by only a 4 man team. Clearly there was no advantage in the system's low weight to volume ratio over the small amount of rigid shuttering that would have been required by established methods. However, it will be appreciated from the evidence in case studies discussed that weight can play a significant part.

To maintain handling ease in some conditions special care must be taken in terms of size and method of installation. For instance, when sheet sizes reach 300 m² (3078 sq ft) in open exposed sites, high winds can be extremely dangerous. The form can fill with wind in the same way as a boat sail, and can easily lift 5 or 6 men off their feet, which could possibly result in a fatal accident.

Further, when placing large areas underwater, it is much safer for the formwork to be packed like a parachute, and similarly deployed when in the approximate position for its installation. Undercurrent and wave action resemble wind effect and can be more dangerous for the installation team. In one known application where an antiscour protection form was being positioned around an offshore structure, the form was wrenched from the divers and was lost for several days. Fortunately, the divers were not entangled in the sheet. The shutter turned up intact, but several miles along the coast. It was decided to proceed using flexible forms, but on smaller unit sizes.

1c ADAPTABILITY OF SHAPE AND FORM

The effectiveness of the strut in the case study under discussion clearly depended on it being in contact with the sheet piles both sides of the river to a minimum depth of 0.5 m (1.64 ft).

The design authority insisted that the whole profile of the pile pan should be filled with concrete that was integral to the slab formation. The sheet piles were Larson number 5, having a pan depth of 0.23 m (9 ins).

The adaptability of flexible forms is infinite, and in this case it was quite simple to tailor the side walls of the form to follow the pan profiles. The question of tolerance was overcome by using a unidirectional stretch woven fabric. This was an open construction in polyethylene, and provided a 20% elongation well below its ultimate tensile strength. The penetration of cement laden fines through this fabric facilitated a tight bond to the steel piles.

The form for the slab profile was fabricated to provide a dual layer envelope in a woven polypropylene having the following physical characteristics:

	Warp	Weft
Tensile Strength	60 kN/m	60 kN/m
Elongation	20%	20%
Permeability	545 L/m² /s	545 L/m² /s
Particle Retention	O_{90}	104 µm

To resist the ballooning effect of the internal hydraulic pressure, the top surface of the form was joined to the bottom surface by tubular columns in the same fabric. This provided an adequate uniform cross section within the tolerances of ± 75 mm (3 ins) imposed by the design authority.

1d SCOPE FOR ALTERNATIVE FILLING MATERIAL

The specification of the filling material will mainly be dictated by the structural qualities demanded in the finished construction.

In the situation described, the slab was required to have specific structural qualities, and fine aggregate concrete was preferred by the design authority. In terms of suitability to current formwork fabrics the filling material selection can be from the following range:

Material	Preferred Application
Neat cement grout	Structural repairs
Fine aggregate concrete (cement rich mortars)	Thin section slabs/shapes for severe exposure
Plasticized concrete	Thick section slabs/shapes, severe exposure
Resinous grouts	Thin sections in polluted environments
PFA cement mixes	Thin sections of high strength, light weight for severe exposure
Bentonite	Temporary constructions
Asphaltic grout	Thin sections in settling conditions of severe exposure

In selecting a suitable fabric to meet a particular filling material specification, it is important to balance the relationship between controlled bleeding/solids retention and internal hydraulic pressures.

From the earlier notes on the porous wall feature it will be readily understood that rapid expulsion of the free water in the mix will greatly reduce the hydraulic head on the fabric wall.

Flexible forms behave in much the same way as other liquid retaining membranes. Hydraulic pressures on the wall of the form act in an identical manner to those on a dam wall. The modulus of elasticity of the principal textiles used is around a 50th of that of steel. A curved surface will, therefore, always develop in the unrestrained areas.

The most drastic ballooning effects occur in trying to achieve a vertical plane. This can be expressed mathematically.

Assume the fabric between two anchor points behaves as a catenary under unfirom pressure. The tension in the fabric is obtained by matching the length and extension under tension to an assumed deformed shape, using an iterative process.

Assume value $a = {}^{f}/{2L}$ (1)

From relation $\frac{2aL}{h} + 1 = \cosh {}^{L}/{h}$

Obtain ${}^{L}/{h}$ where $h = {}^{H}/{p}$ (2)

Calculate the arc length

$s = \sqrt{f^2 + 2hf}$ (3)

Reaction $V = Ps$
$H = Ph$

and tension $T = P\,(f+h)$

Calculate extension of catenary

$As \quad \frac{(T+H)\,s}{2AE}$ (4)

where A = area
E = elastic modulus

then compare $L + \Delta s$ with s (5)

if compatible end of solutions,
otherwise back to step 1.

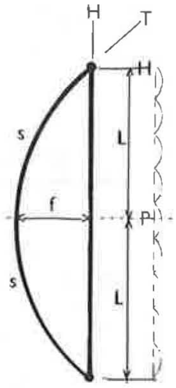

Fig 2:

It is essential therefore that if fabric stresses are to be minimised, the final shape of the filled form must be so designed as to distribute them evenly throughout the form. Furthermore, the shape must still impose an early restraint on the slump of the filling material to fully utilize the porous wall effect which is essential to the physical properties of the fill as well as reducing hydraulic pressures.

It is interesting to note high stretch fabrics may balloon to an unacceptable extent, but have the unique feature of increasing hydraulic bleeding as the pressure increases. As the bleeding increases, pressure reduces and a balancing effect, albeit indiscriminate, occurs during the filling operation.

In the writer's experience the most reliable way to determine the optimum container shape has been to construct a scale model using multi-directional lightweight fabric such as a jersey knit. The model is then injected with plaster and later used to plot dimensions for the fabrication of the form. The profile data obtained is then used to ascertain the fabric stresses.

