Beales Corner

Temporary Barrier System

Post Incident Review

Date: July 2021

Version: Final v1

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Published by:
Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH
www.gov.uk/environment-agency

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Document history record

Doc No.				
Title:	**Critical Asset inspection Report**			
Rev	Date	Description/Reason for Issue	Author	Accepted
Final v1	30/07/2021	Post Incident Review	Lindsey Sayner BEng(hons)MSc CEng MICE Catchment Engineer West Midlands Area	Anthony Perry Operations Manager West Midlands Area

Contents

Foreword

The Beales Corner Temporary Barrier System Post Incident Review was commissioned by the Environment Agency (EA) West Midlands Operations Manager following the abnormal barrier operation and breach of the barrier on the 22nd January 2021. The purpose of the review was to investigate the abnormal operation of the flood barrier, to assess the overall risks due to barrier failure, and to determine what actions could be taken to reduce the risk of reoccurrence. The review has drawn upon a number of assessments undertaken for the EA by external suppliers following the incident. These include a Ground Investigation, Geophysical Survey, Topographical Survey, Sliding Review and a Highways Assessment.

1 Background

1.1 Aims of the Post Incident Review

The purpose of the review was to investigate the abnormal operation of the flood barrier and allow an informed decision on redeployment to be made. The following aims were identified:

- Review the performance of the barrier superstructure.
- Review the performance of the foundation.
- Identify the presence of any voiding or unconsolidated ground beneath the carriageway.
- Identify and investigate factors contributing to sliding failure including site specific environmental considerations.
- Review the operational procedures and documentation.
- Calculate the overall Factor of Safety (FoS) which can be achieved on the site and determine whether this is sufficient to allow redeployment.
- Identify mitigation measures to increase the passive resistance against sliding, if required.
- Produce recommendations for the Environment Agency and its Professional Partners to reduce the risks to operatives and the public associated with any future barrier deployment.

1.2 History of the Temporary Barrier Trial

Bewdley is frequently impacted by fluvial flooding with many major high river level events, witnessed most recently in 2021. The highest recorded flood event reached a height of 5.82m above the local stage datum (ASD) at the Bewdley Gauge, with regular events in recent years consistently above 5m ASD, and in 2020 reaching 5.48m ASD (Bewdley Gauge).[1] Flooding to property can occur directly and indirectly from the River Severn (due to rising groundwater within cellars, and from sewers when the rise in river levels causes them to surcharge). At Beales Corner, high river levels lead to the flooding of Kidderminster Road and Stourport road. A total of 30 properties at Beales Corner are at risk from the 1% Annual Exceedance Probability (AEP) flood event, and a further 15 in isolated areas upstream and downstream.

In the EA's Catchment Flood Management Plan, Bewdley forms part of the Middle Severn Corridor, where the policy recommends further action may be taken to maintain the current level of flood risk into the future (responding to the potential increases in risk from urban development, land use change and climate change). In spring 2003, the Environment Agency was allocated funding from the Department for Environment, Food and Rural Affairs (Defra) to purchase plant and equipment that would facilitate the trials of temporary flood defence barriers. Three locations along the River Severn were initially identified as test locations, which were later extended to an additional three including Beales Corner in Wribbenhall, Bewdley, in 2006. The barriers protect 19 properties to a 10% AEP, and are effective in combination with a storage area on the Riddings Brook (Wribbenhall). It is believed that the temporary barriers have been deployed 25 times since the trial began.

The barrier trial offers a level of protection, known as standard of service, to the properties behind the barrier of 5.0m ASD (Bewdley Gauge), which corresponds to approximately 21.82m AOD (Above Ordnance survey Datum). Above this level, water levels rise behind the barrier from just inside Pewterers Alley and the scheme is outflanked due to there being insufficient high ground for the barrier to tie into. This standard of service has been communicated to the local community and information is available on the Bewdley Town Council website.

Set at a deployment trigger level in between the Severn Side Phase 1 and Phase 2 demountable defence deployment triggers (3.85m ASD and 4.55m ASD respectively), the Beales Corner temporary barriers are deployed by 4.0m ASD (Bewdley Gauge). The alignments of each defence are shown in Figure 1.

[1] EA 'Bewdley: Beales Specific Gaugeboard Data' 2021.

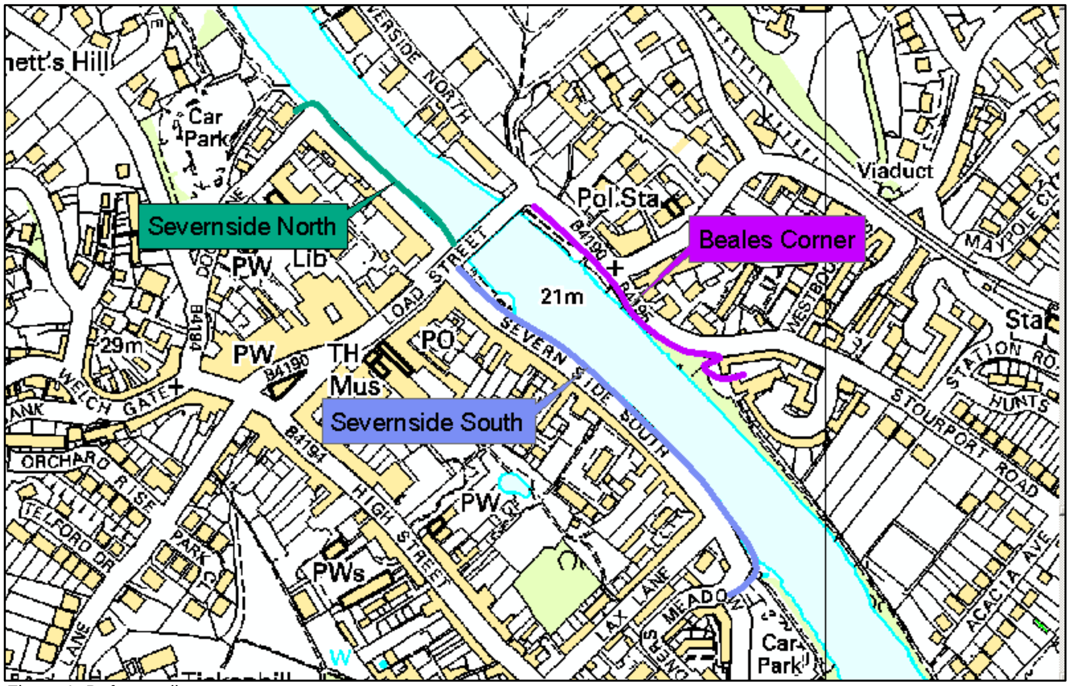


Figure 1: Defence alignments

The original barrier trial consisted of a short length of 1.8m and then 1.25m high barriers. An assessment was carried out by the EA in 2014, based on an independent engineering report, which identified risks with the continued use of temporary barriers in this location. Analysis of the necessary events required for successful operation of the flood defence asset produced nine discrete actions:

1. Flooding correctly forecast in time for the barrier to be erected
2. Warning issued to area staff
3. Trained team available in sufficient numbers
4. Storage depot accessible and transport available
5. Road to site clear
6. Road at site closed and all equipment available
7. Barrier erected within time available
8. Pumps delivered and operational
9. Barrier and pumps perform satisfactorily

Actions 1 and 2 are supported by the EA Incident Management and Resilience Teams, and an additional forecasting officer is placed on duty for large or significant weather events.

However, in recent events the first flood peak has arrived earlier and higher than that expected in any of the reasonable worst-case forecast scenarios. Whilst a large number of EA operatives and wider EA personnel are trained in barrier deployment, the resource is shared between Beales Corner, Severn Side and other operational sites across the county; due to forecast uncertainties it is not always possible to bring in additional outside resource in time. The 1.8m high barrier system required an additional fixed axle lorry for delivery, an additional 2 operatives, and took an additional 3 hours to deploy; increasing the risk to achieving actions 3, 4, 5 and 7.

A 2019 assessment concluded that the standard of protection of 5.0m ASD (Bewdley Gauge) is achieved solely with the 1.25m barrier sections due to the outflanking at higher levels. This meant that the barrier could be delivered in a shorter timescale requiring only 1 articulated lorry, and erected more quickly in an emergency (within 4 hours), therefore the short 1.8m barrier section was discontinued.

The structural analysis completed for the 2014 report indicated that there was a high risk that the barriers could move under full height loading when erected on paved surfaces, and highlighted the lubrication effects of flood and rain water. Due to local conditions, it has not been possible to provide permanent fixings in the highway to support the erection of the temporary barriers or to extend the polythene sheet any further. Combined with the uneven road surface, this contributes to a higher rate of seepage than other trial sites, and additional pumping is required to deal with seepage at Beales Corner. During flood events, problems with delamination of the tarmac surface of the road, causing ‘blisters’ in the road surface have also been observed.

Due to these considerations, a total of 44 properties at Beales Corner have received Property Flood Resilience (PFR) measures; this included the 19 properties which were impacted by the 22nd January 2021 event. The local residents were made aware of the residual risks associated with continued deployment; the preference of the community was that the barriers continue to be deployed while a permanent scheme is investigated.

In recent years, in order to raise the standard of protection the barrier provides, a sandbag defence has been constructed in Pewterers Alley to delay the outflanking occurring. This activity has been undertaken on a best endeavours basis when time allows and is not a designed defence. It is understood that the last time an overtopping event occurred in February 2020 it corresponded to a level of 5.36m ASD on the Bewdley Gauge, which demonstrates that the sandbags were holding back 0.36m of water at this point.

The Beales Corner temporary barrier system was compromised on Friday 22nd January 2021 at 23:45. The level at the time of breach was 5.225m ASD (Bewdley Gauge).

2 Asset Information

2.1 Information and Plans

2.1.1 Asset Name

Beales Corner Temporary Defence System

2.1.2 Address & National grid reference

Beales Corner, Bewdley, Worcestershire, DY12 1AB.
SO7881575415.

2.1.3 Asset Management Plans

The following documents were available to review and have been referred to throughout the report:

Type of Plan	Version No/ Date	Location of Plan
Site Pack/Construction Phase Plan[2]	2021	Incident Management Tool box
Operational Asset Plans 0-3[3]	Draft: Nov 2020	Incident Management Tool box
Gaugeboard Data: Significant Levels, Beales Corner Specific[4]	2021	Incident Management Tool box
Deployment of temporary flood defences at Beales corner, Bewdley Action Plan[5]	Sept 2009	Incident Management Tool box
Wribbenhall Temporary Barrier Community Involvement Plan[6]	Nov 2016	Incident Management Tool box
Multi Agency Flood Plan[7]	V2: Apr 2018	Incident Management Tool box

Table 1: Operational and Planning Documents Reviewed

A great deal of information is contained in the asset operation and management plans listed in Table1, they are stored in a number of places across the EA Incident Management Toolbox and some are currently working drafts or contain historic information. Whilst this information

[2] EA 'Beales Corner Barrier Deployment CPP' Draft, Jul 2021.
[3] EA 'West Midlands OAP0, OAP1, OAP2 and OAP2' Draft, Nov 2020
[4] EA 'Bewdley: Beales Specific Gaugeboard Data' 2021.
[5] West Mercia Local Resilience Forum 'Beales Corner Deployment Action Plan' Sept 2009 (superseded).
[6] Bewdley Town Council, 'Wribbenhall Temporary Barrier Community Involvement Plan' Nov 2016.
[7] West Mercia Local Resilience Forum, 'Beales Corner Multi-Agency Operational Response Arrangements v2.0,' April 2018.

had no impact on the compromise and resulting flooding, it would be beneficial to incorporate the relevant information from all of the documents into a Temporary Defence Deployment Plan, which is a new EA operational template for temporary barrier sites.

Recommendation 1: The EA should work with the Local Authority to update the Temporary Barrier Community Involvement Plan. This will include updated evacuation levels.

Recommendation 2: The EA should work with West Mercia Local Resilience Forum to update the Multi Agency Flood Plan.

Recommendation 3: The EA should combine existing operational documents into a Temporary Defence Deployment Plan (TDDP) specific to Beales Corner, which will incorporate learning from the Post Incident Review.

2.1.4 Asset Reference/Associated Assets

The current 1.25m high temporary flood protection system at Beales Corner consists of removable flood protection products that are wholly installed during a flood event and removed completely when levels have receded for storage in an EA depot. The barriers sit within the Flood Risk Management System of FR/06/S106 but do not have a permanent asset reference number. Money is bid for maintenance activities and replacement parts through the EA's national asset management system.

The following assets are located adjacent to the scheme:

Asset Name	Asset ID	Grid Reference
Outfall	257197	SO78758 75450
Outfall Bewdley	257971	SO78762 75452
Outfall	257200	SO78767 75455
Outfall	245786	SO78769 75451
Outfall	257199	SO78772 75449
Outfall	272311	SO78775 75446
Outfall	257203	SO78778 75447
Outfall	257202	SO78781 77441
Outfall	257201	SO78783 75439
Outfall	257198	`SO78786 75437
Outfall	257968	SO78788 75434
Outfall	257210	SO78790 75432
Outfall	257209	SO78792 754 30
Outfall	257208	SO78794 75428

Table 2: Assets adjacent to the scheme.

2.2 Temporary Barrier System

2.2.1 System Components

For the system to operate successfully, and prevent the entry of floodwater into a protected area, the following components are important:

- the barrier superstructure
- the foundation or bedding structure;
- the seals, joints and interactions within the structure and with the adjacent structures and subsoil.

2.2.2 Barrier Superstructure

The barrier superstructure is a proprietary design which was awarded the BSI PAS 11882 Kitemark in May 2003, and has subsequently been renewed. This indicates that the barrier has been testing in accordance with:

- PAS 1188:2014 – Flood Protection Products
- PAS 1188-2:2014 – Flood Protection products. Part 2: Temporary and demountable flood protection products

In addition to these standards, the manufacturer passes annual BSI audits.

The barrier system consists of rigid framed barriers with an impermeable membrane. It relies on supporting frames and the weight of the water on the membrane to provide anchoring stability. The barrier is modular and sections are connected together to form a continuous barrier.

Figures 2 and 3 show the modular nature of construction of the system with legs, plate bars and plates.

Leakage often occurs at low water levels and combines with surface water. To minimise this the membrane is weighted with chains and 2 x 6" Pioneer Pumps can be deployed behind the barrier connected to the road drain opposite Rickett's Place (Figure 4).

Figure 4: Pump discharge hoses can be observed crossing the barrier.

The impermeable membrane extends upstream and away from the barrier to form a long sleeve. The weight of the water acting on the membrane increases the system's stability and sealing with the ground surface. The membrane used is supplied by the manufacturer, however due to site restrictions (available footprint/access chambers) it can be difficult to fully unfold and attach in the dimensions provided.

Recommendation 4: The EA should discuss membrane sizing with the barrier manufacturer to determine the membrane with the optimum dimensions for the specific site.

The following is a summary of the plant and equipment required for the deployment of the barrier:

- 1 x Teletruck
- 11 stillages of 30 x plates
- 8 stillages of 21 x 1.2m Legs
- 4 stillages of 108 x Plate bars
- Ancillary items in large coloured stillage's (corner plates/ adjustable bars/ chains/ clamps/spring clip washer assembly for locking plates/ spare lynch pins
- 6 x Rolls of reinforced barrier sheeting 4.75m wide and 42m long
- 1 x pallet sandbags (35-40)
- Pumps, including 2 x 6" trailer mounted pumps and a number of submersible 3" and 4" pumps.

In addition to EA pumping arrangements, Severn Trent Water attend site to manage surface water and prevent surcharging in the sewer utilising up to 5 x 6" pumps, 2 x 4" pumps and self-feeding fuel bowsers. Their operating procedures are in detailed in Severn Trent's Standard

Operating Procedure.[8] Figures 5 and 6 show the set-up of the surface water pumps at the access chambers at the Kidderminster Road-Stourport Road Junction.

Figure 5: Severn Trent Pumps on Kidderminster Road (Source: Severn Trent).

Figure 6: Severn Trent Pump on Stourport Road (Source: Severn Trent).

