Institution: University of Liverpool

Unit of Assessment: 15 – General Engineering

Title of case study: New Tidal Flood Forecasting Systems

1. Summary of the impact (indicative maximum 100 words)

This case study is based on impact on the Flood Warning Service of the Environment Agency. A new coastal flooding forecasting system combines forecasts of weather and sea conditions with modelling of wave transformation close to the coast, and from this information, using the outcomes of research at University of Liverpool between 1998 and 2005, predicts the wave overtopping of seawalls. The new system allows wind and wave conditions to be incorporated into coastal flooding predictions, improving on the previous methodology that was largely based on sea level. The Liverpool contribution to the system specifically improves on the conservatism of the previous overtopping prediction, leading to a model which issues less false alerts. Versions of the system are now in operation on the North East coast of England, and around the Firths or Forth and Tay, and over 200 alerts have been issued from the North East system since 2008.

2. Underpinning research (indicative maximum 500 words)

The Liverpool research was undertaken by Eur Ing Terry Hedges of the then Department of Civil Engineering, and his research team. In 1995, Hedges analysed data available from HR Wallingford (formerly, the UK Government's Hydraulics Research Station) on the overtopping of seawalls by random waves. This dataset was later supplemented by data from Japan, provided by Professor Hajime Mase from the Disaster Prevention Research Institute, Kyoto University, and by additional information from experiments undertaken at HR Wallingford. Hedges used a semi-empirical methodology in which the selected empirical form was based upon a theory to quantify the discharge over a weir produced by regular waves. This approach was consistent with the known boundary conditions (defining freeboard as the part of the seawall above the normal still water level): (a) for large seawall freeboards, when wave overtopping should be zero; and (b) for zero freeboards when the overtopping would be large but finite. As most seawalls are designed to limit wave overtopping to very small values during extreme storm conditions, it is especially important to satisfy the requirement that large freeboards result in zero overtopping (apart, possibly, from wind-blown spray), a constraint which was not satisfied in earlier, wholly-empirical, overtopping models. The accuracy of the Liverpool model in predicting small overtopping discharges has made it especially suitable for use in a flood forecasting and warning system. The model is documented in references [1]-[5].

The Environment Agency required confidence in the new flood forecasting and warning system before it was formally launched. Consequently, full-scale trials were carried out to identify any deficiencies in the system. The system was online to warn of the flooding on 9th November 2007, caused by a 3m tidal surge and gale force winds in the North Sea. Whilst the system failed to issue a warning for Sandsend, it successfully issued flood warnings for Whitley Bay, Scarborough and Roker, Sunderland. A performance review in 2008 showed that the missed warning was not due to a failure of the overtopping model but to an inaccurate prediction of the surge at Sandsend by another part of the forecasting and warning system. The trial established the credibility of the Liverpool overtopping prediction model, which was then adopted in the Environmental Agency's new tidal flood forecasting system for the North East [6]. In November, 2012 the new flood coastal warning system for the Firths of Forth and Tay also adopted the Liverpool wave overtopping

model.

To ensure the greatest possible benefit from the wave overtopping research, Hedges and colleagues arranged for the later stages of their work (2004 to 2007) to be guided by a steering group. This group included members drawn from industry: Black & Veatch, Royal Haskoning, Bullen Consultants, Mouchel, Coastal Engineering UK and Laboratório Nacional de Engenharia Civil, Lisbon. Involvement of the industrial members helped to guarantee the rapid dissemination and uptake of the research. In particular, Hu of Royal Haskoning saw its potential for the new flood warning system for North East England and the Firths of Forth and Tay.

3. References to the research (indicative maximum of six references)

A broad range of papers describe the Liverpool wave overtopping model and related research. They include (in date order):

[1] Hedges, T. S. and Reis, M. T. 'Random wave overtopping of simple seawalls: a new regression model', Water, Maritime and Energy Journal, Proc. Institution of Civil Engineers, Vol. 130, 1998, 1-10. DOI:10.1680/iwtme.1998.30223

[2] Hedges, T.S. and Mase, H. 'Modified Hunt's equation incorporating wave set-up', Journal of Waterway, Port, Coastal and Ocean Engineering, American Society of Civil Engineers, Vol. 130, No. 3, 2004, 109-113. DOI:10.1061/(ASCE)0733-950X(2004)130:3(109)

[3] Hedges, T.S. and Reis, M.T. 'Accounting for random wave run-up in overtopping predictions', Maritime Engineering, Proc. Institution of Civil Engineers, Vol.157, No.3, 2004, 113-122. DOI:10.1680/maen.2004.157.3.113

