DEMONSTRATION TRIALS OF A LOW COST SELF ERECTING FLOOD BARRIER

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Abstract: Flooding incidents dominate the national and international headlines on a regular basis and there is concern that flood events will increase due to the effects of climate change.

Control of flood waters is essential to save lives, property and land resources. The cost of traditional permanent flood defence is often prohibitively high and they are often intrusive to the waterside landscape. Temporary demountable barriers can be effective but rely on considerable human resource to erect and dismantle.

An innovative low cost, self erecting barrier using a geosynthetic membrane has been designed (Patent pending). Demonstration trials of the prototype at a site near Lea Marston, Warwickshire, are reported, the basic design is analysed and applications of the barrier discussed.

Keywords: barrier, environment protection, geomembrane, earth pressure, groundwater, innovative-geosynthetics.

INTRODUCTION

Unwanted flooding may occur for a variety of reasons including inadequate ground drainage during periods of intense rainfall, overflowing of swollen rivers, exceptionally high tides or sometimes from accidental spillage of liquids or failure of retaining bunds and dams. The effects of climate change, with the possibility of more extremes of weather conditions, are likely to further increase the risk of flooding events. The Environment Agency estimate that over 5 million people in 2 million properties are at risk from flooding in the UK alone (Environment Agency Flood Line web site publication – reducing flood risk, 2008).

Traditional, permanent methods of flood protection have included embankments and walls. Whilst these, if correctly designed, are generally effective in controlling the anticipated flood levels, they are costly and tend to be a major visual and physical intrusion into the waterside landscape.

To overcome the problems of visual intrusion and restrictions of access to the waterside, temporary demountable barriers have been developed and sometimes successfully deployed at times of flood in towns such as Bewdley (BBC on-line, 2004) and Upton upon Severn (Telegraph on-line 2007). The Environment Agency is trialling temporary flood defences at Shrewsbury, Worcester and Ironbridge in the Severn Valley (environment-agency.gov.uk). The temporary demountable flood barriers often utilise geomembranes. However these demountable barriers are costly to install and maintain, may be complex in their design and are not self-erecting. There have been problems where the stored demountable barrier could not be brought to site from the storage area because of the local flooding and road congestion.

Other more robust temporary barriers such as the Tilt dam (NCE, 2005) can rest in place at the waterside and be erected manually but again it is very expensive to install and still requires manual operation.

It is considered that there is great need both in the UK and internationally for application of a low cost flood defence for the prevention of fluvial flooding and to help resist the destructive forces of storm surge and tidal flooding. A low cost, self erecting product has been developed by the lead author (Patent pending) in conjunction with Nottingham Trent University, Faber Maunsell Ltd and PAGeotechnical Ltd. The innovative barrier utilizes the properties of available Geomembranes, to provide a product which has the potential to fill the gap in the current worldwide market.

Details of the initial trials of the low cost, self erecting barrier and an assessment of the potential applications and risks associated with the barrier were given by Greenwood (2007) and Greenwood et al (2008). The current paper summarises the pilot trials carried out to date and discusses aspects of the design relating particularly to the use and selection of geomembrane products.

DESCRIPTION

The barrier consists of a flexible geomembrane held in a trench as illustrated in Figure 1 and Figure 2. Protective rigid covers and floats (possibly incorporated in the covers) are attached so that the geomembrane will rise up with any flood waters and protect the land and property behind it. Stability is maintained by the mass of soil backfill replaced in the trench, slabs of concrete or other material on top of the backfill and by flexible ties, attached to the geomembrane (or possibly formed as an extension of the geomembrane), to resist the hydraulic forces on the erect barrier. The geomembrane buried in the trench also acts as a cut-off to prevent flood waters passing beneath the barrier.

The geomembrane is a high strength coated fabric membrane. It remains flexible across wide temperature and environmental ranges, it does not suffer from UV degradation (or ESC) and has a permanent plastic memory. The main parameters for its choice in the flood barrier were its high tensile strength, puncture and burst resistance (Table 1) as well as its ability to remain flexible having been immobile for considerable lengths of time.