8 Severn Trent 'Standard Operating Procedure (SOP), Beales Corner, Bewdley River Flooding Contingency Plan, Sept 2018'

1.2.6 Foundation Structure

The barrier frames have a tendency to exert high bearing pressures on the bedding surface (in this case the road) (Figures 7 and 8), therefore ground conditions are important when considering deployment.



Figures 7 and 8: Barrier feet with protruding ‘collars’ which make contact with the surface below.

Following the 2019-20 flood event, the surface dressing layer was damaged by the flood barrier to a depth of 10mm (Figure 9). The carriageway remained fit for purpose as a road structure, with damage falling below the requirement for responsive and reactive carriageway maintenance. Care was taken on the subsequent deployment to avoid placing the legs onto the damaged surface.


Figure 9: Damage caused by 2019-20 flood event (Source: Julian Browne, Worcestershire County Council).

To inform the Post Incident Review into the failure of the temporary barriers, and to understand more about the performance of the pavement below the barrier system, an engineering highway assessment was commissioned.[9] Due to the large number of events over the last few years with high levels of water against the barrier for a sustained period of time, one of the desired outputs of this review was to identify voiding or unconsolidated ground beneath the carriageway. To support this assessment, a ground penetrating radar (GPR) survey was commissioned for interpretation in combination with the ground investigation[10]. The findings of these investigations are detailed in Section 5.2 Ground Investigation.

[9] Arup 'Bewdley Left Bank Pavement Investigation Report.' 2021.

[10] Arup, 'Bewdley Left Bank Geotechnical Interpretative Report - Phase 1,' June 2021.

3 Operation & Performance

3.1 Maintenance

During normal ‘non flood’ conditions on the River Severn the barrier system is stored offsite in a secure location. Damaged membranes or structural members are disposed of when the barrier is demobilised and a full post operational inspection of the frame occurs. A stock of spare parts are available in the local EA depot.

Learning from the initial site visit and sliding review could be of benefit to the post inspection procedure.

Recommendation 5: The EA should review the demobilisation inspection and sign off procedure to see whether it can further be improved.

3.2 Operation

When the River Severn is rising and an initial forecast of greater than 4.0m ASD at the Bewdley River Gauge is received, or if there is sufficient risk of a rapid rise in the river levels, the trigger is given for the EA and its partners make a decision over the erection of the barriers. The barriers do not retain water until 4.3m ASD (Bewdley Gauge), however they are deployed by 4.0m ASD (Bewdley Gauge) is reached, as this is the threshold of flooding occurring on the Stourport Road.

Prior to the agreed time of deployment Worcester County Council (WCC) are requested to install ‘road closure,’ and ‘diversion’ signs and barriers to ensure a safe working area and to close the site to members of the public and traffic. West Mercia Police (WMP) provide a police presence to assist this operation. EA Community Information Officers (CIO’s) or Field Operatives are placed in the relevant access locations before any Operations begin on site, to seek to prevent access by members of the public and vehicle traffic.

The barrier deployment area is cleared of debris and vegetation to ensure a secure surface for the barrier legs. When the site supervisor has confirmed all preparations have been completed, unloading of the stillages from the transport vehicle commences.

WCC provide and erect pedestrian barriers adjacent to the footpath leading to Pewterer’s Alley to prevent the public gaining access to the barrier or the pumps after the barrier has been erected. STW install trailer-mounted diesel pumps to cope with any surcharging in local sewers which may occur from manholes situated in the roadway.

The barrier is deployed in a staged manner with resource managed between Beales Corner and Severn Side Deployment. Figures 10 and 11 illustrate the two phases.

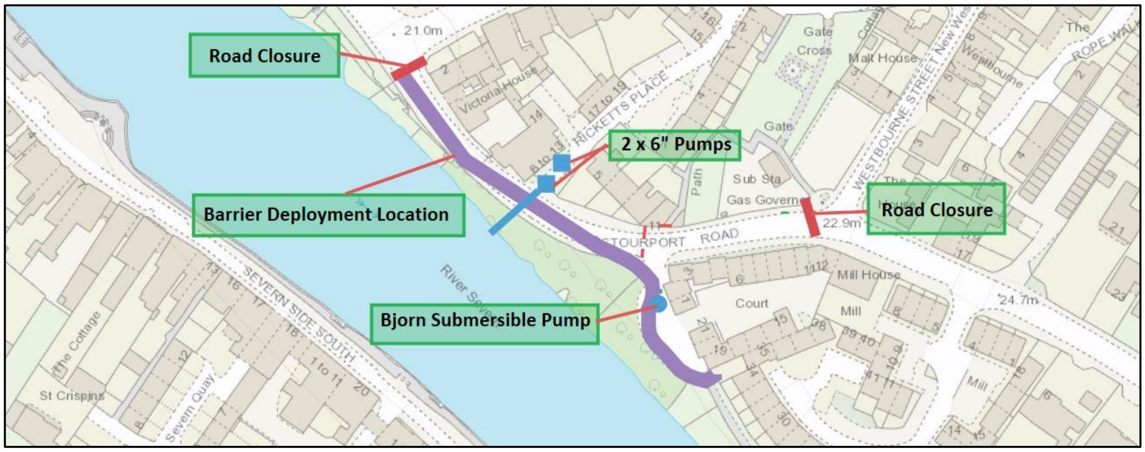


Figure 10: Bewdley temporary barriers Phase 1

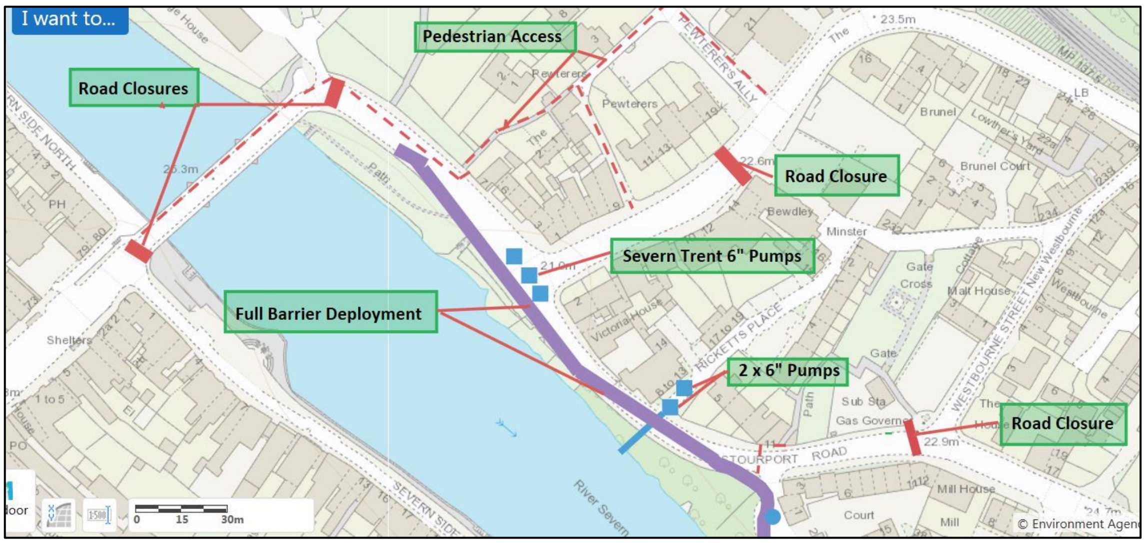


Figure 11: Bewdley Temporary Barriers Phase 2

The EA will only apply polythene sheeting to the barrier when the forecast confirms that river levels will reach the barrier. The deployment process is methodical and carried out by operatives who have undertaken training with the majority having prior experience on the site. A qualified engineer completes visual checks.

Recommendation 6: The EA should review the construction inspection and sign off procedure to see whether it can be further improved and incorporate the relevant recommendations from the sliding review.

Recommendation 7: The EA should update the temporary barrier training for the Bewdley site to incorporate relevant lessons identified through this investigation. This should include the training provided to temporary resources that support only during significant flood events, and the buddying process used to ensure competency.

24-hour security to the site is provided, and the EA seek to ensure that all personnel involved are fully briefed and given appropriate telephone numbers to contact in the event of an emergency. The operational performance of the barrier is monitored during a flood to assess the effectiveness of the asset. The EA are in attendance and may seal any unforeseen leaks from manholes and the barrier itself and, along with STW, to ensure the pumps are operating correctly and fuelled. STW will monitor the sewers to ensure that no surcharging and flooding occurs during barrier deployment.

The current Multi Agency Flood Plan, 'West Mercia Local Resilience Forum Beales Corner Multi-Agency Operational Response Arrangements v2.0' instructs the activation of a Bronze Cell when the operational on the ground staff (EA / STW) request a multi-agency operational response in place, or the decision is made to deploy the barriers.

The Bronze Cell includes the Environment Agency, Worcestershire County Council (Highways / Emergency Planning / Communications/ Chair of County Volunteers Emergency Committee (CVEC), Wyre Forest District Council (Emergency Planning- Resilience Manager & Duty Emergency Response Team Leader / Operational Services Manager / Communications), Warwickshire & West Mercia Police, Hereford & Worcester Fire and Rescue Service, West Midlands Ambulance Service NHS Trust, Severn Trent Water Ltd, Worcestershire Health & Care NHS Trust, and Bewdley Town Council – Clerk.

A Tactical Coordination Group (TCG) is triggered when the river level is predicted to be at or above 4.6m ASD (Bewdley Gauge), following discussion at the Bronze Cell. The EA Site Controller briefs the operatives on site that the site will be evacuated if this level is exceeded. Based on the alignment recommended in Section 5.11, this would correspond to a height of water of 0.8m of water against the barrier at the lowest point. The Construction Phase Plan states that if the Site Controller receives warning of a possible risk of overtopping, all non-essential personnel are to move to a safe location with remaining essential Field Operatives to be delegated tasks including removal of all non-essential plant and equipment to higher ground, warning local residents and assisting local residents where possible to prevent water ingress to property.

Recommendation 8: The EA to review the evacuation thresholds for Beales Corner, Bewdley, to be informed by this Post Incident Review. This may exclude LRF partners such as Fire and Rescue working with their own additional safe systems of control. Consider updating of the Multi Agency Plan (see Recommendation 2).

3.3 Health, Safety and Deployment Planning

The Construction Phase Plan[11] (CPP) is used by the local EA Field Operations teams to plan and organise the safe installation of the barrier. It contains an emergency plan, method statements, risk assessments, detailed step by step installation guides and plans showing where temporary defences/mobile assets should be positioned.

As per Recommendation 3 in Section 2.1.3, it is advised that following this review a full Temporary Defence Deployment Plan (TDDP) is developed for this site to complement the CPP, providing clear information on the technical aspects of deployment.

The Field Operations team members present during the barrier installation in January 2021 were very familiar with the site and the barrier system, and demonstrated a high degree of operational awareness. However, due to the resource being shared between Beales Corner, Severn Side and other operational sites across the county, there can be a lot of pressure on operatives to achieve deployment across multiple sites due to late forecast changes.

Recommendation 9: The EA should consider whether Beales Corner Temporary Barrier System can be resourced independently to the other defences in Bewdley and Worcestershire, potentially utilising support from adjacent Field Teams. This will help ensure operatives have the time to focus on deployment of this complex system and any additional resistance measures.

The temporary barriers are currently inspected at key stages to ensure that they are constructed, used, maintained and then dismantled safely and in accordance with any current manufactures' recommendations. As per Recommendations 5 and 6 in Section 3.2, it is recommended that the EA may wish to consider seeking to further improve the sign off for the staged deployment checklist by a qualified person. To assist those managing future deployments, the record of trained and experienced operatives should be kept within the CPP and if external resource or new operatives are required then the 'buddy' system with a trained operative is used and recorded.

Evacuation levels are used to inform operational staff and the public that they should leave to a safe location before they are no longer safe behind the barrier due to significant loading or risk of overtopping. The Construction Phase Plan should be updated in line with the findings of this review, including an updated maximum safe working level of water against the barrier, and with a prescribed method of safely determining this level. Currently the Site Controller briefs the team that a level associated with the forming of the TGC (4.6m ASD Bewdley Gauge) is the operative evacuation level (informed by the incident room), but that essential staff may access site to perform an activity. Recommendation 7 (Section 3.2) suggests the EA should review the 'all operative' evacuation trigger level, informed by sliding calculations to ensure the risks are properly managed. This may be managed through a series of triggers which should all be referenced back to levels at the Bewdley Gauge and informed by the EA incident room chain of command. Staff should not be required to measure levels on site.

[11] EA 'Beales Corner Barrier Deployment CPP' Draft, Jul 2021.

Risks to staff operating behind the barrier include slips and trips, which were more likely when the previous 1.8m barrier system was acro-propped against the kerb. The barriers can leak at lower levels and require an operational response to ensure the integrity of the membrane, however it should be made clear in the CPP that no operative should be expected to enter flood water on the river side of the barrier to undertake this work without appropriate control measures.

Recommendation 10: The EA should review and update the Construction Phase Plan to ensure it clearly states that operatives are not to enter the watercourse without appropriate control measures.

The barriers have historically 'settled' under loading, and it is not unusual for minor lateral movement and creaking to occur as the weight of the water increases the frictional resistance due to the angle of the barrier. Procedures should be in place for reporting these instances to the incident room.

Recommendation 11: The EA should consider introducing a way of recording and monitoring any lateral movement and seepage and consider associated risk controls.

Other operational activities required behind the barrier include checking the membrane (clips and chains) - especially in storm conditions, pump refuelling and the deployment of additional pumps if surface water levels require action. Use of additional mobile CCTV cameras could reduce the need for physical checks and fuel cubes could reduce the need for refuelling.

Recommendation 12: The EA should record in the TDDP all know activities which require operative access behind the barrier under load. There should be no additional activities permitted. An exercise to review and reduce these activities should be undertaken prior to redeployment and measures put in place.

Barrier security is provided 24-hour by the EA or EA contractors, supported by WCC and WMP. The EA barrier deployment notice for Beales Corner (Wribbenhall) contains the following wording:

'We advise that no-one should be in the area protected by the barriers as there is always a risk that the temporary flood barriers could fail'.

However, despite road and footpath closures there was evidence of unauthorised access to the barrier site during the 2021 event. Due to the number of pedestrian access points it cannot be assumed that members of the public can be kept away from the barrier system, it is therefore recommended that the FoS against sliding is robust and deployment of the barriers does not increase risk to life.

Recommendation 13: The EA must assume a robust Factor of Safety against sliding failure up to full load, as determined in the Post Incident Review, as it cannot be guaranteed that members of the public are not in proximity to the barrier.

3.4 Operation History and Performance

Records indicate that the barrier system has been deployed 25 times since the trial began.

Figure 12: Beales Corner Temporary Barrier System under deployment.

Figure 13 displays the water levels which reached above 4m ASD on the Bewdley gauge from 2006 onwards. The trajectory of the average depth of the peak appears to be increasing over time.

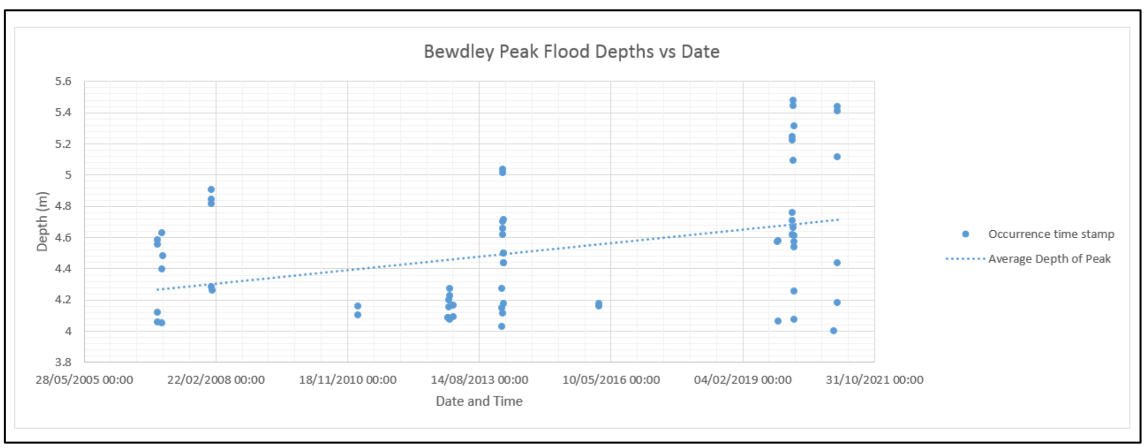


Figure 13: Historic level data (Source: EA Wiski data).

