Use of non-invasive measuring techniques in asset inspection

based on

FRMRC2 WP4.2 – Performance based inspection of flood defence infrastructure: Integrating visual inspection and quantitative survey measurements

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Structure

- Background
- Assessment methodology
- Selected case studies
- Conclusion

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FRMRC 1 WP4.3 :
Performance based visual inspection

- UFMO – Delivered a proof of concept report on a new methodology for visual inspection
- Step towards performance based assessment
  - Includes failure mode analysis
  - Includes measure of uncertainty
  - Flowchart based assessment to reduce inspector bias
- Integrates with PAMS/RASP/NFCDD

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FRMRC1 WP5.2 :
Exploiting new data types

- UFMO – delivered a *state of the art* report on the use of new data types to create digital surface models for flood risk analysis
- Examined a number of technologies
  - LiDAR, Aerial Photogrammetry, SAR, CASI, GPS
- Identified benefits/limitations of the various approaches and when they could/should be used
- Only examined asset surface geometry

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Project Aim

"To develop (to proof of concept) an approach to condition assessment that provides an increased accuracy over purely visual inspection without significant overall increases in assessment cost."

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Plan of Work

- Review current research
  - Establish relationships: performance models & potential monitoring data
- Identify & exploit available data sources
  - EA survey data
  - TE2100 work
  - EA Ops Delivery asset data & knowledge
  - Asset Inspection Training course data
- Experimental Work
  - Identify potential sites

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Asset Monitoring (1) – A Tiered Approach

- **Low level survey**
  - Provides a broad screening
  - Normally relatively low cost
  - Provides triggers for assets that need higher tier inspection
  - Visual Inspection
    - Does not require expert knowledge but training on the qualitative assessment of visual indicators which can be given a score (e.g. Condition grade (Environment Agency)
    - Can be based on subjective judgement
    - Provide condition based on surface information or inferred sub-surface condition
  - Remote measurement – low resolution and not necessarily the highest potential accuracy
    - LiDAR
    - Photogrammetry
    - Radar based systems (SA, InSAR,...)
    - Sonar and wide swathe bathymetry

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Asset Monitoring (2) – A Tiered Approach

- **High level survey (1)**
  - Detailed inspection
  - Quantitative measurement
  - Trained professional or expert
  - Normally relatively expensive
  - Provides definitive decision on asset condition
  - Remote measurement – high resolution and high accuracy
    - LiDAR
    - Photogrammetry
    - Radar based systems (SA, InSAR,...)
    - Sonar and wide swathe bathymetry

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Asset Monitoring (3) – A Tiered Approach

- **High level survey (2)**
  - Detail Survey
    - Engineering or topographic survey
    - Non-Destructive Testing (NDT) methods e.g. Ultrasonic scanning
    - Invasive testing and geotechnical surveys
  - Fixed point continuous monitoring
    - Motion and positional sensors
      - Gauges and tell tales; Accelerometers – MEMS; Inclinometers; Time domain reflectometry (TDR)
      - Radio frequency Identification Tag (RFID) – RF sensor network; GPS station network; etc.
    - Fixed cameras
    - Moisture detectors
    - Ground penetrating radar
    - Integrated sensor arrays

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Asset Monitoring (4) – A Tiered Approach

- **Mid-level survey**
  - Detailed inspection
    - Aimed at the level between a standard visual inspection and a detail survey
    - Not required external consultants; would require extra time/resources
    - Asset specific
    - Ideally go beyond visual inspection and assess more than just current condition
      - Could assess the potential lifespan
      - Could assess the most likely modes of failure given the current condition
      - Provide an objective risk based assessment of performance and likely failure

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Research plan based on the aim

- **Due to the scale of the demand, low level surveys became the focus of work (aim)**
- **Due to the extent of certain key infrastructure assets they would form the structure of reporting rather than the technology e.g. Linear features (embankments)**
- **Performance indicators**
  - To make any form of assessment performance parameters of a feature (asset) must be identified
  - These parameters then become the performance and failure indicators

Extract from Table: Illustration of details of typical failure modes, their performance indicators and visual indicators for an earth embankment