When not in use the barrier will rest at or near ground level, protected by the rigid covers (Figure 2.). The covers are hinged from a reference kerb which may be of timber, concrete, plastic or other composite materials. The hinge may be the geomembrane itself or a positive mechanical hinge depending on the particular application.

Where the barrier is to be constructed in an urban area or as a walkway or roadway, kerbs of timber, concrete or other suitable material may be placed at the edges of the backfilled trench to support more rigid covers which are able to withstand traffic loading. Alternatively a box structures, of a form similar to a polymer crate, may be placed in the trench (Greenwood, 2007) to provide stability and support the covers in the event of traffic or other loading when the barrier is not in use.

Table 1. Properties of membrane

Property	**Test Standard**	**Value**
Thickness	ASTM D-751	0.75 mm
Tear strength	ASTM D-751	150N/150N* (min)
Breaking yield strength	ASTM D-751 Grab tensile	2450N/2450N* (min)
Low Temperature	ASTM	-30 degrees C No cracking
Dimensional stability	ASTM D2136	212 degrees F - 1Hr 1% max
Puncture resistance	ASTM D4833	1100N (min)
Bursting strength	ASTM D751 Ball tip	2900N (min) 3500N (typical)

* machine direction and transverse direction.

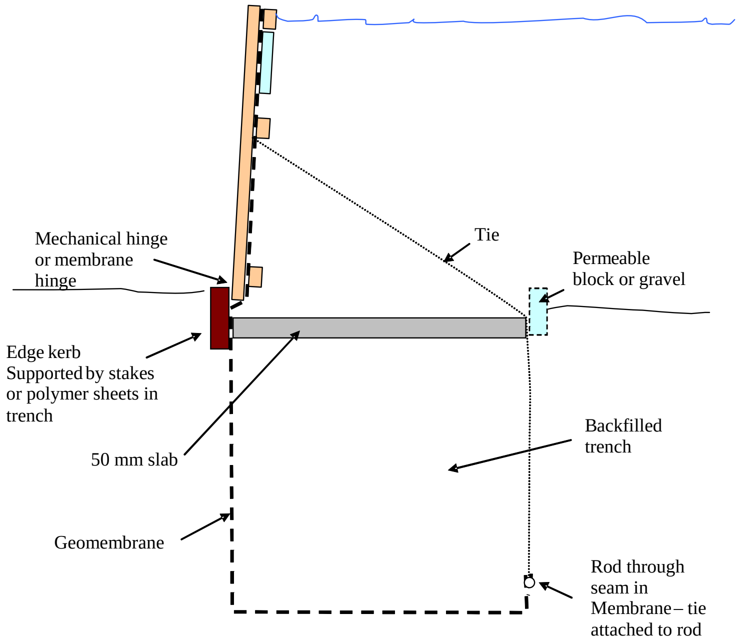

Figure 1. The barrier self erects at time of flood

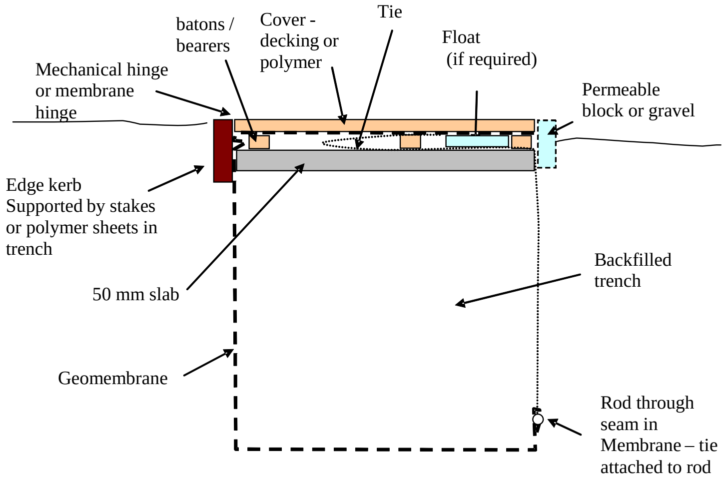

Figure 2. The barrier at ground level when not in use

Whilst the basic barrier design principle is straightforward and the material and construction costs are likely to be low, it is important that the design details are carefully considered for efficiency of construction, safety in operation and convenience when not in use.