There have been a number of occasions where barriers were deployed but river levels did not rise sufficiently to have water against them.

The difficulty in reducing unnecessary deployment is influenced by 3 factors:

1. The accuracy of the flood forecasting. The influence of the flashy Dowles Brook tributary upstream of Bewdley adds to these difficulties.
2. A degree of precaution when decisions are made to deploy the barriers.
3. The time taken to organise and deploy the barriers.

Due to the above 3 factors and access requirements, the barriers must be installed well in advance of the level when they will be effective protecting property. These transportation risks were highlighted in the July 2007 floods when, due to flood water on roads, the temporary flood barriers were unable to reach the trial sites in Hylton Road, Worcester and Upton-Upon-Severn and property flooded.

In February 2020, an unprecedented rise on the main River Severn at Bewdley occurred on the night of 15th/16th February, with the first peak arriving earlier and higher than that expected in any of the reasonable worst-case forecast scenarios, meaning there was not sufficient time to put up all of the barriers.

Exceedance events have occurred since the barrier system was first trialled in 2006. However there is no recorded evidence of the barrier previously sliding under full load or during an overtopping scenario. It should be assumed for health and safety planning that the barrier would be unstable during an exceedance event.

3.5 Abnormal Barrier Operation and Breach January 2021

The EA began the erection of the Beales Corner temporary barrier System on 20th January 2021 in response to Storm Christoph forecasts for levels on the river Severn to exceed 4m ASD at the Bewdley Gauge. The full temporary barrier system was in place by the morning of 22nd January 2021, and as the forecast developed river levels were expected to exceed 5m ASD (Bewdley Gauge) that evening. Residents were informed as early as possible through the EA Flood Warning Service, allowing five hours to make preparations:

At 13:14 on 22nd January 2021, the following Flood Warning was issued – 031FWFSE370 – River Severn at Wribbenhall, Bewdley:

> *As a result of recent heavy rainfall River levels have risen at the Bewdley gauge. BEALES CORNER barrier will become ineffective from this evening, 22/01/21. Flood water will overtop or outflank the Beales Corner temporary barrier. Flooding may affect Beales Corner, Severnside South, Kidderminster Road, B456, access to Bewdley Bridge including property on Stourport Road. Millside Court, Kidderminster and Stourport Roads, Greenacres Lane, Pewterers Alley, Springfield Place, Ricketts Place, Springfield Villas, Nunneries and Acacia Avenue. Predicted Peak:- Bewdley 5.2 to 5.4m Saturday afternoon 22/01/21. Our incident response staff are liaising with emergency services. Move possessions and valuables off the ground or to safety and have a bag ready with vital items like medicines and insurance documents. Please follow advice from emergency services. This message will be updated by 10am tomorrow 23/01/21, or as the situation changes*

This was followed up by door knocking on site to ensure that the warning had been received and to provide support where possible. The standard of service the barrier provides (5m ASD at the Bewdley Gauge) was reached at 18:40 on 22nd January 2021.

As per the operational procedures, the two EA operations staff on site were not behind the barrier once the evacuation had been triggered, and no barrier performance issues had been observed by the point that the standard of service was met.

Timeline Summary	
Monday 18th January	Beales Corner scheduled for deployment on 20th January
Wednesday 20th January	Phased deployment started. 13:01: Initial Flood Alert issued (031WAF108 – River Severn in Worcestershire).
Thursday 21st January	Membrane attached to first section (Phase 1)
Friday 22nd January	Barrier System completed with Phase 2 in place and all membrane secured. Additional pumps and sandbags provided to residents to bolster PFR. 13:14: Flood Warning (031FWFSE370 – River Severn at Wribbenhall, Bewdley) informed residents that Beales Corner will become ineffective from this evening, 22/01/21. 15:45: Sandbag wall at Pewterers Alley constructed as per best endeavours approach. 18:40: Standard of Service at 5.0mASD (Bewdley Gauge) exceeded. 23:45: Barrier system compromised at 5.225mASD (Bewdley Gauge)
Saturday 23rd January	05:20: Level at Bewdley Gauge rose above 5.36mASD, which is estimated to be the overtop level in January 2020. 08:00 An additional 10 submersible pumps ordered for EA staff to assist homeowners. 12:00 Peak level of 5.435mASD recorded (Bewdley Gauge).

Table 3: January 2021 Event Timeline

4 Analysis of the abnormal operation

4.1 Beales Corner Temporary Barrier Initial Assessment

Following the abnormal barrier operation and breach on 22nd January 2021, water levels receded on Monday 25th January 2021. A drone survey was carried out on the undisturbed defence as it became visible, and the EA West Midlands Area Catchment Engineer undertook an initial site assessment, accompanied by a representative from the barrier manufacturer. The initial assessment report broke down the site into 4 main sections:

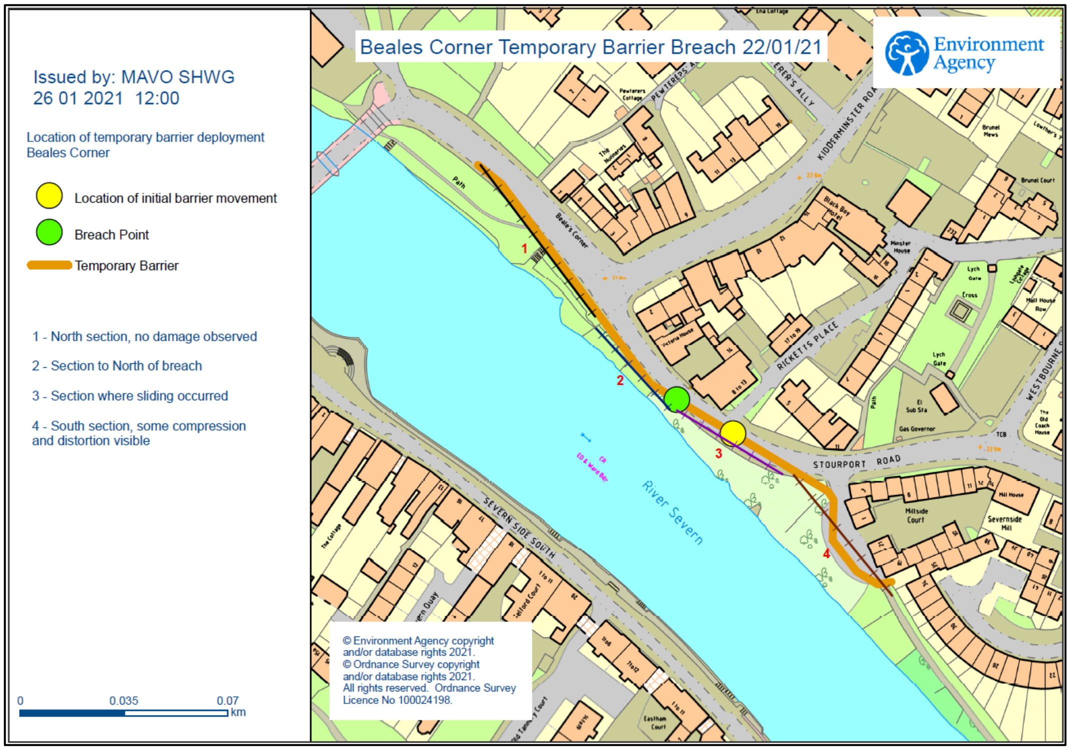


Figure 14: Plan dividing the defence into 4 sections for inspection purposes.

4.1.1 Section 1

Section 1 is the northern section of barrier. This was observed to have remained on its original alignment with no visible damage until past the Beales Corner road junction.

Figure 15: Section1 aerial view.

Figure 16: Section 1.

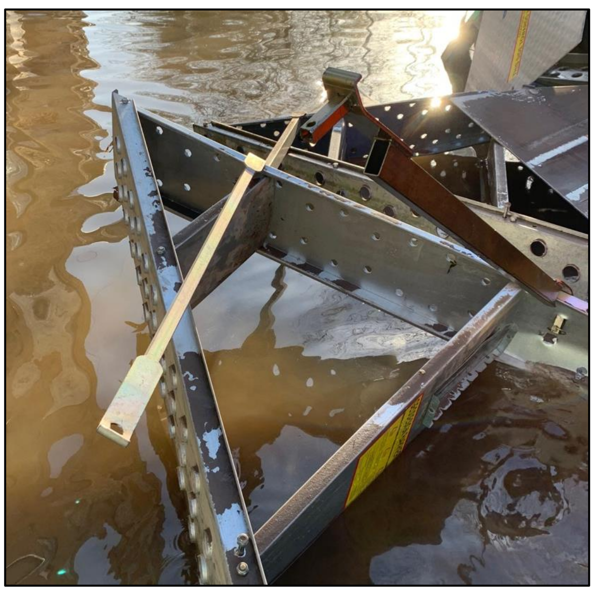
The hydrostatic force on this section of the barrier is lowest due to the topography of the road and the membrane apron and chain appeared undisturbed.

4.1.2 Section 2

Section 2 is the section of temporary barrier which culminates at the breach. At the point of breach the camber was observed to be more significant and the membrane apron had torn. Upstream of the breach, the membrane had displaced toward the toe of the barrier.

Figure 17: Section 2 aerial view.

In this location, a spacer bar was observed with its weld broken (in the foreground of Figure 19 compared to the adjacent bar, both twisted) and the barriers were deformed backwards against the back of the adjacent barrier, which was thought to have been caused by the force of the water flowing through the breach point.



Figures 18 and 19: Section of barrier where the breach occurred twisted back, a weld was observed to be broken.

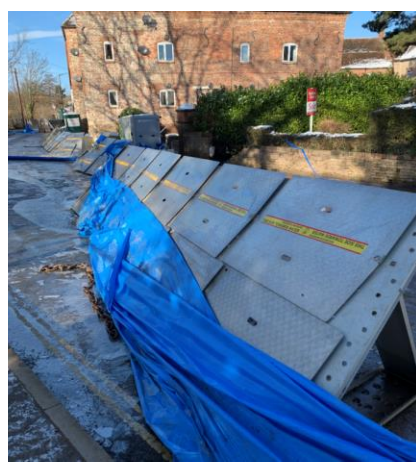
4.1.3 Section 3

Section 3 is comprised of barrier which had moved from its original alignment just behind the toe of the kerb, approximately 4m inland across the road. Damage to the road service in the form of scrape marks was observed as most evident at the entrance to Ricketts Place, which is the low spot in the scheme. This observation ties in with where the initial movement was described by residents and captured by CCTV.

Figure 20: Section 3 aerial view.

The membrane was damaged and the barrier deformed most at the centre of the slide where there were no kerb or barrier to restrict the lateral movement.

The assessment considered it likely that as the barrier began to move, and exert force on each adjacent section through the bars and pins, it eventually sheared and breached at the upstream section of Section 3, and was washed backwards against the kerb in this section.

Figures 21 and 22: Section 3.

4.1.4 Section 4

Section 4 was recorded as having evidence of compression and displacement at the bottom end, and bins and other debris had struck legs damaging spacer bars and exerting pressure along the line. The alignment remained unchanged, however some material has been washed out and many feet were unevenly seated. At this downstream end of the barrier the camber is minimal and membrane was mostly intact.

Figure 23: Section 4 aerial view.

4.2 Failure Modes

The Temporary and Demountable Flood Protection Guide[12] recognises that temporary barrier systems can be affected by three principal modes of failure:

- Functional Failure
- Structural Failure
- Operational Failure

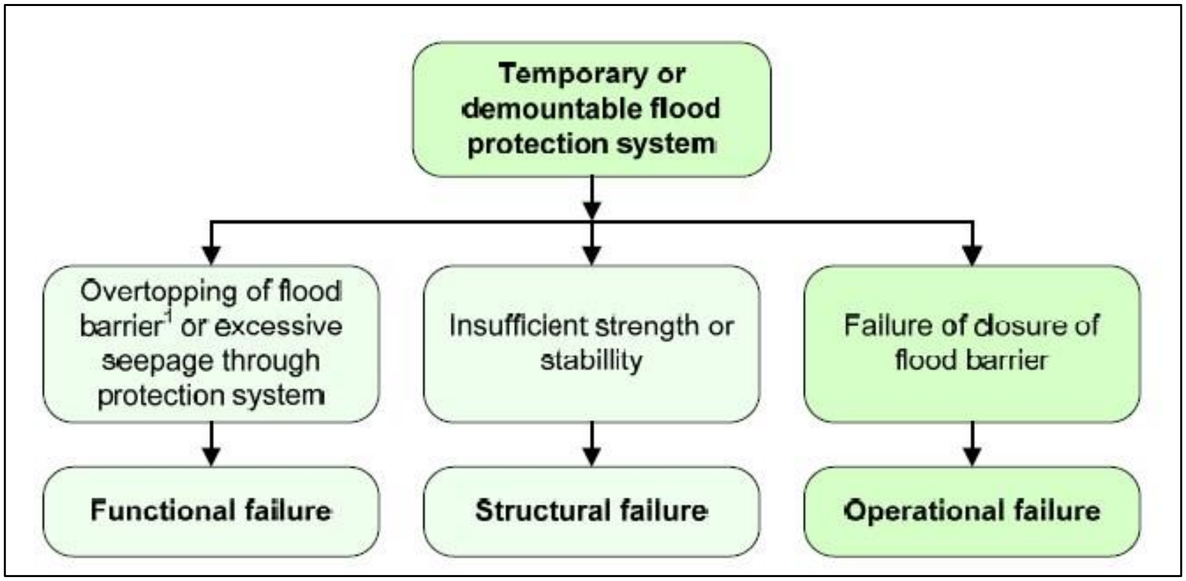


Figure 24 – Temporary system failure categories (Source: Temporary and Demountable Flood Protection Guide).

4.2.1 Functional Failure

Functional Failure is the inability of the structure to restrict flow of water over, around, under or through it to a pre-determined performance level under specified conditions.

There is no evidence that the barrier functionally failed due to overtopping, outflanking or uncontrolled leakage. The barrier system is expected to outflank at levels above 5m ASD (Bewdley Gauge). If outflanking measures are in place at Pewterers Alley, as they were on Friday 22nd January 2021, then river levels could reach 5.36mASD (Bewdley Gauge) by the point overtopping occurs.

The waterproof membrane was observed to be undamaged with the exception of where the barrier movement occurred. The barrier system did seep during operation, and as river levels rose EA staff observed that the road surface was leaking more than had been seen on the previous deployments, with water issuing under pressure from many small points across the surface on the dry side of the barrier.

[12] EA, 'Temporary and Demountable Flood Protection Guide,' August 2011.

4.2.2 Structural Failure

Structural failure of a temporary barrier system can occur due to breaching, piping, foundation failure, collapse, overturning, rolling or sliding. The flood protection system fails when, as a result of any of these occurrences, the system is unable to meet its performance objective. The failure of a component of a protection system does not necessarily imply the failure of the system, even though it could progressively lead to a system failure.

During the incident on 22nd January 2021, the barrier system moved (sliding failure) and sections sheared. Footage captured by remote camera earlier in the day as water loaded the barrier suggested a small initial movement. Just before the breach a more significant inland movement can be observed in the temporary barrier alignment. Eyewitness accounts from residents describe watching the barrier move just before the barrier sheared and the breach occurred.

Figure 25: EA Remote Camera photograph showing inward movement of a section of barrier at the centre of the image at 23:34.

Whilst there was no evidence of foundation settlement, water was observed seeping through the ground under the barrier and emerging through the carriageway pavement.

General observation of the site showed a marked deterioration in carriageway pavement condition with gouge marks from the barrier system, stress cracks and loss of surface material. Some of these issues may have been present before the event.

4.2.3 Operational Failure

Operational failure is the failure to successfully erect or close the barrier before water rises above the lowest permanent protection level, however this can also be used to describe operator error.