Failure Mode	Description	Performance Parameters	Visual Indicators
*Non-structural failure (overtopping)	Flooding occurs without breach of the defence due to water level exceeding the crest height	Water Level Crest Height	None
Overflowing / Overtopping leading to erosion of outer slope	Water running down outer slope leads to degradation of surface protection and eventual erosion of outer slope over time. Eventually leads to a breach of defence.	Crest Height Grass quality slope angle	Rutting of crest Crest Height below SoP Vegetation on outer slope
Slope Instability	Geotechnical weaknesses initiate slipping or sliding of either slope. Range of potential causes such as poor design, third party damage, etc. Subcategories include circular slipping, sliding, deep seated failure, etc.	Crack Width Slip distance Slope angle Slip width Slip height Slip circle radius	Cracking, slumping or uplift evident Slope Movement Animal burrowing 3rd party damage to slope or toe

*As stated, this is usually not considered to be a failure but is included for completeness

Table 2: Surface features related to damage and failure for an embankment

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Surface condition appraisal and monitoring

surface features related to damage and failure for an embankment

Visual Indicator	Location	Description	Dimensions (m) Slight	Minor	Major
Rutting	Crest/Slope	Wearing of crest or slope due to traffic (human or livestock)	X:0.1-0.3 Y :0.2-0.5 Z:0.05-0.1	X:0.3-0.6 Y:0.5-1.0 Z:0.1-0.3	X: 0.6+ Y: 1.0+ Z:0.3+
Circular Slip	Slope (either)	Semicircular cracking and lowering of slope section	X :0.1-0.3 Y :0.05-0.1 Z:0.01-0.05 SA: 1-5°	X: 0.3-1.0 Y:0.1-0.5 Z: 0.05-0.2 SA: 5-10°	X: 1.0+ Y: 0.5+ Z: 0.2+ SA: 10°
Vermin Holes	Slope (either)	Holes in slope caused by vermin. Slight = vole/rat size, Minor=Rabbit size and Major=Badger/Fox size	X:0.05-0.1 Y:0.05-0.1 Z:0.05-0.2	X:0.1-0.3 Y:0.1-0.5 Z:0.1-0.3	X:0.3-0.6 Y:0.3-0.6 Z:0.3-0.6
Slumping	Toe/Crest	Depression at toe or crest. If at toe, there may also be movement of slope above slump leading to a change in slope angle (SA)	X:0.1-0.2 Y:0.1-0.3 Z:0.02-0.05 SA: 1-5°	X: 0.2-1.0 Y: 0.2-1.0 Z: 0.05-0.4 SA: 5-10°	X: 1.0+ Y: 1.0+ Z: 0.4+ SA: 10°+
Heaving	Toe/Crest	Uplift at toe or crest caused by geotechnical or hydraulic issues. May be slumping behind heave point	X:0.1-0.2 Y:0.1-0.3 Z:0.02-0.05	X: 0.2-0.6 Y: 0.2-0.6 Z: 0.05-0.2	X: 0.5+ Y: 0.5+ Z: 0.2+
Cracking and Fissuring	All	Presence of openings in bank and potential movement or erosion at crack or fissure points	X:0.01-0.05 Y:0.001-0.01 Z:Negligible	X: 0.05-0.5 Y: 0.01-0.2 Z: 0.001-0.1	X: 0.5+ Y:0.2+ Z:0.1+

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A critical performance indicator – crest height

- **Many survey methods can be used for crest height measurement**
  - Levelling – site or engineering surveying to precise levelling
  - Total station surveying
  - GPS – various methods including Real-time kinematic
  - Laser scanning – various methods, static, mobile and airborne (LiDAR)
  - Photogrammetry – various terrestrial, mobile and airborne

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A critical performance indicator – crest height

- **Low level survey**
  - LiDAR
  - Photogrammetry
  - Visual inspection
- **Digital Surface Model (DSM)**
  - Typically generated from LiDAR and photogrammetric measurements
  - Issues to be considered:
    - Accuracy of point coordinate measurement
    - Point density
    - Grid size (less than crest width or it will miss it completely)
    - Vegetation cover – what point/surface is actually being measured?
    - Processing time

A critical performance indicator – crest height

- **Profiling with kinematic GPS**
  - Typically generated from the measurements
  - Issues to be considered:
    - Requires a base station – locally provided or network based for corrections
    - High accuracy of point coordinate measurement (potential 1-2cm)
    - Open sky required
    - Measurement of track of antenna
    - Can it be combined with visual inspection?