Ie COST ADVANTAGE

In the current economic climate, many prospective clients are adopting a "least cost" criterion in the selection of preferred methods. Field experience has shown that one or more of the technical advantages detailed above provide an indisputable cost benefit in favour of flexible formwork over established methods.

The reason for the economic attractiveness can be summarised for clarity as follows:

i It provides ease of access into otherwise difficult and, therefore, expensive locations.

ii It possesses the ability to produce improved qualities in the filling material, therefore widening the choice of materials to be used.

iii It provides the technical feasibility to produce consolidated masses underwater, negating the need for cofferdams and dewatering. Also, in tidal zones the working shift need not be affected by changing water levels.

In situations where underwater concreting prevents the movement of expensive shipping traffic, e.g.; in RO RO berths, the rapid consolidation of the concrete when placed in flexible formwork facilitates a return to normal working in only a few hours.

iv Time saving: The forms are easily installed and in many cases are left in place as part of the finished structure, therefore dismantling time does not apply. The low weight of the fabric often enables movement on site to be carried out by hand, eliminating the need to wait for availability of more specialised equipment, e.g.; high lift cranes.

v Its low weight offers cost saving in transport to sites.

In the situation described, the total cost of the strut construction was £25,000 (approx. $37,000).

The volume of fine aggregate concrete used was 260 cubic metres (340 cubic yards), costing a total of £9,100 (approx. $16,600).

The balance covered the cost of preparing the bed together with supplying, laying and filling of the form. It can be seen that this amount would have been considerably greater had a cofferdam been used.

The mass placement of underwater concrete is an aspect in the use of flexible forms which has an increasing opportunity for growth. The following case study is an example of one specialised application, where it has been successfully used.

2 BELGIUM

A precast caisson forming a tunnel segment was required to be anchored into a canal bed in some 20 m (66 ft) of water.

The design involved sheet piles driven in line on the bed being concreted to a semi-rigid neoprene mounting cast into the tunnel segment.

This was achieved by using a steel bell-shaped shutter 50 m (164 ft) long, incorporating fixings for the mounting. A flexible form was attached to hang below the housing to provide a bottom and side enclosure for the pumped concrete.

Boom, Belgium

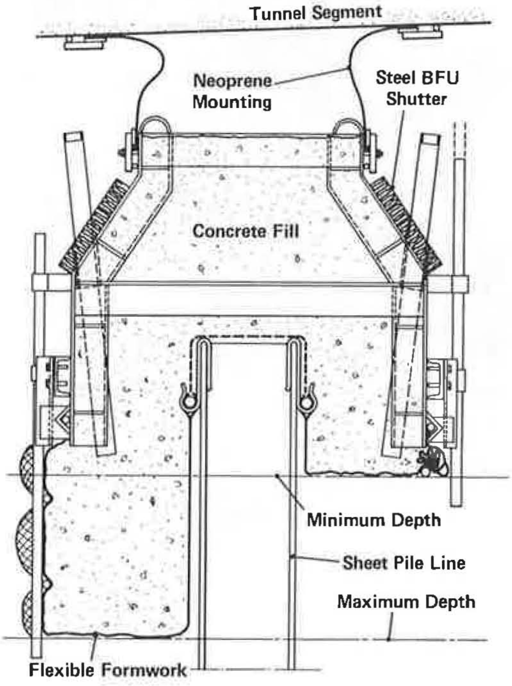

Fig 3: Typical cross section through formwork.

As we describe the site conditions in greater detail, it will be seen that the adaptability of shape and provided by this technique is an invaluable tool in the hands of the innovative engineer.

In spite of zero visibility below the water, it was ascertained that the bed level varied both sides of the driven steel piles. The bed level also varied along the length of the pile run and these variations were continually changeable.

The flexible form was provided with a fullness of fabric accomodating the maximum depth of bed variation. Experience has shownthat any excess material is merely trapped by the injected material, and this fact precludes over stress.

The internal faces of the form following the line of sheet piles was manufactured from a very open woven mesh fabric. This ensures a good adhesion between the concrete and the piles.

Excessive balooning of the outside walls was restricted by steel bars fixed vertically to the steel shutter above, and by horizontal bars threaded into pockets in the side walls of the flexible form.

The above case study also introduces another aspect of the applications of flexible formwork where increasing opportunities exist. That is the combination of rigid and flexible components, thus providing a shutter which utilises the porous wall feature to obtain quality improvements to the injected concrete, together with the flatter surfaces provided by more rigid materials.

The following case study illustrates how simply this complementary aspect can be applied.

3 HOLLAND

The site was a general refuse tip. A considerable number of piers carrying a railway track were reported as being damaged by acid attack and machinery impact.

figure 4a the rigid components assembled

Figure 4b the flexible formwork being filled

The formwork proposed combined a permeable textile with steel wire mesh, and standard angle iron, thus providing the removeable shutter components. Preferred steel caps afforded permanent protection to the leading edges of the finished structure.

The main advantages of using flexible formwork in this case were:

i The speed with which each pier could be protected without involving a multiplicity of heavy weight shutters.

ii Little preparation work being required around each pier.

iii The need to provide access for cranes etc. being eliminated.

CONCLUSION

In conclusion it can be seen from the growing numbers attending conferences such as this, that textile engineering is becoming a more progressive science.

It is, therefore, difficult to avoid the conclusion that it will have to become a more important part of engineering educational courses.

The use of flexible formwork is typical of one small, but important, segment of textile engineering applications. These present new possibilities and design challenges to the mechanical and civil engineer of the future.

ACKNOWLEDGEMENTS

The writer wishes to express his gratitude to Henri F J M Hillen for his encouragement and inspiration.

The fabrics referred to are, in the main, from the range of industrial textiles produced by SA UCO NV of Belgium.