The team that deployed the barrier were all trained and experienced in temporary barriers, and the construction process is methodical and checked by a qualified engineer.

Following any changes to the deployment alignment or process proposed by this review, it would be good practise to have formal sign off sheets recording completion and inspection of each stage; these observations have been captured in Recommendations 5 and 6.

Sufficient lead time was made available to install the temporary barrier and sufficient resource in terms of manpower, material and plant were available.

5 Sliding (Structural Failure)

This section includes interpretation of and direct reference to the following reports commissioned by the EA to inform this review: Arup, 'Environment Agency Bewdley Left Bank Barrier Sliding Review,' 2021; Arup, 'Bewdley Left Bank Geotechnical Interpretative Report - Phase 1,' June 2021; Arup 'Bewdley Left Bank Pavement Investigation Report.' 2021.

5.1 Sliding Review Approach and Assumptions.

From observation and analysis, the primary cause for abnormal barrier operation was insufficient structural stability. This was as a result of water pressure forces exceeding the anchoring forces provided by the barrier system, therefore the limit state taken for the analysis is sliding.

The temporary barrier system has no fixed foundation or seepage cut off, and is seated on asphalt, which is in line with the EA 'Temporary and Demountable Flood Protection Guide, 2011', which states:

> *'The likely modes of failure are sliding and seepage. To avoid sliding on cohesive soil and grass, the system should be pinned down with anchor pins to a depth of 100mm (one per support). For friction soils like sand, gravel, moraine or asphalt, the friction is sufficient, and no anchor pin is needed. For concrete, the system should be bolted to the ground (one per support). The seepage through the barrier membrane is almost none. Even the seepage through the soil is comparatively low and of no great significance. However, the seepage through drains and gullies can be significant and could potentially cause failure to the emergency operation. Pumps are always necessary.'*[13]

Assessments undertaken by the EA in the last 12 months have demonstrated that the anchor forces are based on two factors;

- The friction between the bottom beam and the ground which is estimated to provide 65-75% of the resisting force.
- The friction between the membrane and the tarmac/steel frame (35-25% of the resisting force)

Figure 23 is a representation of the forces acting on the Beales Corner barrier system, including the disturbing force (from the hydrostatic pressure of the water being retained by the defence) and the resisting frictional forces arising from the frame and membrane sliding on the asphalt.

[13] EA, 'Temporary and Demountable Flood Protection Guide,' August 2011.

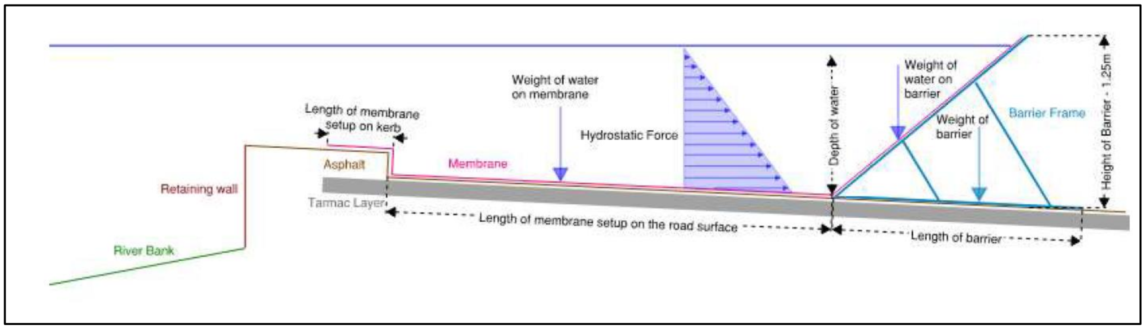


Figure 26: Force Diagram (Source: Arup 2021).

The 2021 sliding review assumed friction coefficients for the site from published values (see Table 4).

Two scenarios were considered throughout the investigation:

1. The ‘improved’ road surface which was modelled using intermediate coefficients of friction; and,
2. The ‘worst-case’ road surface which was modelled using lower bound coefficients of friction.

It is assumed that resurfacing of the road will lead to the intermediate coefficients of frictions associated with the ‘improved’ road surface being valid. The lower bound, or ‘worst-case’ values will also apply to the condition of the road following degradation with time. At any point in the road’s usage, the actual coefficient of frictions may be between these two states, and so both are considered valid for the purposes of this assessment.

Interface	**Assumed Coefficient of Friction**	
	Intermediate	Lower Bound
Underside of steel dam frame/ Road surface	0.6 (concrete/ steel (sliding))	0.45 (concrete/ steel (sliding))
Reinforced polypropylene membrane/ Road surface	0.45** (rubber/ concrete (wet))	0.25*** (rubber/ asphalt (wet))
Reinforced polypropylene membrane/ Steel frame	0.3* (polystyrene/ steel)	0.2* (polyethylene/ steel)

Table 4: Sensitivity of friction coefficients (Source: Arup 2021).

* Published coefficients that do not refer directly to the polypropylene sheeting material. The membrane may have a higher value of frictional resistance, but these values provide some context for sensitivity checks.
** Lower value of a range of 0.45 – 0.75 for sliding coefficients for rubber / concrete (wet).
*** Lower value of a range 0.25 – 0.75 for sliding coefficients for rubber / asphalt (wet). Used as no published coefficients that refer directly to the polypropylene sheeting material.

The Temporary works design guidance (TWf2014:01 “The use of European Standards for Temporary Works design”, which references BS5975 and EN 12812), was used to provide advice for the required Factor of Safety (FoS) against slide for the system. For the purposes of this assessment, the temporary barriers are considered to be a form of temporary works. A FoS of 1.0 is the absolute minimum required for a system, in that the restoring forces are at least equal to or greater than the disturbing forces. However, it is stated in TWf2014:01 that:

> *“The use of the global (or combined) safety factor of 1.65 (based on the product of a material factor of 1.1 and load factor of 1.5), might be suitable for steel or aluminium products”.*

On this basis, the FoS limit to be adopted from the system is 1.65, given the nature of the temporary barrier construction.

To enable a comprehensive review of the potential for sliding failure of the temporary barrier system at Bewdley, and whether this risk can be reduced, this review has identified and assessed several factors which may influence the performance of the system

1. Flood depth
2. Road camber
3. Proximity to the kerb line
4. Membrane apron width
5. Carriageway macrotexture
6. Uplift
7. In use arrangements
8. Dynamic loading

A ground investigation was commissioned primarily to identify voiding or unconsolidated ground beneath the carriageway. A ground penetrating radar (GPR) survey was also undertaken to provide better coverage across the whole site. These investigations have also been valuable in assessing the condition of the highway and informing the sliding review of uplift.

5.2 Ground Investigation 2021

The Ground Investigation was completed between 29th March and 24th April 2021 and comprised of five cable percussion boreholes, drilled to depths of 3.4 to 7.4 m, two trial trenches excavated to depths of 2.0 to 2.1 m using vacuum extraction, six trial pits excavated to depths of 0.4 to 1.0 m using a breaker and vacuum extraction, and two dynamic sampler holes (window samples) drilled to depths of 3.5 to 4.0m. Exploratory holes were targeted to investigate the area of the failure of the temporary barriers as well as the wider geology. In situ testing in the form of Standard Penetration Tests (SPTs) were undertaken in the boreholes and window samples. Groundwater monitoring installations in the form of standpipes were installed in BH101, BH103 and BH105 with response zone depths ranging from 2.7 to 6.9 m below ground level (m bgl). Groundwater monitoring was conducted continuously in all three installations using data-loggers (divers). The groundwater monitoring is ongoing at the time of writing, and is for a six-month period starting from April 2021.

The following geotechnical laboratory testing was carried out on selected soil samples:

- 5no. Moisture content
- 5no. Atterberg limits
- 14no. Particle Size Distribution (PSD) Wet Sieve
- 2no. Sedimentation (Hydrometer)
- 2no. Sedimentation (Pipette)
- 5no. Recompacted permeability test in a triaxial cell

Buried services in the area were very congested which impacted where the investigations could be sighted. This can be observed in Figure 27. The locations of the exploratory holes are shown in Figure 28.

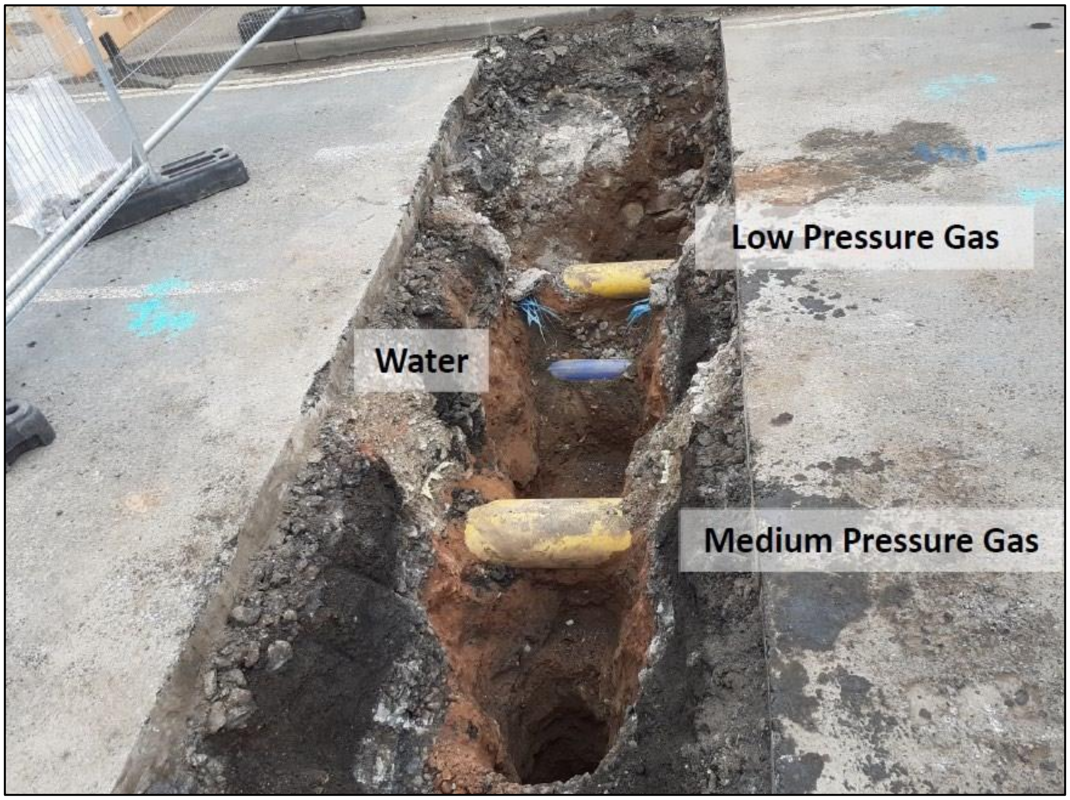


Figure 27: Trial Trench (Source: Arup 2021).

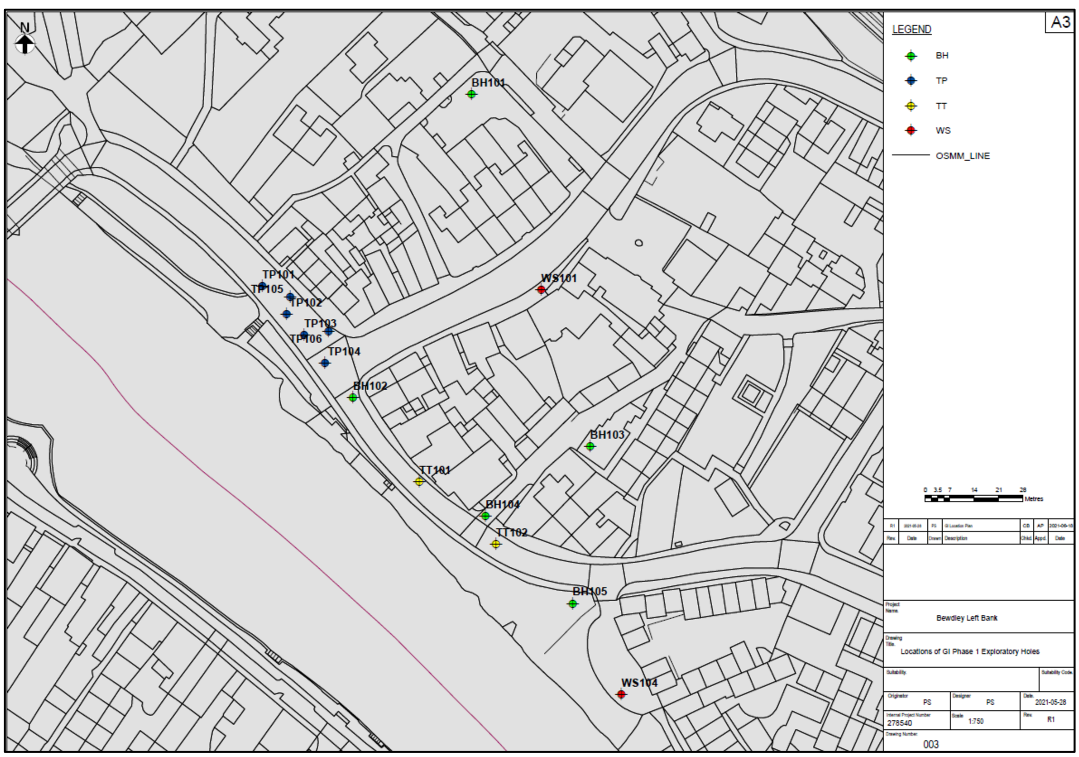


Figure 28: Ground Investigation Plan (Source: Arup 2021).

It was considered likely that debonding of the road surface had occurred from the Post Incident Inspection due to the water seepage under pressure observed behind the barrier. Full construction records do not exist for the road, however it can be assumed that if constructed in accordance with the Specification for Highways Works, layers will be bonded under heat to the underlying layers. The exception is the surface dressing which is a spray applied coating of bitumen with applied chippings which does not have the same level of adhesion to the underlying pavement layers. This makes the surface dressing more prone to impact and scraping damage when compared to asphalt concrete or hot rolled asphalt.

It is likely that the frictional forces between the barrier and the surface dressing surpassed the level of adhesive bonding achieved between the surface dressing and the asphalt below. However, as demonstrated by the presence of water seeping to the surface from below, the pavement is not behaving as a totally continuous and impervious structure.

This can be attributed to the significant volumes of water, temporarily high local water table and adverse freezing weather conditions present at the time of the flood event. Freeze/thaw mechanisms may have led to some flexure and expansion of asphalt and void space in sub-surface pavement layers which subsequently fill with water and jet out locally under pressure. It is believed that the granular nature of the underlying materials beneath the carriageway is leading to groundwater flow from the river in flooding events under the road surface. Under the environmental conditions experienced, groundwater will attempt to percolate under pressure through any drainage paths present in the pavement structure, which are most likely to be damage-induced, predominantly vertical drainage paths. A CCTV investigation was commissioned to evaluate potential routes for water to circumvent the defences through drains, and two outfalls are currently unflapped.

Recommendation 14: To further minimise water infiltration, flap valves relating to the barrier site should be inspected on an increased frequency with any required remedial work addressed promptly

Recommendation 15: The EA should work with the County Council to establish reinstatement conditions for utility providers operating in the highway in the future.

From the trial trenches, the top asphalt layer has an estimated thickness of 200 - 350mm and between 200mm-350mm at TT102. Below this layer, slightly sandy angular limestone gravel with interbedded asphalt layers were observed at both trial trenches with a thickness between 400-450mm. Site photographs taken after the vacuum excavation indicate that the upper pavement layer appears to be in a fair condition generally and there appears to be little evidence of lack of bonding, cohesion or adhesion issues at these locations.

The ground investigation confirmed made ground underlain by Power House Terrace Deposits (PHTD) and Bridgnorth Sandstone bedrock, summarised in Table 5.