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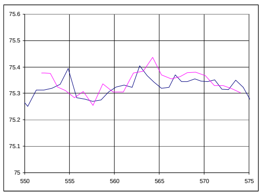
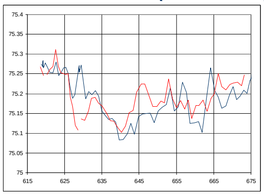
Case Study: Crest and failure profiling via Kinematic GPS

Data Collection System (GPS, Digital Compass and Camera fixed on surveying wheel)

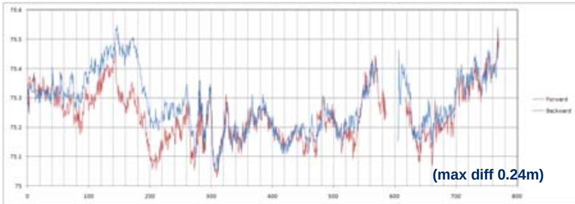
(max diff 0.13m)





2 profiles of the forward and backward survey of the top of Silverdale Embankment

Data Collection System (GPS in a back pack)



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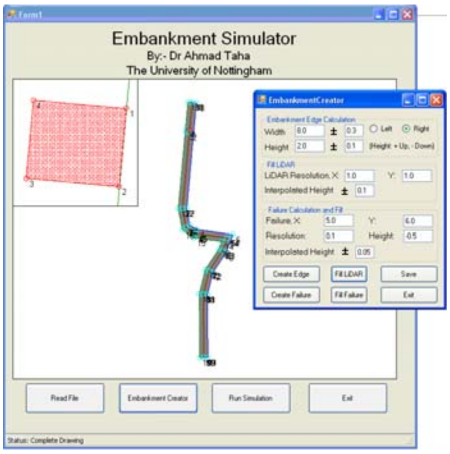
A critical performance indicator – Slipping/sliding

- **Commonly caused by geotechnical processes in the embankment or underlying soil**
- **Accurate assessment of slope angle useful**
- **Changes in elevation of surface**
- **Quantitative assessment by digital surface modelling could be beneficial**
  - Photogrammetry
  - LiDAR
  - Issues to be considered:
    - Effects of vegetation cover to mask slip, dependent on time of year – imagery of potential benefit
    - Accuracy of measurement method verses magnitude of slip
    - Grid interval required to detect what size of slip?
- **Difficult to obtain variety of data to assess some of these issues - simulation**

LiDAR simulator

1. Create embankment DSM – Embankment creator
2. Simulate LiDAR survey of the embankment
   1. Interpolation of points coordinates
   2. Introduction of noise – influencing factors: vegetation, measurement quality, atmospheric effects, etc.
3. Simulate failure with in the embankment



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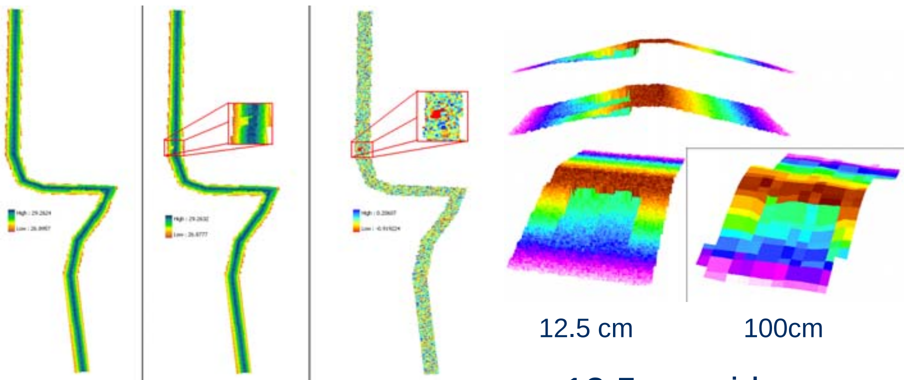
Case study: LiDAR Simulation



Before Slip

After Slip

Difference

12.5cm grid or 100cm grid?

Conclusions - Summary Tables

Extract from a table: Indicator/asset type summary

- ● (red) Probably not worth following up (despite some supporters)
- ● (orange) OK but some problems
- ● (green) Worth considering now
- ● (yellow) Needs further investigation (possible future method)