DEMONSTRATION TRIALS

The design concept was tested initially by small scale model trials then taken forward to full scale trials in September 2007. The pilot trials, carried out at a site made available by the Environment Agency adjacent to a lake at Lea Marston, Warwickshire, demonstrated the viability of the basic construction and design principles and successful operation under flood conditions. The various stages of construction and operation of the barrier are illustrated in Figure 3.

	
a) Trench excavated, reference kerbs placed,	b) Webbing ties attached to membrane (Seaman XR5) at base of trench.
	
c) Trench backfilled and paving slabs positioned.	d) Geomembrane enclosing polystyrene float and webbing ties attached
	
e) Flood barrier at rest – ready for the flood, and showing potential as walkway	f) Water pumped in to simulate the flood. The barrier rises.

Figure 3. Stages of construction and operation of the barrier during pilot trials.

The barrier successfully rose and retained 600mm depth of water (Figure 4).

Figure 4. Members of the project team discuss the successful pilot trial

DESIGN ASPECTS

Earth and Water forces

The soil and water forces acting on the flood barrier may be assessed as for any retaining structure to ensure stability under the most severe flood conditions. The various forces to be considered are shown in Figure 5 for a barrier designed to retain a flood of depth, d, in soil having a bulk unit weight γ_b kN/m^3 .(γ_w = Unit weight of water, normally taken as approximately 10 kN/m^3). The active and passive coefficients of lateral earth pressure, K_a and K_p, are related to the soil's effective angle of friction, ϕ', by conventional Rankine earth pressure theory.