Stratum	Typical description	Upper surface (mOD)	Thickness (m)
Made Ground - Surfacing	Brick setts, asphalt and bituminous bound material	20.9 to 24.7	0.05 to 0.4
Made Ground	Gravelly fine to coarse sand	20.9 to 24.6	0.6 to 3.8
Power House Terrace Deposits	Loose to medium dense gravelly to very gravelly fine to coarse sand Soft gravelly sandy clay (BH104)	17.8 to 23.5	0.4 to 3.8 (>5.7m in WS101)
Bridgnorth Sandstone	Weathered reddish brown fine to coarse grained sandstone	16.1 to 17.8	Not penetrated

Table 5: Typical Ground Conditions (Source: Arup 2021).

During the ground investigation, groundwater strikes were recorded during the advancement of the majority of the exploratory holes. The typical river level adjacent to the site is approximately 17.5m AOD and the majority of groundwater strikes and subsequent rises were at or up to around 1.5m above the river level. This suggests that there is hydraulic connectivity to the river and forms the basis of the conceptual model for the baseline.

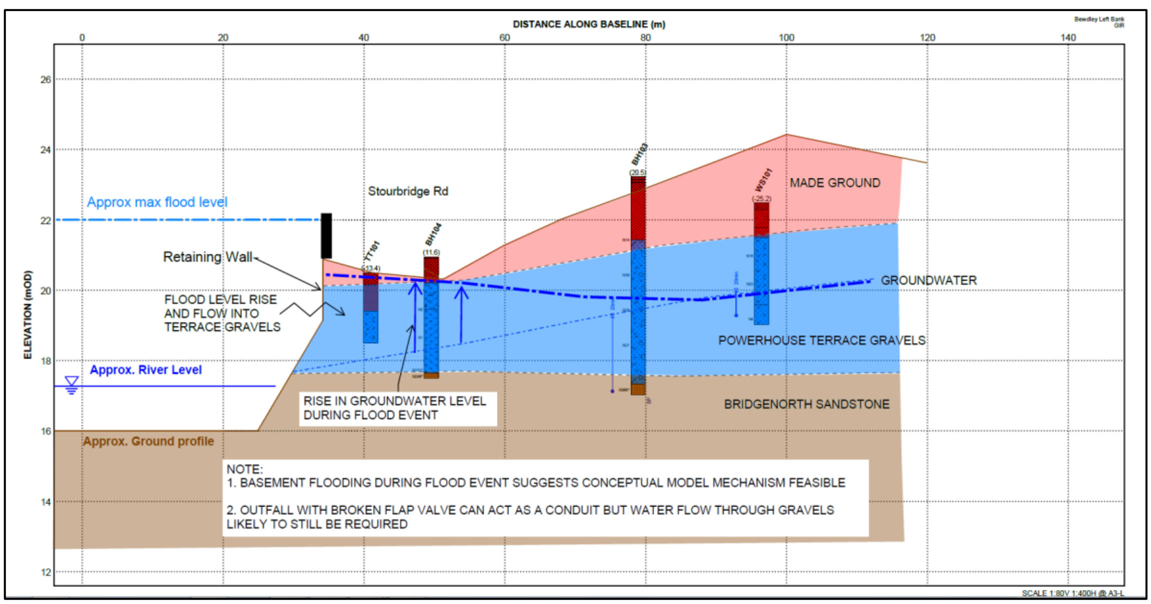


Figure 29: Groundwater Conceptual Model (Source: Arup 2021).

From Figure 29 it can be seen that the granular made ground associated with the road structure is retained by a stone retaining wall around 1m high (along most of Stourport Road). The riverbank is formed within the PHTD and the Bridgnorth Sandstone.

The PHTD are granular but variable in the form of cohesive material or recent alluvium at the riverbank. The groundwater levels suggest that groundwater is elevated further away from the river and flows towards the river in hydraulic connectivity through the granular PHTD during normal river levels. This is assessed to be a significant contributing factor to the flooding of the existing basements in local properties.

During a flood event, the increased water levels cause an increase in head of water flowing through the PHTD away from the river. This flow path can establish directly through the stone wall. This causes the groundwater level below the road to rise up through the granular composition. The dip in elevation of Stourport Road will cause a higher head of flood water at the low point causing increased uplift pressures below the road.

The Ground Penetrating Radar (GPR) survey has investigated a continuous profile of around 2m depth along the length and width of Stourport Road. Supported by the borehole logs, the presence of material loss and voiding is thought to be minimal. Some anomalies were identified around areas of gravelly fine to coarse sand but these are likely to represent either wetter areas of the made ground or a looser condition of the made ground. The exploratory holes across the site did not identify any voids with the exception of BH105 that encountered material loss from 2 to 2.8m depth within made ground. The made ground encountered within BH105 is considered to be different to that underlying Stourport Road and is not considered representative of the material below Stourport Road.

5.3 Flood Depth

Flood depth is known to have an impact on the FoS against sliding of a temporary barrier system.

To conduct the initial assessments on the effects of camber, kerb positioning and uplift, a baseline idealised scenario was assumed where the membrane is laying on the carriageway and the other factors remain constant:

- The membrane length is 3m;
- The road camber is zero;
- There is no kerb line present beneath the membrane;
- There are no uplift forces beneath the membrane.

The following graph shows the effect of just increasing the water depth variable against the barrier. For the intermediate case of friction coefficients (repaired road surface), the recommended FoS of 1.65 is achieved at all water depths, however the lower friction coefficients (deteriorated road surface) fall below this recommended FoS at full water height against the barrier.

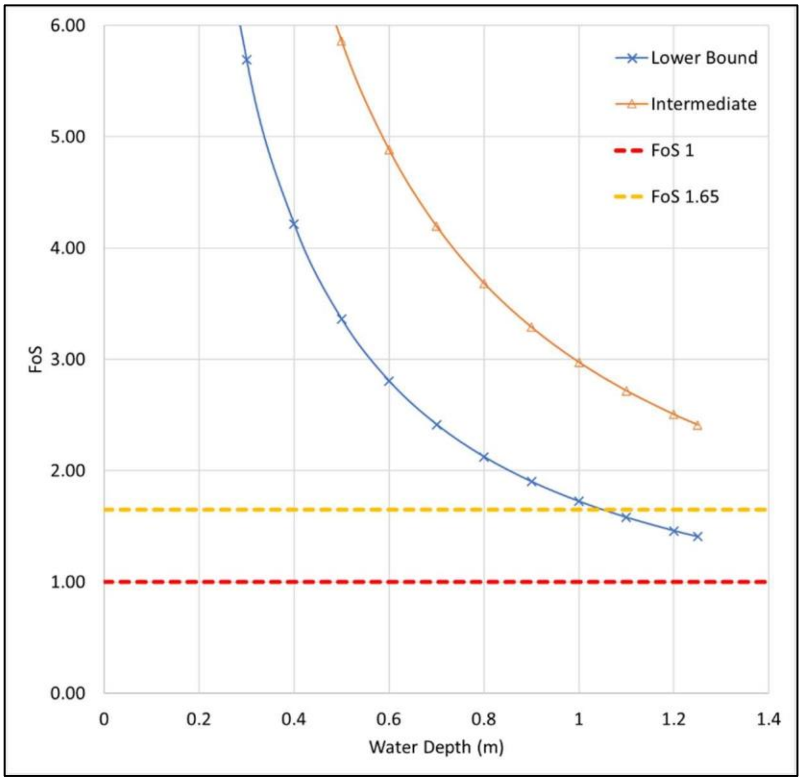


Figure 30: Representation of how FoS varies with water depth (Source: Arup 2021).

Figure 31 is based on the 2021 topographical survey and demonstrates the water depths in bands across the site at the designed standard of service (5m ASD Bewdley Gauge).

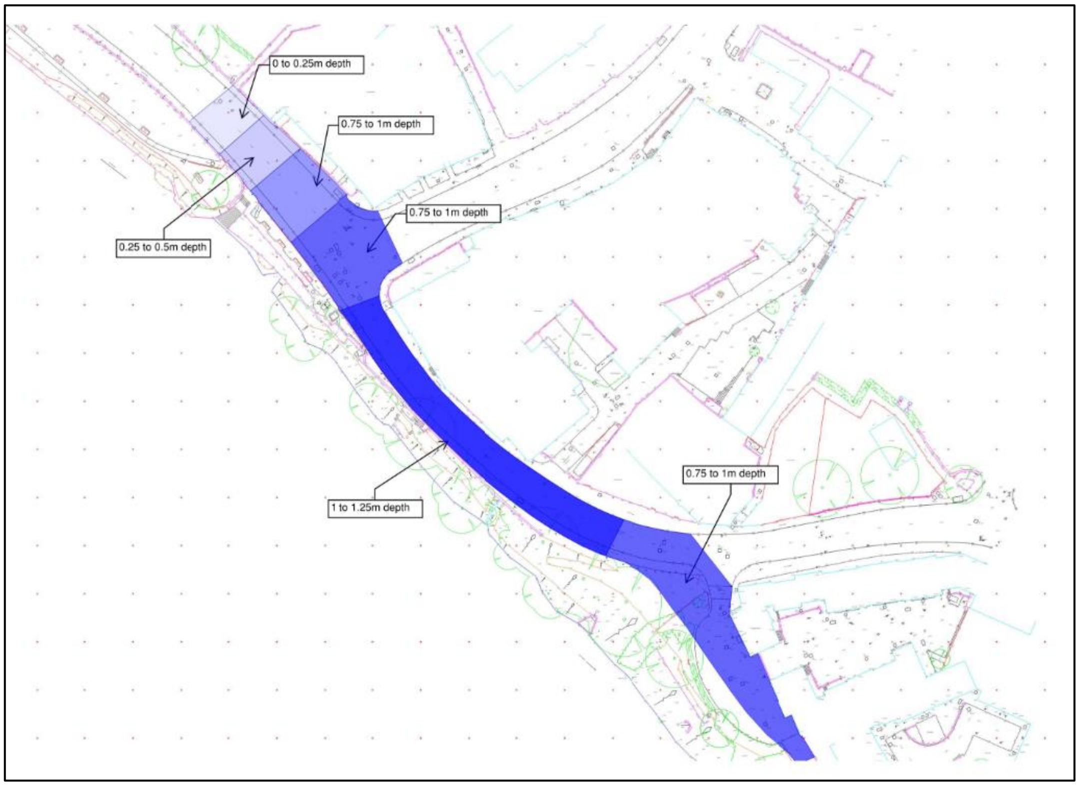


Figure 31: Water depth profile at Beales Corner (Source: Arup 2021).

The lowest section in the centre of the barrier deployment with the largest hydrostatic force against the barrier corresponds to where the barrier failed.

5.4 Road camber

The presence of a camber increases the disturbing forces on the barrier where the camber falls towards the dry side of the barrier. The 2021 topographical survey determined that the camber falls towards the dry side for the majority of the alignment, increasing to a 4 degree negative camber at the location of sliding failure (figure 32).

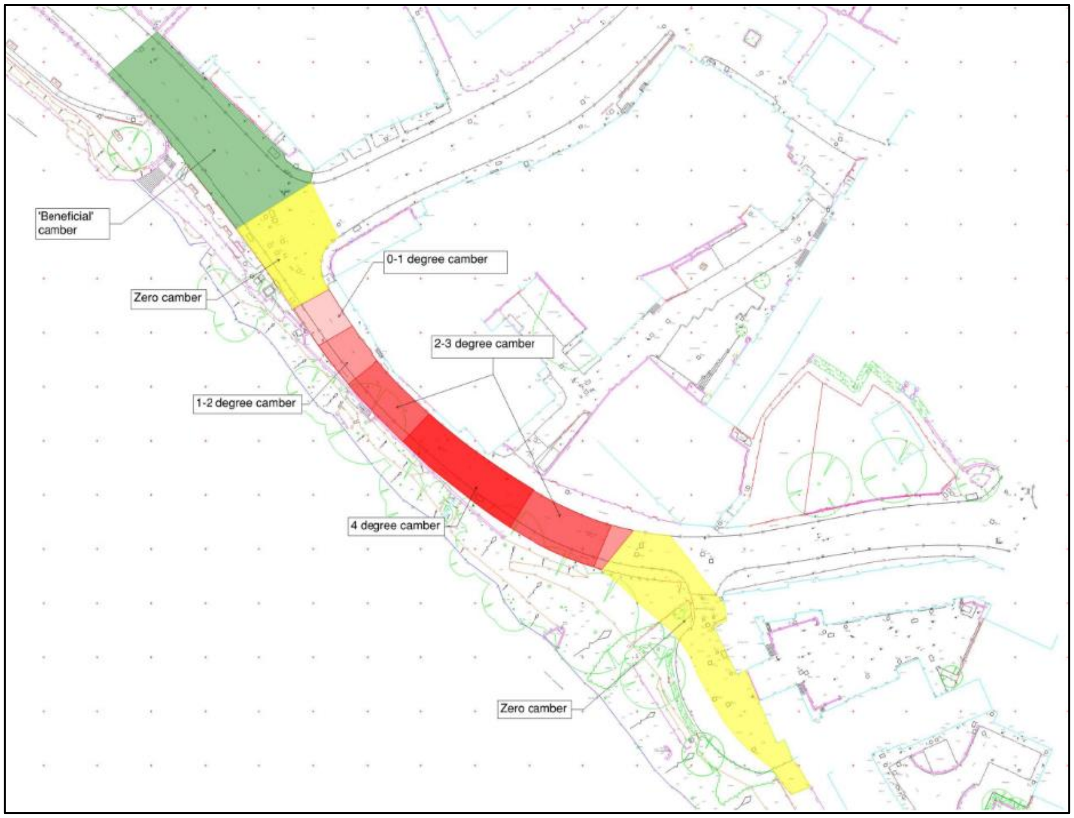


Figure 32: Camber profile at Beales Corner (Source: Arup 2021).

To understand the sensitivity of the analysis to the impact of the camber, the sliding assessment of water depth against FoS was updated to include this, assuming all other factors are constant as described in Section 5.3 (Figure 33).

The effect of the camber is shown to be greatest at lower water depths, however this could be one of a number of contributing factors which lowers the overall FoS of the scheme.

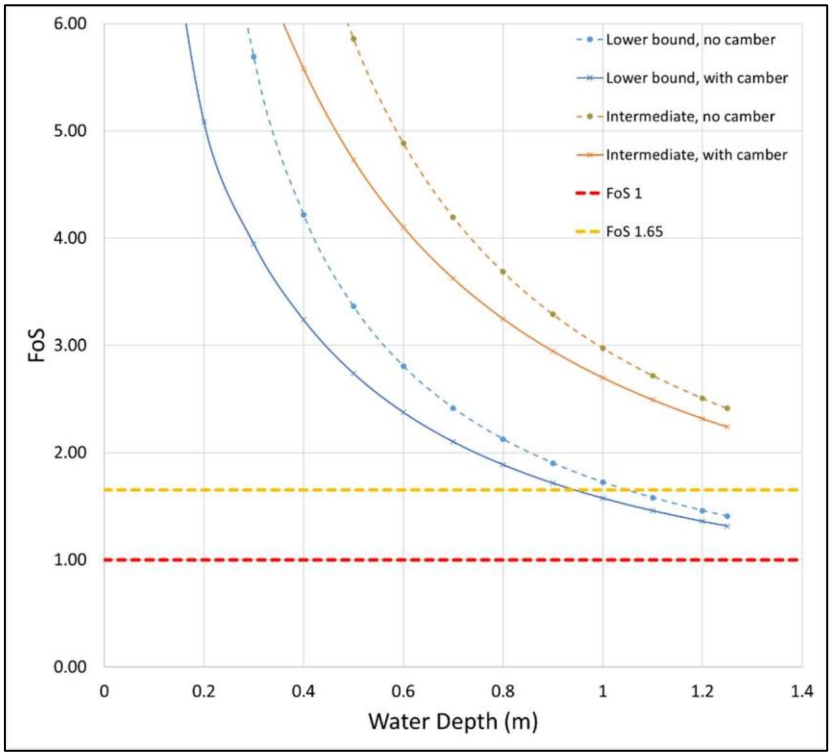


Figure 33: Effect of the camber on FoS (Source: Arup 2021).