Visual Indicator / Asset type	Location	Description	Size (m)	Method and comments	●●●●
Crest Height 3.3.1	Crest				
Slight			X: any Y: any Z:0.05-0.1	RTK GPS Backpack mounted – Can combine with regular visual inspections. May not be accurate enough LiDAR with 0.125m grid. Vegetation a possible problem. May miss some features. Slope differences may improve accuracy Geo-referenced photography – accurate measurements difficult Photogrammetry – large amount of processing required, some manual. Vegetation can cause problems. Terrestrial Laser Scanning (TLS) – lot of work for just crest height, not practical for a significant length Mobile Laser Scanning (MLS) OK but possible problems with vehicular access	orange orange orange orange orange orange
Minor			X: any Y: any Z:0.1-0.3	RTK GPS Backpack mounted – Can be combined with regular visual inspections RTK GPS Vehicle (grass cutter) mounted – not possible on all embankments? LiDAR with 0.25m grid. Vegetation a possible problem. May miss some features. Slope differences may improve accuracy Geo-referenced photography – accurate measurements difficult Photogrammetry – Needs considerable processing but can be very accurate. Vegetation can cause problems. Terrestrial Laser Scanning (TLS) – lot of work for just crest height, not practical. May be better than LiDAR with large grid Mobile Laser Scanning (MLS) OK but possible problems with vehicular access. May be better than LiDAR with large grid	green yellow orange orange orange orange orange
Major			X: 0.6+ Y: 1.0+ Z:0.3+	RTK GPS Backpack mounted – Can be combined with regular visual inspections RTK GPS Vehicle (grass cutter) mounted – not possible on all embankments? LiDAR with 0.5m grid. Vegetation a possible problem Geo-referenced photography – accurate measurements difficult Photogrammetry – needs considerable processing. Vegetation can cause problems. Terrestrial Laser Scanning (TLS) – lot of work for just crest height, not practical Mobile Laser Scanning (MLS) OK but possible problems with vehicular access	green yellow green green orange orange orange
Rutting 3.3.3	Crest / Slope	Wearing of crest or slope due to traffic (human or livestock)			
Slight			X:0.1-0.3 Y :0.2-0.5 Z:0.05-0.1	RTK GPS Backpack mounted – Can combine with regular visual inspections. May not be accurate enough LiDAR with 0.125m grid. Vegetation a possible problem. May miss some features. Slope differences may improve accuracy Geo-referenced photography – accurate measurements difficult Photogrammetry Terrestrial Laser Scanning (TLS) – lot of work, not practical for a significant length Mobile Laser Scanning (MLS) OK but possible problems with vehicular access	orange orange orange orange orange orange
Minor			X:0.3-0.6 Y:0.5-1.0 Z:0.1-0.3	RTK GPS Backpack mounted – Can be combined with regular visual inspections RTK GPS Vehicle (grass cutter) mounted LiDAR with 0.25m grid. Vegetation a possible problem. May miss some features. Slope differences may improve accuracy Geo-referenced photography – accurate measurements difficult Photogrammetry – Needs considerable processing but can be very accurate. Vegetation can cause problems. Terrestrial Laser Scanning (TLS) – lot of work, not practical. May be better than LiDAR with large grid Mobile Laser Scanning (MLS) OK but possible problems with vehicular access. May be better than LiDAR with large grid	green yellow orange orange orange orange orange

Conclusions - Summary Tables

- Summary of potential technologies and methodologies for flood defence asset monitoring
  - System level surveys
  - Detailed inspection and remote monitoring
  - Indicator/asset type summary
  - Technology summary

Extract from a table: System level surveys

Technology	Coverage	Accuracy	Benefits	Limitations
Aerial Photogrammetry (top-down)	System->Sub-reach depending on altitude	High (5cm/pixel)	- Highly accurate in assessing x and y dimensions of assets - High resolution images of assets systems can be easily acquired - Can be used in conjunction with LiDAR to create a highly accurate 3D model of asset system	– Low accuracy in the z dimension – Limited view of asset slopes or faces – Effected by cloud cover – Environmental conditions limit use frequently – Does not produce a true crest/asset profile where there are trees, buildings or other obstructions
Oblique Aerial Photography (bird's eye)	Reach->-Sub-reach	High	- Only method capable of examining underwater features - Highly accurate in terms of the requirements of the project	– Crest elevation difficult to accurately assess – Camera angle obscures view of some features – Multiple shots required for all sides of assets – Cost to cover a large area such as an asset system

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Conclusions

- High resolution LiDAR shows good potential for high coverage quantitative assessment
  - Needs careful planning and tailoring to local needs
  - Limitations should be considered
- RTK GPS could be easily used for regular crest profiling by inspection/Ops Del. Operatives
  - Combining grass maintenance with profiling represents a significant opportunity where practical
- A range of simple additions to visual inspection could improve the value of the process
  - Basic GPS, Measure & Logging of faults, geo-referenced photography, Basic gauges & tell-tales