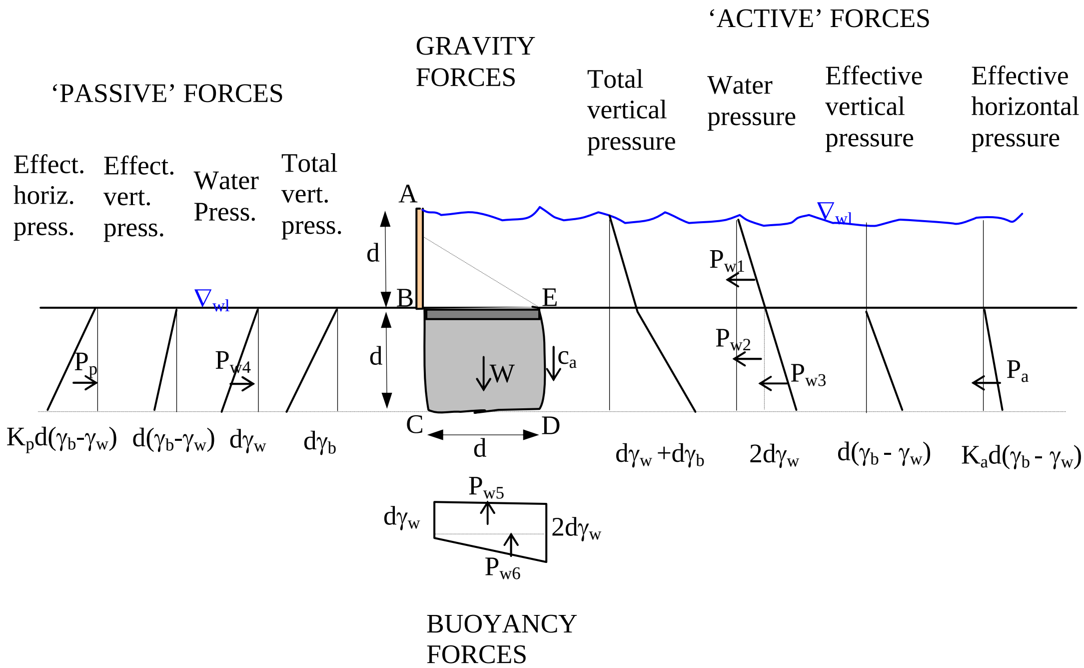

Figure 5. Forces acting on the flood barrier

An example calculation of the forces on a barrier to protect against a predicted flood height, d, of 0.9m is presented in Table 2. It is assumed that the soil has a bulk density γ_b of 20 kN/m^3 and effective stress parameters ϕ' =30°, c′ =0. Stability is checked by calculating the earth and water forces on the flood barrier assuming the water table is at ground level on the protected side and hydrostatic water pressures below the retained flood level.

Table 2. Calculation of forces acting on the flood barrier at peak flood level

Element	**Symbol**	**Equation**	**Example Calculated Forces** (kN /m run) assuming: d= 0.9m, γ_b =20kN/m^3, ϕ' =30°, c′ =0 (hence K_a = 0.33, K_p=3)
Water force on cover (AB)	P_{w1}	$\frac{1}{2}\ d^2\ \gamma_w$	4.05
Active force on ED	P_a	$\frac{1}{2}\ K_a\ d^2(\gamma_b - \gamma_w)$	1.35
Water force on ED	$P_{w2} + P_{w3}$	$d^2\ \gamma_w + \frac{1}{2}\ d^2\ \gamma_w$	8.1+4.05 =12.15
Passive soil resistance on BC	P_p	$\frac{1}{2}\ K_p\ d^2(\gamma_b - \gamma_w)$	12.15
Water force on BC	P_{w4}	$\frac{1}{2}\ d^2\ \gamma_w$	4.05
Total vertical force on CD	W	$d(d\gamma_b + d\gamma_w)$	24.3
Uplift force on CD	$P_{w5} + P_{w6}$	$d^2\ \gamma_w + \frac{1}{2}\ d^2\ \gamma_w$	8.1+4.05 =12.15
Adhesion along ED	c_a	$P_a \tan\phi'$	1.35 x 0.577 = 0.78

The Stability check is carried out by taking moments about point C (Figure 5.)

Overturning moment = P_a (d/3) + P_{w1}(d+d/3) + P_{w2}(d/2) + P_{w3}(d/3) + P_{w5}(d/2) + P_{w6}(2d/3) kN-m

Restoring moment = P_p (d/3) + P_{w4} (d/3) +W(d/2) + c_a(d) kN-m

For the example of the 0.9m high flood barrier :-

Overturning moment = 0.405 + 4.86 + 3.645 + 1.215 + 3.645 + 2.43 = **16.20** kN–m

Restoring moment = 3.645 + 1.215 + 10.94 + 0.70 = **16.50** kN-m

This indicates that the barrier is just stable under the most severe assumptions of groundwater conditions.

In practice the stability of the barrier will be checked for the actual soil and predicted groundwater conditions at each particular site. If necessary the ‘below ground’ dimensions may be extended to increase the factor of safety by increasing the mass of soil contained within the membrane which is acting as the restoring force.

Force taken by the geomembrane

The potential forces in the geomembrane and tie may be assessed with reference to Figure 6. It is assumed that the geomembrane is attached to the cover and firmly anchored in the backfilled soil trench below point B. The membrane, together with the tie, will be required to resist the full water force if the cover is not restrained by a kerb unit.