5.5 Proximity to kerb line

Due to the on-site constraints such as access chambers, it is necessary to lay the membrane on the footpath to achieve the required membrane apron width in some areas. Where the kerb is present within the footprint of the deployed membrane, the depth of water is reduced. This can result in a reduction of the normal (vertical) force associated with the weight of water, and therefore the sliding resistance. Conservatively it has been assumed that the hydrostatic pressure that develops at the barrier will be the generated from the full height of water that can be resisted.

To examine the impact of the varying distances between the kerb and the frame in the current alignment, three cases (where the kerb is 3m, 2m and 1m from the frame), have been analysed for FoS of 1.0 and 1.65. All other variables are kept constant as described in Section 5.3. The assessment using the lower case friction coefficients (deteriorated surface) has shown that to achieve the recommended FoS, a significant 0.4m increase in membrane apron width may be required in the instances where the pavement is located 1m away from the frame, compared when the pavement line is 3m away (Figure 34).

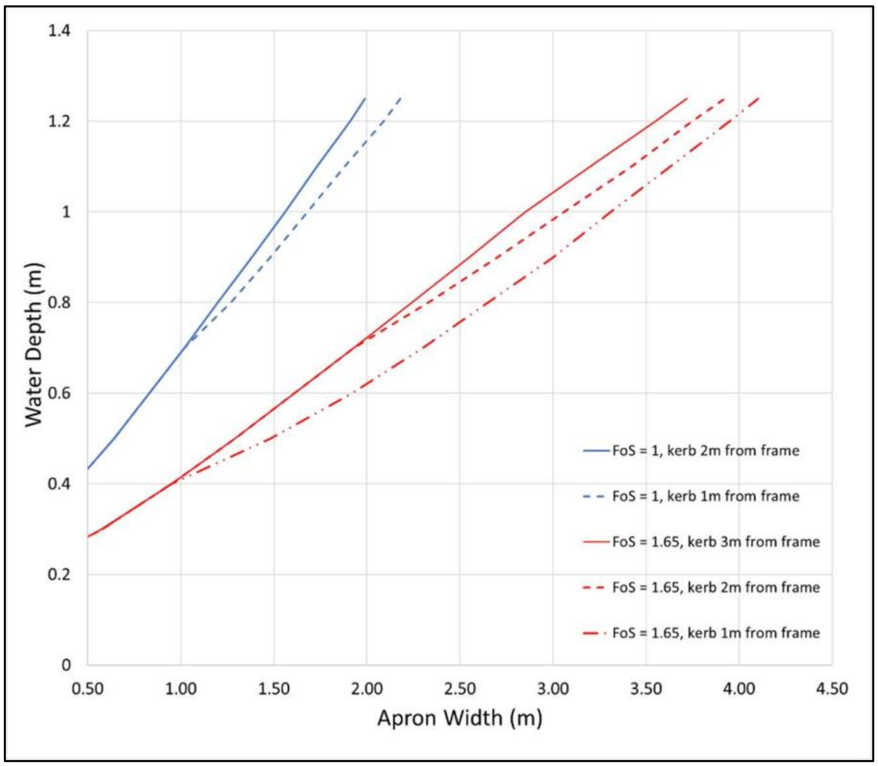


Figure 34: Effect of water depth on membrane length – lower bound (Source: Arup 2021).

The same analysis was completed for the intermediate case (repaired road surface). The additional membrane apron width required to achieve the recommended FoS where the pavement is located 1m away from the frame is 0.2, compared when the pavement line is 3m away. This confirms that the presence of a kerb could be one of a number of contributing factors which lowers the overall FoS of the scheme.

5.6 Membrane apron width

The friction between the membrane and the tarmac/steel frame has been calculated to provide 25-35% of the resisting force against sliding. The 2021 sliding review has demonstrated that the FoS of the system is proportional to the membrane length, but inversely proportional to the height of the water against the barrier, and the camber of the road. A membrane width, based on the height of the barrier system, of up to 3m is considered beneficial, however as this is not achievable at Beales Corner. An alignment achieving the maximum membrane width has been considered in Section 5.10.

The development of uplift water pressure between the underside of the membrane and the road pavement reduces the normal forces and therefore the sliding resistance.

5.7 Carriageway Macrotexture

It is understood that no as-built information is available for this section of carriageway. It is likely to have been part of a 14th century highway network and therefore will have had numerous structural treatments as well as reinstatements following utility installations and ongoing maintenance. More recently, Worcestershire County Council as the local highway authority surface dressed the carriageway with 10/6 stone during July of 2015.

Whilst the temporary barrier product is suitable for deployment on a range of bedding surfaces, the friction between the bottom beam and the ground is estimated to provide 65-75% of the resisting force, and on certain surfaces such as concrete or cohesive soil additional anchoring is necessary. The coefficient of friction achievable between the steel structure and asphalt carriageway is dependent on the condition of the road surface and varies between 0.45 and 0.6 (Table 4).

The surface damage to the carriageway caused by the sliding failure suggests that a macro-mechanical failure of the surface has occurred during this event, whereby the metal collars protruding from the base of the barrier have caused damage to the upper surfaces of the pavement. The surface dressing is a spray applied coating of bitumen with chippings which is prone to impact and scraping damage when compared to asphalt, concrete or hot rolled asphalt. Loss of material at the surface is considered to be a result of the 'weaker' surface dressed layer providing a lower level of bonding between dressed layer and pavement structure below (Figure 35).

Figure 35: Loose aggregates in the dressing layer no longer bonded to the pavement structure.

The current road surface meets the necessary performance requirements of a highway, however it can be observed throughout Section 5 that the friction coefficient of the road surface can have a significant effect on the FoS achieved by the barrier system.

The option of Hot Rolled Asphalt (HRA) resurfacing has a positive surface texture due to the methodology of spreading and rolling aggregate chippings into a bitumen layer. It is possible that a HRA surface course may interlock with the collar of the barrier foot and provide enhanced resistance to sliding. In contrast, Stone Mastic Asphalt (SMA) has a negative texture with a more regular surface overall and therefore potentially a more predictable level of frictional performance due to greater contact area between the barrier and the pavement surface, when compared with HRA.

Worcestershire County Council have plans to reinstate the road surface this summer, in order to support the redeployment of the temporary barrier system.

Recommendation 16: Due to the highway damage caused earlier this year, the road surface needs to be replaced with a new HRA or SMA surface prior to the barrier being able to be safely deployed.

5.8 Uplift

The carriageway damage observed in 2021 demonstrates a general increase in damage to the pavement than previously recorded between 2019 and 2020. There is evidence of pavement deterioration and loss of surface dressing layer material, potentially arising from the barrier and pavement interaction during failure. The sliding motion of the barrier at failure appears to have gouged the pavement in a similar pattern way to past flood events, with damage potentially impacting at slightly increased depths than previously observed. Water is known to percolate through the highway surface as described in Section 5.2. These are assessed as most likely to be damage-induced, predominantly vertical drainage paths.

The barrier system is designed to hold floodwater on one side of the system only. As such, it can be considered that a hydraulic gradient is generated between the membrane and the asphalt – where a driving head of water is present on the river side of the system. Conceptually, this hydraulic gradient generates an uplift pressure beneath the membrane. Although the 'Temporary and Demountable Flood Protection Guide - Project: SC080019' notes that it is not expected that there is seepage through the membrane, minimal seepage has been observed.

The sliding assessment considered the impact of uplift through two mechanisms:

1. Seepage between the membrane and the asphalt surface
2. Seepage through cracks in pavement surface, leading to water ingress
    a. under the membrane
    b. on the dry side of the barrier

As described in Section 5.3, the baseline assessment scenario assumes all other variables remain constant.

5.7.1 Mechanism 1 – uplift between membrane and asphalt

It is feasible that water can flow between the barrier membrane and the asphalt. Although the weight of the water will minimise the cross-sectional area of these flow paths, it is expected that small gaps will exist on the surface of the highway that may connect to form a network of channels.

Adopting the principles of hydraulic flow through a soil, a differential in water level and therefore head exists along the membrane length leading to a hydraulic gradient being developed along the 'gap' between the membrane and the asphalt (see figure 36). Applying Darcy's Law, this hydraulic gradient will lead to water flow beneath the membrane and the asphalt.

The uplift pressure is assumed to linearly fall across the length of the flow path with a triangular distribution. The assessment considers the uplift force acting against the weight of the water on the membrane, reducing the normal force that is therefore applied to the underside of the membrane, and as a result, the frictional force mobilised.

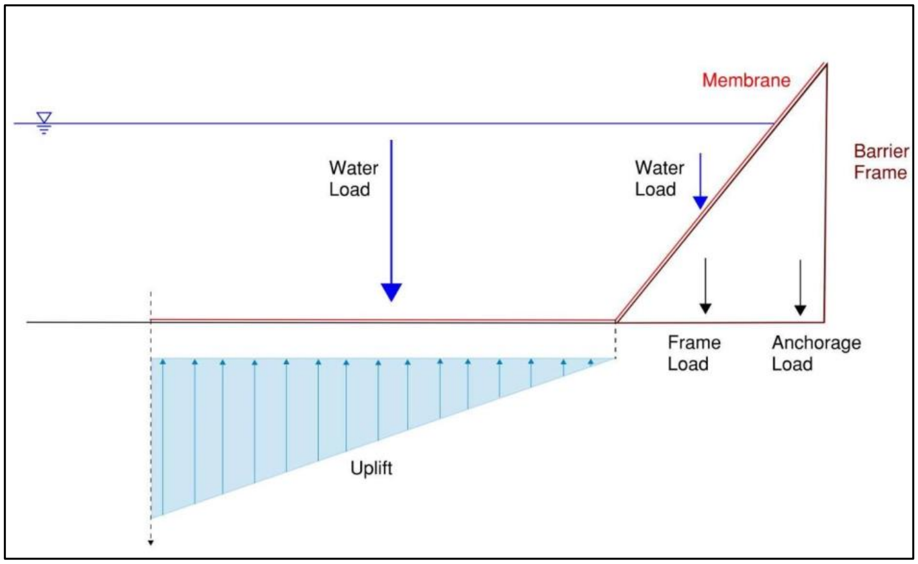


Figure 36: Mechanism 1, hydraulic gradient between the membrane and the asphalt (Source: Arup 2021).

The impact of Mechanism 1 is calculated as significant, for the lower bound case the FoS drops below the recommended value at an approximate water depth of 0.55m and for the intermediate case at a water depth of 1.0m.

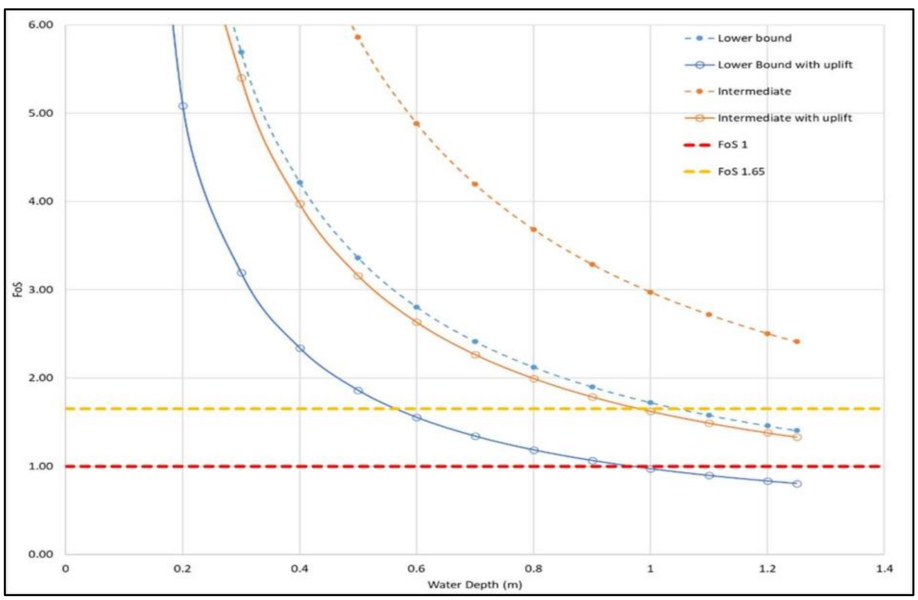


Figure 37: Mechanism 1, FoS with water depth (Source: Arup 2021).

5.7.1 Mechanism 2 –uplift beneath membrane with surface cracking

This scenario models the observed cracking in the highway surface, which allows water to egress beneath the barrier membrane. The seepage of water through the pavement suggests that water is present beneath the asphalt layer and it is possible that water is able to flow freely beneath the highway surface, and that this water is in hydraulic continuity with the river. Reinstatement of the road surface will prevent this mechanism from occurring, however it may have influenced the 2021 sliding failure.

The formation of a crack in the highway surface will increase the uplift pressure beneath the membrane at the point of the crack. The location of the crack in this assessment is critical, as it dictates the distribution of uplift pressure beneath the membrane and therefore the resultant uplift force (see figure 38). For the purpose of this assessment, it has been assumed that the crack is located a) at the frame, b) 1m from the frame, and c) 2m from the frame.

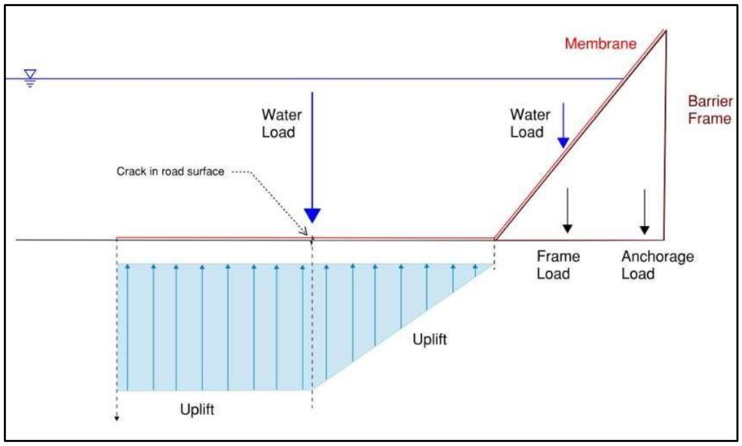


Figure 38: Mechanism 2 - Crack in road surface under membrane (Source: Arup 2021).

For the lower bound coefficient of friction, the analyses show that the closer the crack location to the frame, the greater the uplift force generated and therefore the lower the FoS (figure 39).

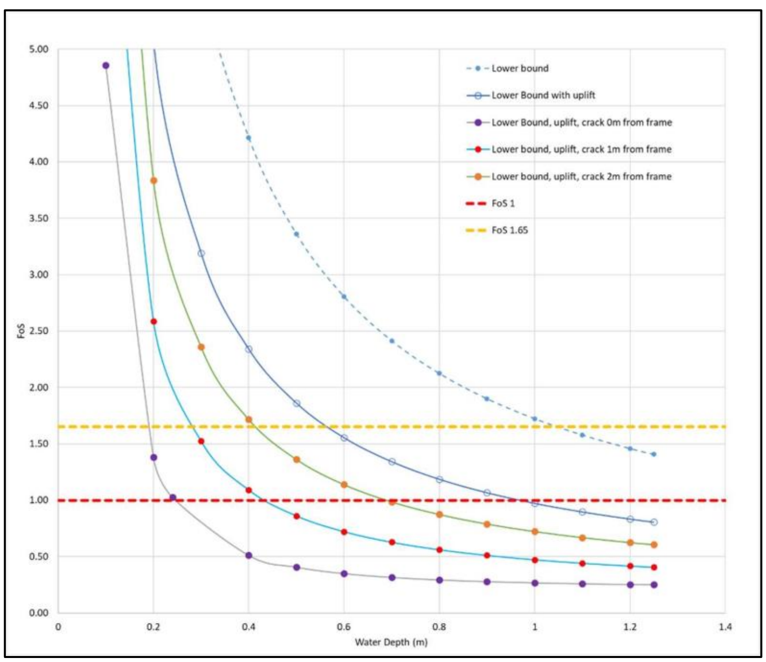


Figure 39: Mechanism 2 – FoS with water depth (Source: Arup 2021).

The worst case occurs when there is a surface crack close to the frame location, as the corresponding water height for the recommended FoS of 1.65 is 0.15m. This effectively negates the frictional force provided by the membrane, and as a result the sliding resistance is only being offered by the frame.