[4] Mase, H., Miyahira, A. and Hedges, T.S. 'Random wave run-up on seawalls near shorelines with and without artificial reefs', Coastal Engineering Journal, Vol.46, No.3, 2004, 247-268. DOI:10.1142/S0578563404001063

[5] Reis, M.T., Hu, K., Hedges, T.S. and Mase, H. 'A comparison of empirical, semi-empirical and numerical wave overtopping models', Journal of Coastal Research, Vol.24, Issue sp2, 2008, 250-262. DOI:10.2112/05-0592.1

[6] Lane, A., Hu, K., Hedges, T.S. and Reis, M.T. 'New north east of England tidal flood forecasting system', Flood Risk Management: Research and Practice, Proc. FLOODrisk 2008, Oxford, CRC Press, 2009, 1377-1387. DOI:10.1201/9780203883020.ch163

4. Details of the impact (indicative maximum 750 words)

Large areas of England and Wales, mainly in the south and east of England, are below the highest sea levels. About 10% of the population live or work within areas potentially at risk from river or coastal flooding or from coastal erosion. The capital value of assets at risk is now approximately £275 billion, with coastal flooding representing 60% of this figure. Without flood and sea defences, the average annual economic damage in England and Wales would be more than £3.5 billion. In practice, insurance companies pay out around £1 billion annually. Even so, the true costs are much greater than the sums paid out by insurance companies, because some households and businesses are not insured or are underinsured. In addition, the costs of emergency measures

and repairs to infrastructure fall on central and local government. Furthermore, there are hidden costs to society, such as increased health care expenditure due to sickness and stress-related illnesses. Days are lost from work due to the need to deal with disruption.

Unfortunately, changes in our climate are resulting in rising sea levels and more severe storms, increasing the probability of coastal flooding. However, with sufficient warning of sea defences being overwhelmed by waves, the emergency services can be alerted, local government authorities can take appropriate action, and the general public can prepare themselves. Flood warning is the provision of advanced warning of conditions likely to cause flooding to property and risk to human life. Its main purpose is to save lives by allowing people to prepare for flooding and to alert the support and emergency services. A secondary purpose is to reduce the impacts of the flooding by providing time for valuable property to be moved to safer locations and for operating authorities to close flood gates and other control structures. Temporary measures can also be implemented, such as fitting flood boards and deploying sandbags in order to prevent water from entering properties.

To assist local government authorities and the emergency services in responding to floods, it is necessary to provide information in good time, both of the expected location and likely extent of the flooding. The new systems for North East England and the Firths of Forth and Tay replace earlier schemes which provided less accurate and more regionalised information. They combine computer predictions of weather and sea conditions from the UK Meteorological Office with (a) modelling of wave transformation close to the coast, and (b) the Liverpool wave overtopping model described in section 3, in order to provide warnings up to about 36 hours ahead of real events. The new system for the North East was developed by Black & Veatch and Royal Haskoning, and has now been fully operational following an assessment of performance in January, 2008. The system incorporates a prediction of inshore waves which are then analysed using the Liverpool wave overtopping model to predict flooding. The methodology was implemented in the new Firths of Forth and Tay flood warning scheme introduced by the Scottish Environmental Protection Agency in 2012.

For the North East coastline, over 200 alerts (the list is in the evidence) have been issued in the period of operation. A key feature is that these alerts are localised to one part of the coastline, allowing a targeted reaction. The Liverpool overtopping model provides a reduction in conservatism of these flood alerts, increasing the credibility of the system. The paper with Lane from the Environment Agency as first author, describes the development and evaluation of the warning system, and states that development work showed that the standard overtopping model available "significantly over-predicted overtopping in some places. This would lead to warnings being issued when there was no need for them and would result in a warning system that the public would soon distrust." The Liverpool overtopping prediction resolved this difficulty.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. The Environment Agency's assessment of the full economic and environmental impact of flooding is summarised in their publication "Flooding in England: A National Assessment of Flood Risk".
2. The impact of Eur Ing Hedges' research on improving the reliability of flood warning is described in the Environment Agency's document "New north east of England tidal flood

forecasting system", which was co-authored by him. Lists of alerts and locations issued by the new system are contained in data provided by the Environment Agency, and can be provided on request.

3. Further expansion of the use of Eur Ing Hedges' research into the Firths of Forth and Tay were recently presented at the "Coasts, Marine Structure and Breakwaters 2013" conference in Edinburgh, September 2013, which included an analysis of the storm of December 2012.