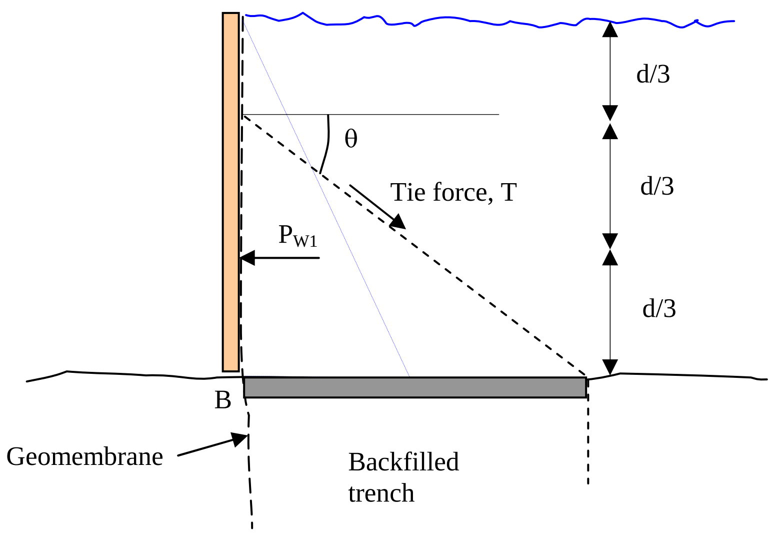

Figure 6. Forces on geomembrane and tie

Total water force, $P_{W1} = \frac{\gamma_w d^2}{2}$ (assumes static water – no allowance for waves)

The Membrane at point B, may take the full water force, P_{w1} at the base of cover although the tie, typically located at the 1/3 point, will attract a proportion of the force.

Taking moments about the tie position (assumed to be at 2d/3 as shown in Figure 6.)

$$T_m \times 2/3\, d = P_{w1} \times 1/3\, d = \frac{\gamma_w d^2}{2} \times 1/3\, d$$

$$\text{Force in membrane, } T_m = \frac{\gamma_w d^2}{4}$$

Table 3. Force to be resisted by geomembrane for various barrier heights..

Height of barrier, d (m)	**Geomembrane force** if assumed = full water force (kN/m run)	**Geomembrane force**, T_m, assuming tie takes proportion of load (kN/m run)
0.6	1.8	0.9
0.9	4.1	2.05
1.5	11.2	5.6

These forces are well within the design strength of the selected geomembrane products (See later discussion)

Force taken by the tie

The force in the tie (T kN per m run of barrier) is estimated as follows with reference to Figure 6.

Taking moments about the base of the cover (point B) $T \cos\theta x \frac{2}{3} d = \frac{\gamma_w d^2}{2} x \frac{1}{3} d$

$$T = \frac{\gamma_w d^2}{4 \cos\theta}$$

Table 4. Tie forces calculated for varying barrier heights

Height of barrier, d (m)	**Tie force**, T, (kN/m run) assuming θ = 35 deg
0.6m	1.1
0.9	2.5
1.5	6.9

Tie forces of this order can be accommodated by commercially available polyester ties.

Risk of softer ground at toe of barrier retaining flood waters

There is a concern that softened ground adjacent to the kerb (point B area, Figure 6.) could lead to deformation or distortion of the barrier under hydrostatic forces. The design of a particular installation will consider this local effect and if necessary the kerb area may be reinforced by concrete bedding or an additional tie may be included running along the top of the slab and attached to the kerb.

Seepage beneath the flood barrier

The embedment of the geomembrane in the backfilled trench maintains the stability of the structure and also helps to reduce water seepage through the soil. By drawing a simple flow net, as shown in Figure 7, the flow beneath the barrier may be estimated.