5.9 In use arrangements

During deployment of the barriers, the barrier manufacturer recommends that pumping capacity be increased to displace any floodwater on the dry side of the barrier caused by permeability of the foundation material or surface water. At Bewdley, the hoses of these pumps are attached to steel A-frames and are positioned over the temporary barrier, as shown in Figure 40.

Figure 40: EA Remote Camera photograph hoses discharging in front of the barrier (taken just prior to figure 25)

Whilst the hoses are supported on frames adjacent to the barrier, it is thought likely that there is some transfer of weight from the hose to the temporary barrier. This additional loading is considered to be beneficial, as it would increase the normal force on the base of the frame and therefore the frictional resistance mobilised. However, given that the hoses are not deployed uniformly along the barrier, no consideration has been given to this additional loading in the sliding assessment.

The discharge of water from the hoses in front of the temporary barrier may lead to the development of small currents in front of the barrier system, depending on the hose discharge point relative to the system. Should localised eddies develop, the force generated by these may lead to suctions within the water that have a lifting effect on the membrane, possibly negating the percentage of the total frictional force provided by the membrane.

Recommendation 17: Where possible in advance, consider the discharge points of the pump hoses and whether they can be fixed in position beyond the apron width of the membrane. Additional hoses may be fixed in position in advance and connected to pumps later if required.

Recommendation 18: Where additional unplanned pumps are required during an incident, the location of the discharge points will need to be carefully considered and managed, ideally positioned away from the lap between sections of membrane and the apron edge.

5.10 Dynamic loading

In addition to the operation of pumps and the interaction of hoses with the barrier, dynamic loading of the barrier may occur as a result of:

- Impact loading from floating debris in the river channel
- Wave loading from floodwater held by the flood defence

The magnitude of the force exerted on the barrier is dependent on the velocity of the water in the river, taking into account a reasonable worse case mass of debris material. However, railings are present along Kidderminster and Stourport Roads in front of the alignment of the temporary barrier. Whilst there are some gaps between the railings to allow workers/members of the public to access the riverbank, the railing line is largely present between the Load Street Bridge and Millside Court. The height of the railings is typically 0.8 to 0.9m and given the maximum level of the temporary defence is 1.25m, it is considered unlikely that large items of debris would be able to pass between the railings and impact the barrier, without causing damage to the railings themselves.

It is assumed that the smaller debris that is able to pass through or above the railings may be resisted by the system consisting of multiple units, as any applied loading from this would be distributed along the length of the barrier.

During a flood event, when water is held against the temporary barrier, there is potential for waves to develop within the widened river channel. As the primary direction of the flow within the channel will be parallel to the defence it is unlikely that the wave loading force perpendicular to the barrier will be significant. There is potential for waves to approach the barrier at an angle relative to the channel; however the presence of railings and vegetation between the river channel and the barrier alignment would be expected to intercept the development of wave actions and help to dissipate any wave energy generated within the channel.

To allow for dynamic loading, it is recommended that a FoS of 1.65 is maintained within the system, to ensure that a reserve of resistance can be mobilised if required.

5.11 Optimised Alignment

Using the topographical survey undertaken in 2021, and subsequent technical investigation, a maximised alignment of the barrier has been determined. This ensured that the frame and the membrane do not sit over any of the drainage manholes to avoid an uplift scenario.

The pinch-point of the scheme with the narrowest achievable membrane apron width is at the junction between Stourport Road and Kidderminster Road (Figure 41). The membrane apron width is 1.6m located fully on the pavement, avoiding the access chambers utilised by Severn Trent during an incident.

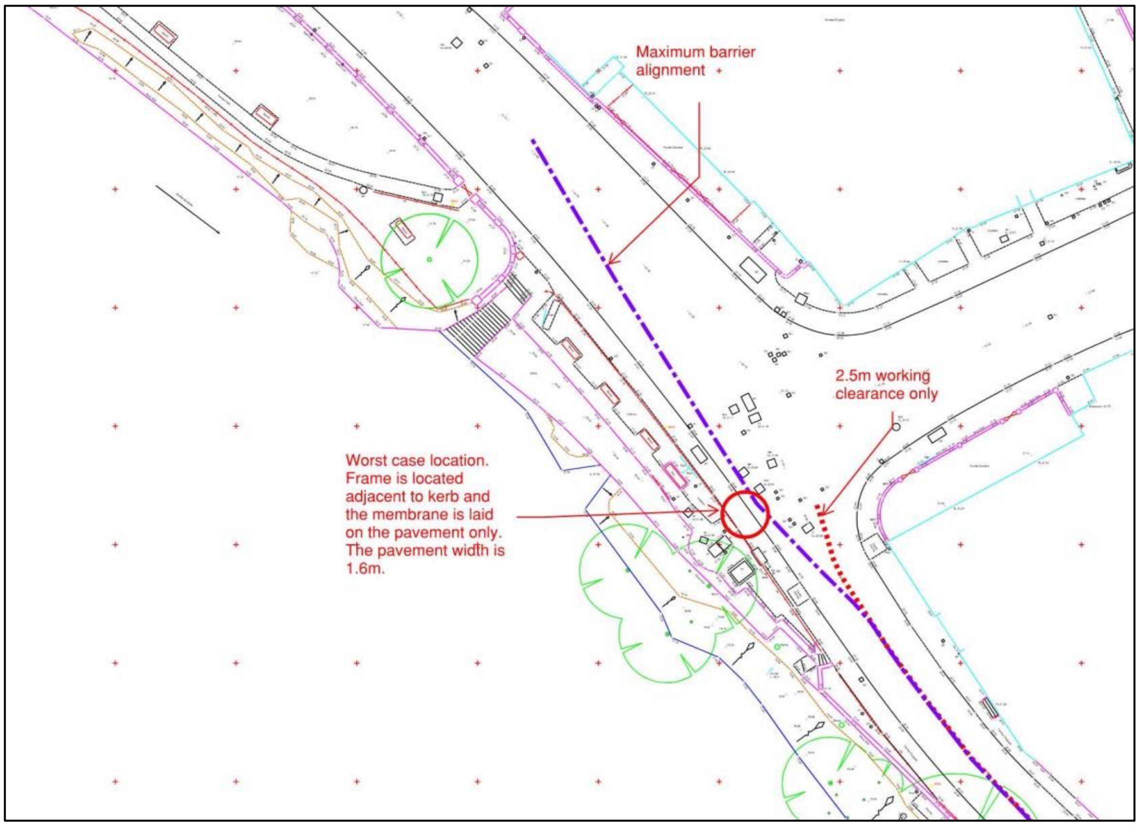


Figure 41: Extract of the maximised route, showing pinch point at junction between Kidderminster and Stourport Roads (Source: Arup 2021).

The alignment assumes a 2.5m working space behind the barrier system (the EA Field Operations Team suggest a minimum access width required is 2.2m) to allow for teletruck units to erect and access the defence. An additional 1m of width has been reserved due to the likelihood of an anchoring system becoming necessary.

Due to the large number of factors will the potential to reduce the frictional resistance to sliding, this alignment was further divided into 5 zones for analysis (figure 42), supported by the camber and water depth heat maps (figures 32 and 31).

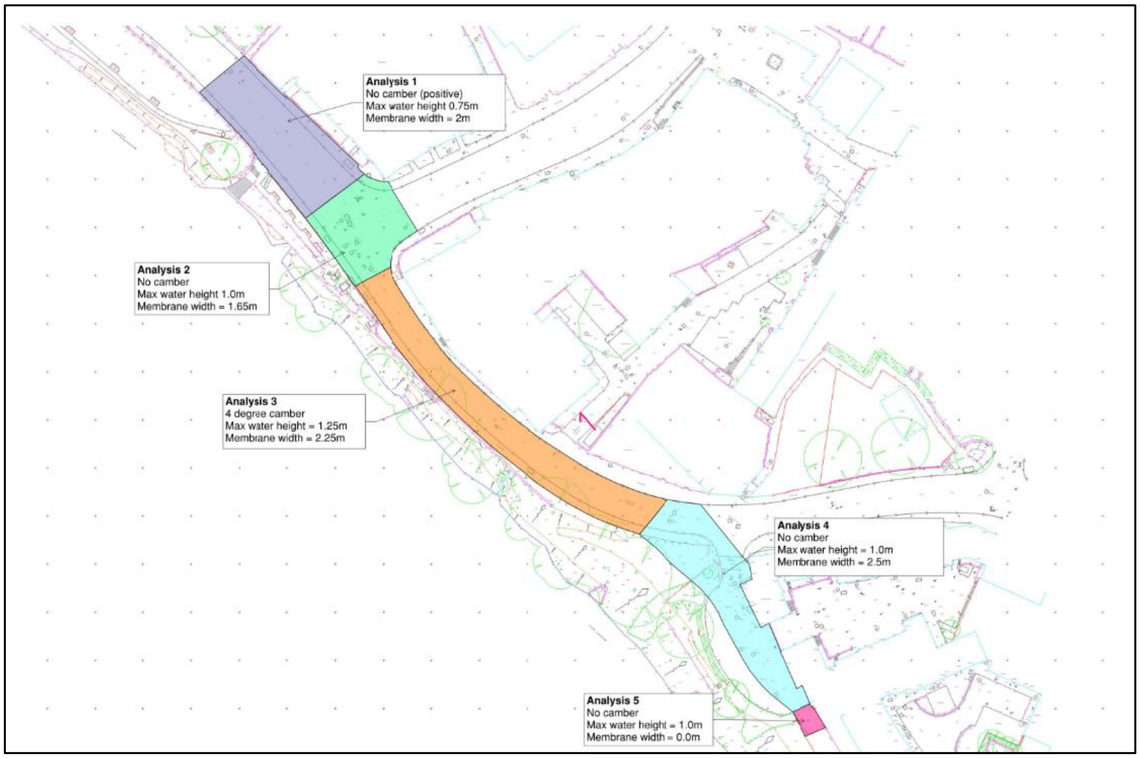


Figure 42: Zoning of the site for FoS Analysis. (Source: Arup 2021).

5.12 FoS against Sliding Achievable

The variables discussed throughout this section of flood depth, road camber, proximity to the kerb line, membrane apron width, road surface and uplift were combined in the sliding review (Arup 2021) to provide individual assessments of the 5 zones making up the optimised barrier alignment (Figure 42). The camber was accounted for by resolving the frictional forces to determine the horizontal component associated with the applied normal forces. The height of water on the membrane was modified to account for the kerb, and so the normal force mobilised by this has reduced. The uplift force has been established by considering the water head at the wet end of the membrane and assuming this force distribution decreases from a maximum water head at the wet side, to zero water head at the barrier. The assessments assume that the carriageway is in good, resurfaced condition.

Zone 1 has no camber, a maximum water depth of 0.75 and a minimum membrane apron width of 2m. The recommended FoS of 1.65 is achieved without the need for additional restraint

Zone 2 has no camber, a maximum water height of 1m and a maximum membrane width of 1.65m, all sited above the kerb on the footpath. The FoS falls below the recommended value at a water height of 0.8m, therefore additional restraint is required. At maximum water height this is calculated at 984 N/m run (figure 43).

Zone 3 has a 4 degree camber, a maximum water height of 1.25m and a maximum membrane width of 2.25m. The FoS falls below the recommended value at a water height of 0.9m, therefore additional restraint is required. At maximum water height this is calculated at 2158 N/m run (figure 44).

Zone 4 has no camber, a maximum water height of 1m and a maximum membrane width of 2.5m. The recommended FoS of 1.65 is achieved without the need for additional restraint.

Zone 5 has no camber, a maximum water height of 1m and a maximum membrane width of 0m. Additional restraint is required.

Recommendation 19: Where the sliding assessment concludes that the recommended FoS cannot be achieved solely through maximising the alignment of the barrier footprint, additional passive restraint will be required to enable the safe redeployment of that section (zone).

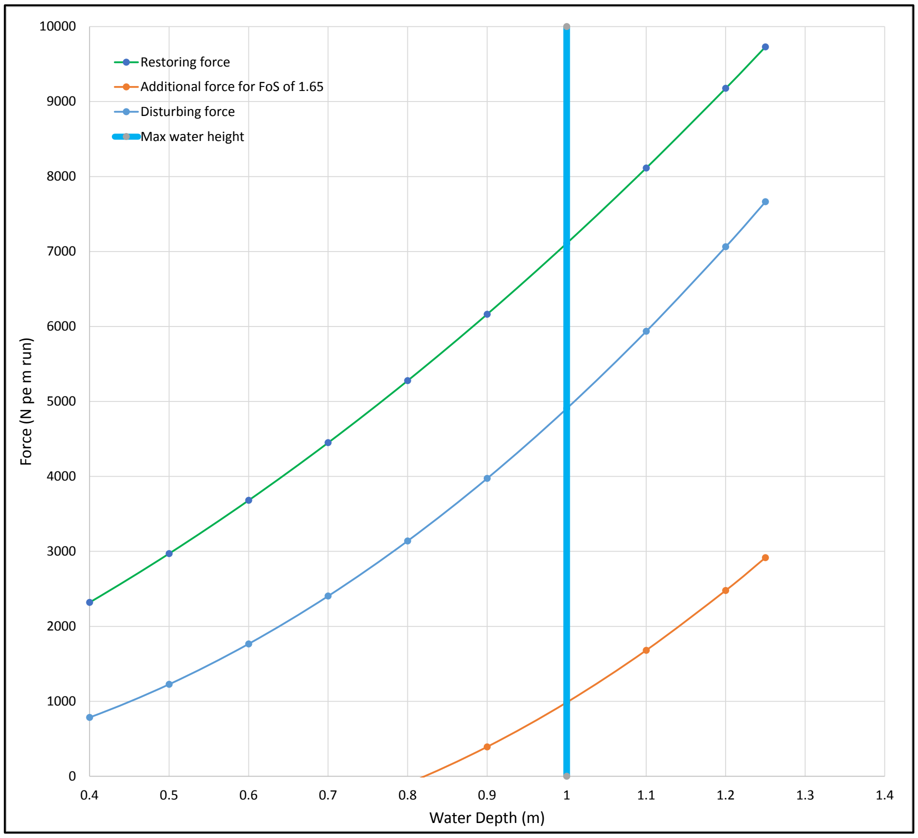


Figure 43: Zone 2: Additional force required at maximum water height (Source: Arup 2021).

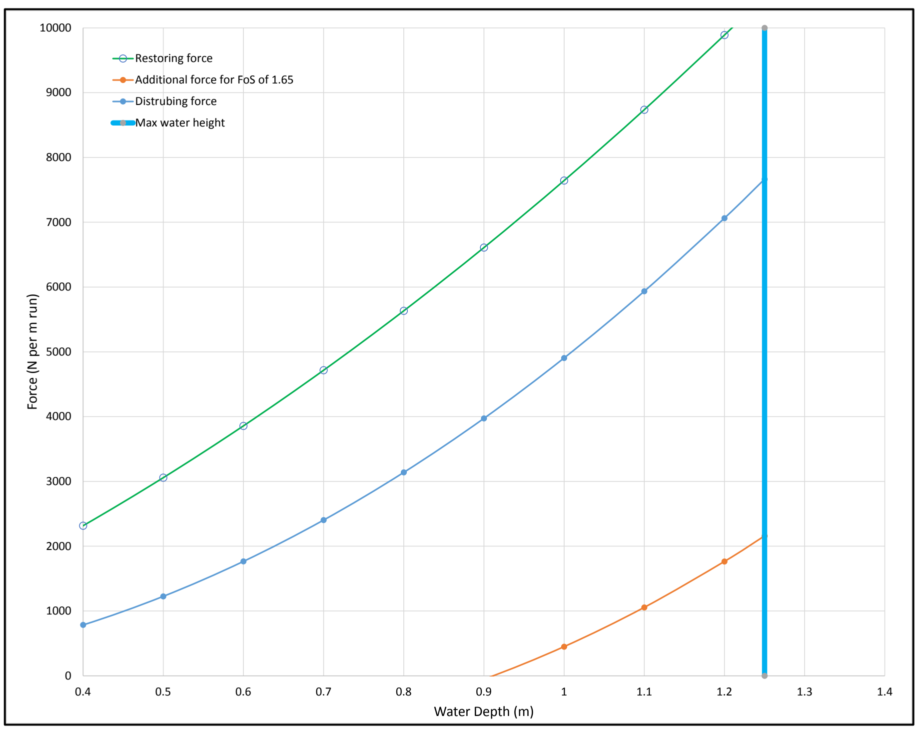


Figure 44: Zone 3: Additional force required at maximum water height (Source: Arup 2021).

The resisting frictional forces against sliding have been proven to be influenced by many factors; particularly significant is the construction and condition of the road surface and the ground it is founded on. While the achievable FoS assumes a resurfaced carriageway, this will deteriorate over time and the analysis completed for the review should be applied for a period of no longer than 3 years. After this point an updated review will be necessary to determine whether the site specific, environmental and ground conditions remain suitable to enable continued deployment. Annual and post deployment visual inspections may bring this review period forward.

Recommendation 20: The Post Incident Review has analysed the FoS against sliding failure based on carriageway resurfacing and current ground conditions. Based on the findings of this report, this analysis can be applied for a maximum 3 year period, beyond which a further in depth review would be required.

5.13 Additional Resistance Measures

The following measure to increase the passive resistance of the scheme were considered:

1. Concrete barriers
2. Water bowsers
3. Dumpy Bags
4. Anchor Bolts
5. False Kerb

5.13.1 Concrete Barriers

Concrete barriers could be utilised to provide extra resistance, they can be deployed on site directly behind the barrier system legs if a steel section or similar is used to ensure that the temporary barrier and the additional restraint act as one system and the resisting force is spread across the multiple legs.

An example concrete barrier is shown in Figure 45.

Jersey Barrier

Type	Length	Width	Height	Weight
Jersey	2500mm	610mm	810mm	1450kg

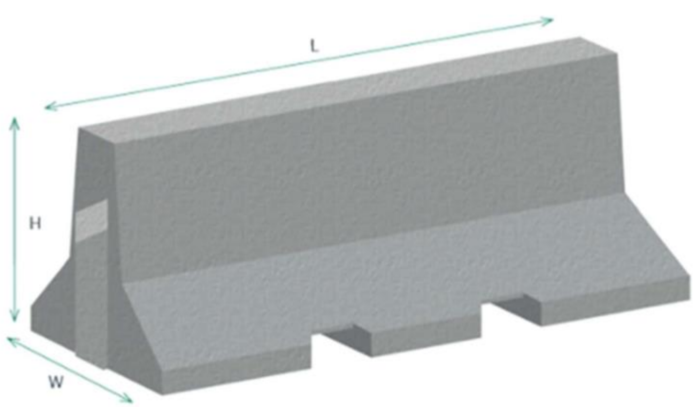


Figure 45: concrete barrier available to provide additional resistance force

5.13.2 Water Bowsers

Water bowers or intermediate bulk containers (UBC's) are an alternative proposal to provide additional sliding resistance to the system and are available in a range of dimensions. These are able to be lifted into place empty, and then filled in position. Numerous sizes and volumes of bowsers are available.

Again, steel sections (or similar) behind the feet of the frames, are required to distribute the anchoring forces across individual sections. Bowsers can either be sat directly onto the tarmac surface or be positioned in skid frames (as in Figure 46). The advantage of the skid frames would be that a higher coefficient of friction could be achieved for this restraint (as steel on asphalt is greater than plastic on asphalt), but this would hinder the ease of deployment of the bowsers and the footprint would be larger.

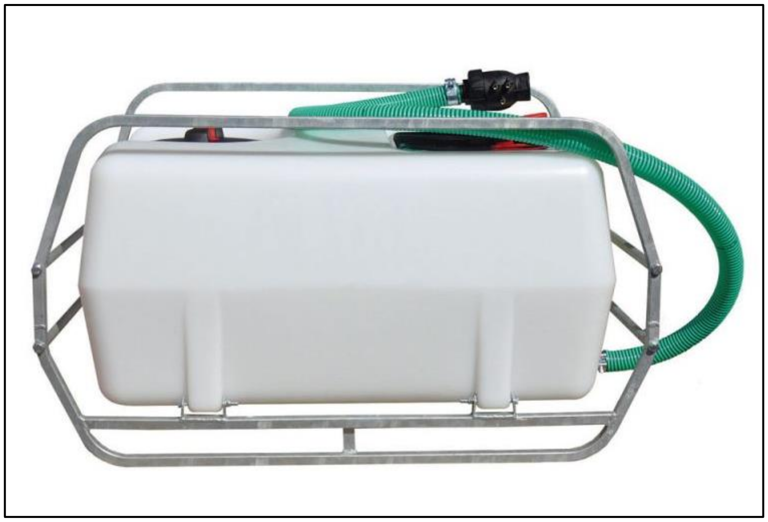


Figure 46: Bowser within a skid frame presented as an option to provide additional resistance force.

5.13.3 Dumpy Bags

The previous studies into the sliding resistance of the temporary barriers have proposed dumpy bags filled with sand. The quantity required, size and weight of the dumpy bags limit the practicality of this as a solution, in particular in more confined situations as per the section along Stourport Road, It is therefore not proposed to consider dumpy bags as a method of increasing resistance to slide.

5.13.4 Anchor Bolts

As stated in the EA 'Temporary and Demountable Flood Protection Guide, 2011,' anchor bolts can be used to connect the barrier system to the underlying ground conditions in certain situations. Whilst this is not specifically recommended in the case of asphalt, it may be possible that the anchor bolts provide any additional restraint required. However, given the water seepage observed in the carriageway from suspected cracking, it is thought that the introduction of bolts into the pavement surface may lead to flow through the road construction. Consideration would also need to be given as to how the pavement surface is maintained (including access to utility services) with this system of anchoring. It is therefore not proposed to introduce anchor bolts as form of restraint.

5.13.5 False kerb within carriageway

Consideration has been given to the potential for a permanent connection detail (threaded socket) to be fitted into the carriageway. This would facilitate the introduction of a steel section acting as a 'kerb.' This solution has been discounted for two reasons. Firstly, the construction of the false kerb line would require excavation into the carriageway to ensure that sufficient restraint was achieved. It would be considered likely that a buried foundation would be needed to provide the required lateral restraint, which may be difficult to achieve given the number of buried services in the carriageway, in particular along Stourport Road.

Secondly, the requirement for access to the buried services makes it likely that the connection details are disturbed and the redeployment of the barriers would rely on 3rd party reinstatement.

Recommendation 21: Passive restraint measures should be agreed to ensure deployment can be achieved in a safe and timely manner allowing for site constraints.

6 Conclusion

6.1 Discussion

Critical flood risk management assets are assessed by the EA for their resilience, which is described as the ability of an asset to continue to operate or recover quickly after an event. Resilience is usually secured through a combination of four activities or components; Reliability, Resistance, Redundancy and Respond & Recover.

Resilience Component	Comments
Reliability ***The ability to perform a required function under stated conditions for range of conditions***	The Beales Corner temporary barrier system has performed well since its first deployment in 2006, with the barrier superstructure sustaining minimal damage during previous exceedance events. However, recent incidents have indicated that the barrier is currently at risk of sliding due to a combination of environmental and site specific factors. The barrier system is only temporary and so when fully deployed, is unable to provide the same degree of reliability provided by a permanent civils asset.
Resistance ***The existence of designed-in factors that enable the asset to cope with normal loading and exceedance events.***	Assessment of the variables which may contribute to sliding failure (including surface camber, proximity to a kerb line, achievable membrane width, uplift and dynamic loading), has led to recommendations which go some way to mitigate their impact. Implementing passive restraint measures to achieve the recommended FoS for the system will make the system more resistant. It is imperative the mobile pumps behind the defence remain operational. If the pumps fail, then water trapped behind the barrier can rise quickly adversely affecting its stability.
Redundancy ***The existence of more than one means of accomplishing the function. Each means of accomplishing the function need not be identical.***	There is no redundancy in the system. The barrier offers a single line of defence.
Respond & Recover ***The ability to return assets or systems to an operable condition as quickly as possible so that they can continue to provide there function.***	The temporary barrier can be redeployed and returned to operable condition quickly, as demonstrated by its reinstatement following an exceedance event in 2020. If the failure is due to sliding failure then the affected barrier components must be replaced so recovery is dependent on a large stock of spares.

Table 6: Resilience Table.

Temporary barriers are less resilient than permanent civil assets. As discussed in Section 5, the reliability of their operation is significantly affected by a number of variables which can be controlled or mitigated for, and a number of environmental or site specific variables which the operator is not in control of. Examples include excavation of the road surface where controls need to be established to monitor for this change.

Raising awareness of the limitations of the temporary system can be supported by updated evacuation guidance (Recommendations 1 and 8).

The Environment Agency works closely with the Flood Forecasting Centre (FFC) at the Met Office, supplemented by local forecasting models and duty officer correlation work to predict levels. The Flood Warnings Direct Service is currently used to issue a Flood Alert to the community, followed by a Barrier Deployment message at 4mASD (Bewdley Gauge). These both remain out whilst the barrier is in place and a Flood Warning is only issued if the barrier is not deployed, breaches, is no longer effective or overtops. There is potential for this service to be used for greater effect to highlight the resilience limitations of temporary barriers. For example, a new Flood Warning issued to notify the community that there is likely to be water against the barrier.

Recommendation 22: The EA should review the use and issue of flood warnings at Bewdley for the temporary and demountable barrier systems.

This Post Incident Review has aimed to investigate the abnormal operation of the Beales Corner flood barrier, to assess the overall risks due to barrier failure and develop the EA's understanding of temporary barrier resilience.

Recommendation 23: The EA to share the learning from the temporary barrier incident at Bewdley.

6.2 Recommendations

Recommendation 1: The EA should work with the Local Authority to update the Temporary Barrier Community Involvement Plan. This will include updated evacuation levels.

Recommendation 2: The EA should work with West Mercia Local Resilience Forum to update the Multi Agency Flood Plan.

Recommendation 3: The EA should combine existing operational documents into a Temporary Defence Deployment Plan (TDDP) specific to Beales Corner, which will incorporate learning from the Post Incident Review.

Recommendation 4: The EA should discuss membrane sizing with the barrier manufacturer to determine the membrane with the optimum dimensions for the specific site.

Recommendation 5: The EA should review the demobilisation inspection and sign off procedure to see whether it can further be improved.

Recommendation 6: The EA should review the construction inspection and sign off procedure to see whether it can be further improved and incorporate the relevant recommendations from the sliding review.

Recommendation 7: The EA should update the temporary barrier training for the Bewdley site to incorporate relevant lessons identified through this investigation. This should include the training provided to temporary resources that support only during significant flood events, and the buddying process used to ensure competency.

Recommendation 8: The EA to review the evacuation thresholds for Beales Corner, Bewdley, to be informed by this Post Incident Review. This may exclude LRF partners such as Fire and Rescue working with their own additional safe systems of control. Consider updating of the Multi Agency Plan (see Recommendation 2).

Recommendation 9: The EA should consider whether Beales Corner Temporary Barrier System can be resourced independently to the other defences in Bewdley and Worcestershire, potentially utilising support from adjacent Field Teams. This will help ensure operatives have the time to focus on deployment of this complex system and any additional resistance measures.

Recommendation 10: The EA should review and update the Construction Phase Plan to ensure it clearly states that operatives are not to enter the watercourse without appropriate control measures.

Recommendation 11: The EA should consider introducing a way of recording and monitoring any lateral movement and seepage and consider associated risk controls.

Recommendation 12: The EA should record in the TDDP all know activities which require operative access behind the barrier under load. There should be no additional activities permitted. An exercise to review and reduce these activities should be undertaken prior to redeployment and measures put in place.

Recommendation 13: The EA must assume a robust Factor of Safety against sliding failure up to full load, as determined in the Post Incident Review, as it cannot be guaranteed that members of the public are not in proximity to the barrier.

Recommendation 14: To further minimise water infiltration, flap valves relating to the barrier site should be inspected on an increased frequency with any required remedial work addressed promptly

Recommendation 15: The EA should work with the County Council to establish reinstatement conditions for utility providers operating in the highway in the future.

Recommendation 16: Due to the highway damage caused earlier this year, the road surface needs to be replaced with a new HRA or SMA surface prior to the barrier being able to be safely deployed.

Recommendation 17: Where possible in advance, consider the discharge points of the pump hoses and whether they can be fixed in position beyond the apron width of the membrane. Additional hoses may be fixed in position in advance and connected to pumps later if required.

Recommendation 18: Where additional unplanned pumps are required during an incident, the location of the discharge points will need to be carefully considered and managed, ideally positioned away from the lap between sections of membrane and the apron edge.

Recommendation 19: Where the sliding assessment concludes that the recommended FoS cannot be achieved solely through maximising the alignment of the barrier footprint, additional passive restraint will be required to enable the safe redeployment of that section (zone).

Recommendation 20: The Post Incident Review has analysed the FoS against sliding failure based on carriageway resurfacing and current ground conditions. Based on the findings of this report, this analysis can be applied for a maximum 3 year period, beyond which a further in depth review would be required.

Recommendation 21: Passive restraint measures should be agreed to ensure deployment can be achieved in a safe and timely manner allowing for site constraints.

Recommendation 22: The EA should review the use and issue of flood warnings at Bewdley for the temporary and demountable barrier systems.

Recommendation 23: The EA to share the learning from the temporary barrier incident at Bewdley.

6.3 Conclusion

The Beales Corner Temporary Barrier System Post Incident Review was commissioned by the West Midlands Operations Manager following the abnormal operation and breach of the barrier on the 22nd January 2021. The Post Incident review has built on the findings of the Initial Assessment and commissioned a number of supporting reports including a Sliding Review and Ground Investigation to enable a thorough assessment of the risk of sliding failure and identify potential remedial actions.

Since the trial began in Beales Corner in 2006, the temporary barrier system is believed to have been deployed approximately 25 times and the EA's understanding of the resilience of the system has evolved over that period. By nature, temporary barriers are less resilient that permanent civil assets, and the reliability of their operation is significantly affected by changes to the environment in which they are deployed.

The temporary barrier system was compromised due to structural (sliding) failure, and a number of contributing factors have been highlighted which have an impact on the Factor of Safety (FoS) against sliding which is achievable by the barrier. The review of the performance of the barrier superstructure determined that the barrier functioned as designed until it was subjected to considerable abnormal load through the sliding motion and a plate bar weld broke and breach occurred. The recommendations include a number of measures to ensure the deployment and sign off procedures are in line with the findings of this review.

The review of the performance of the foundation determined that the frictional resistance of the surface layer of carriageway, the permeability of the surface, and the adhesive bond between the surface layer and subsequent layers are each an integral to achieving the necessary resistive forces. Evidence of voiding or subsidence beneath the carriageway was not found, however a Groundwater Conceptual Model was presented which demonstrates how river water and groundwater can contribute to basement flooding.

The site is difficult to restrict access to, with multiple public and private accesses and the potential need for EA and LRF partners to maintain a presence past the initial public evacuation level. Therefore a recommended FoS was determined in accordance with the relevant British Standard that aims to provide the necessary reserve of resistance to sliding failure against unplanned variables.

A proposed alignment of the barrier which maximises membrane width around operational requirements has been identified. This has enabled a calculation of the achievable FoS of this alignment, taking into account the factors which influence the barrier behaviour. Additional anchoring forces such as bowsers or concrete barriers would be required to improve the FoS to the recommended value in certain sections (zones) along the alignment.

A number of recommendations aiming to reduce the risks (associated with barrier deployment) to the public, the EA and the EA's Professional Partners have been included in Section 6.2. The review concludes that adoption of many of these measures is necessary before redeployment of the temporary defence system can be considered.

The analysis completed can be applied for a maximum of 3 years, supported by regular visual inspection. Beyond which point, an updated review will be necessary to determine whether the site specific, environmental and ground conditions remain suitable to enable continued deployment. The relevant learning from this review will be shared for consideration at other EA temporary barrier deployment sites.

While the Environment Agency and partners will always endeavour to identify new approaches to reduce flood risk, there will always remain a residual risk. We therefore ask communities to be prepared and to consider what they too can do to ensure that their home and their community is climate resilient.