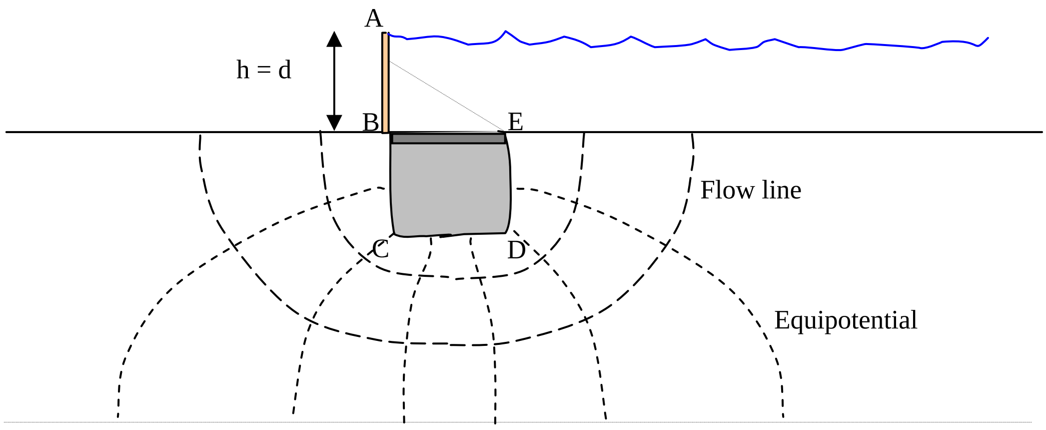

Figure 7. Assessment of possible flow beneath the flood barrier

From conventional flow net theory based on Darcy's law (for example reference Barnes, 2000), the flow q per m run is given by:

$q = kh\ n_f/n_d$

where k is the coefficient of permeability (m/sec), h is the head difference (=d), n_f is the number of flow lines and n_d the number of head drops.

For the flow net shown in Figure 7. where $n_f = 3$ and $n_d = 7$, assuming a sandy soil having a permeability $k = 10^{-5}$ m/sec, and a retained flood water height h=d = 0.9m, the flow beneath the barrier would be :

$q = 10^{-5} \times 0.9 \times 3/7 = 3.86\times10^{-6}\ m^3/sec = 0.014\ m^3/hr$ per m run = 14 litres/ hr per m run.

These flows are small and can be accommodated with small pumps. In general more clayey soils of lower permeability would be expected but in the unlikely event that more permeable soils are present over the full depth of the barrier the membrane depth may be increased to reduce the ground seepage flows.

Geomembrane selection

The geomembrane used in the trials was an Ethylene Interpolymer Alloy (EIA) material, (XR-5 from Seaman Corporation) provided by PA Geotechnical. The properties of the geomembrane which were critical to the trials are:

- Exceptional high strength – coated fabric, based on high strength polyester scrim
- High degree of flexibility – non crystalline structure in coating is not susceptible to environmental stress cracking
- High resistance to UV degradation
- High puncture resistance – 300% higher than HDPE geomembrane; 2 times thicker
- High resistance to biological / chemical degradation, particularly by hydrocarbon products

APPLICATIONS

The main application of the self erecting flood barrier is likely to be to protect against flooding of new and existing properties and land where the construction of a permanent barrier would cause undesirable physical or aesthetic intrusion into the local landscape. The barrier may be placed on top of existing flood defence embankments to increase their effective height with minimal visual intrusion. This has the added benefit of no additional loading of the existing embankment structure which is an important consideration for embankments constructed on soft, compressible alluvial soil foundations.

Other possible applications of the barrier include the temporary storage of water, protection around storage tanks where spillage would cause a hazard, and control of drainage waters and balancing ponds.

It may be that with appropriate design enhancement, such as the inclusion of a shock absorbing system in the ties, the barrier would have a place to help resist the forces of a tsunami wave.

CONCLUDING COMMENTS

The trials demonstrated that the concept of the self erecting flood barrier is practical and provided confidence to proceed with the development of a commercial system.

The team are now working on a number of options for the manufacture of the barrier covers and the hinge system. Options include the use of treated timber or moulded or recycled plastics to form a decking walkway as the cover to the barrier. The use of the geomembrane as the hinge is appealing for its simplicity in certain applications. Further options and the risks associated with the barrier and its operation are discussed in Greenwood et al (2008).

The geomembrane selected for the trial was considered a success and further developments of this component will be limited to the fixings used to secure the geomembrane to the covers / floats.

The Greenwood flood barrier is likely to be applicable worldwide to both small and medium sized sites. Material costs are low and installation is straightforward requiring only 'low tech' excavation equipment and manual labour under engineering supervision. This semi-permanent, self erecting barrier is considered to be particularly applicable as a low cost efficient alternative to the demountable barriers, or where a permanent flood barrier scheme is not affordable or it would intrude into the visual amenities of a waterside area.

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