Institution: University of Bristol

Unit of Assessment: 15 - General Engineering

Title of case study: MoSSaiC - reducing the risk of landslides in developing countries through the management of slope stability in communities

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

An engineering methodology, *Management of Slope Stability in Communities* (MoSSaiC), has been developed to mitigate urban landslide risk in developing countries, and has been implemented in the Eastern Caribbean. The World Bank is now including the methodology in disaster risk mitigation projects more widely in the Latin America and Caribbean regions, starting with Jamaica (September 2011-). MoSSaiC centres on the efficient management of surface water (construction of hillside drainage networks) and is delivered through a community-focussed programme with a benefit-cost ratio of 2.7:1. The impact includes:

- Hillsides of unauthorised housing, previously exhibiting landslides during rainfall events that occur once every two years, have now been successfully stabilised and, in 2010, withstood a 1 in 500 year event.
- ~800 homes in 12 vulnerable urban communities have benefitted from MoSSaiC interventions in three island states in the Caribbean.
- Indirect benefits such as rainwater harvesting, reduced water bills and the saving of community relocation costs for Governments.

In 2011, the World Bank selected 13 methodologies for an '*Aid Effectiveness Showcase*' exhibition at its Washington DC headquarters. Due to its effectiveness, MoSSaiC was included as the only methodology relating to landslides.

2. Underpinning research (indicative maximum 500 words)

Software development

Surface water infiltration is recognised as the dominant mechanism in triggering landslides in weathered slope materials in the humid tropics. The first model, combining the effects of hydrological and geotechnical processes on slope stability, was developed by Anderson (UoB since 1985) at the University of Bristol [1]. This two-dimensional finite difference model, CHASM, was extended by Holcombe (UoB since 2002) & Anderson in 2003, from predicting landslide *hazard* (the likelihood and mechanism of landslide occurrence), to the quantification of landslide *risk*. This was achieved by modelling post-failure slope geometries, landslide runout, costs of debris removal and slope re-instatement, and the associated economic cost [2]. This research enabled different slope stabilisation investment scenarios to be tested for multiple slopes, over budget cycles and design lifetimes, via an integrated cost-benefit analysis module.

Development of a risk reduction methodology

In 2004, the Government of Saint Lucia requested that Holcombe and Anderson develop a prototype methodology (incorporating CHASM), to address landside risk in unauthorised urban communities. The underpinning research findings were: i) previous locally-engineered approaches to slope stabilisation in communities using retaining walls were ineffective [3]; ii) local slope features and soil water convergence were critical in urban landslide hazard assessment; iii) unsaturated and saturated soil conditions need to be modelled. CHASM simulations confirmed the slope destabilising trigger was rainfall and waste water infiltration, controlled by altered natural drainage patterns and micro-topography (a result of urbanisation); processes occurring at a resolution finer than conventional slope stabilisation analyses had accounted for. A systems-based methodology (MoSSaiC) was thus designed to stabilise landslide-prone hillsides by the efficient management of surface water.

The pilot research in the Eastern Caribbean provided the context for further development of CHASM to represent localised human and physical aspects of urban landslide risk, including point water sources, structural loading on slopes and landslide travel distances. A progressive landslide

in one community provided a test case for the code. CHASM analysis, driven by observed rainfall, successfully replicated the timing, location and travel distance of the landslide and confirmed the role of surface water convergence in triggering and continuing to mobilise the failure. Local shear box apparatus for measuring soil strength was benchmarked against a state-of-the-art direct shear box at the University of Bristol, and parameter uncertainty was accounted for in simulations [4,5].

Risk reduction implementation

This underpinning research facilitated slope stability management scenario testing which demonstrated that reducing surface water infiltration could stabilise many landslide-prone slopes. To achieve such reductions in sub-surface water levels, an integrated network of surface drains was designed and constructed to intercept rainfall runoff from slopes in 11 further at-risk communities (2006-2011). Household roof- and grey-water was connected to the drains. The new drains intercepted 70% of surface water runoff, reduced pore water pressures, and lowered ground water levels.

This combination of research and on-the-ground construction produced the MoSSaiC methodology for delivering community-based landslide risk reduction to urban areas in developing countries (www.mossaic.org). The methodology integrates technical and management aspects by capturing local knowledge, expertise, and proven local drain design and construction practices, from residents, contractors, and government engineers. This holistic systems methodology drove policy change in which slope water management was accepted as a means of reducing landslide risk at the community scale. An initial endorsement of the scientific basis *and* delivery of the pilot MoSSaiC intervention was the 2007 Trevithick award from the Institution of Civil Engineers [6].

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

[1] *A.J.C. Collison, M.G. Anderson and D.M. Lloyd, 1996. *Impact of vegetation on slope stability in a humid tropical environment: a modelling approach*. Proceeding of the ICE - Water Maritime and Energy, 112, 168-175, dx.doi.org/10.1680/iwtme.1995.27662. *Awarded the Institution of Civil Engineers' Trevithick Award in 1997*.

[2] *E.A. Holcombe, S. Smith, E. Wright and M.G. Anderson, 2012. *An integrated approach for evaluating the effectiveness of landslide hazard reduction in vulnerable communities in the Caribbean*. Natural Hazards, 61, 351-385, dx.doi.org/10.1007/s11069-011-9920-7 (listed in REF2).

[3] J.R. Blake, J.-P. Renaud, M.G. Anderson and S.R. Hencher, 2003. *Prediction of rainfall-induced transient water pressure head behind a retaining wall using a high-resolution finite element model*, Computers and Geotechnics, 30 (6), 431-442, dx.doi.org/10.1016/S0266-352X(03)00055-7.

[4] *N.A.S. Hamm, J.W. Hall and M.G. Anderson, 2006. *Variance-based sensitivity analysis of the probability of hydrologically induced slope instability.* Computers & Geosciences, 32 (6), 803-817, dx.doi.org/10.1016/j.cageo.2005.10.007.

[5] J.-P. Renaud, M.G. Anderson, P.L. Wilkinson, D.M. Lloyd and D. Muir Wood, 2003. *The importance of visualisation of results from slope stability analysis.* Proceedings of the ICE - Geotechnical Engineering, 156 (1), 27-33, dx.doi.org/10.1680/geng.2003.156.1.27.

[6] M.G. Anderson E.A. Holcombe, 2006. *Sustainable landslide risk reduction in poorer countries*. Proceedings of the ICE - Engineering Sustainability, 159, 23-30, dx.doi.org/10.1680/ensu.2006.159.1.23. *Awarded the Institution of Civil Engineers' Trevithick Award in 2007*.

* References that best indicate the quality of the underpinning research.

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

How research was exploited

The research and landslide mitigation methodology was delivered using a systems engineering, structured development process, from concept [6] to delivery of construction on the ground (Table 1). The systems engineering approach required coordination not just within the public sector, but also between the public sector, civil society and the private sector; it integrated efforts not just vertically within a sector, but horizontally across sectors and geographically within a country. Early

evidence of the uptake of the methodology is provided by the St Lucia Government Cabinet Conclusion #618 of 12 July 2004, which formalised the role of MoSSaiC Management Committee within Government. As a result of MoSSaiC project impact in the Eastern Caribbean, in September 2009 The World Bank approved funding for Anderson and Holcombe to author a book on the methodology to make it more widely available [a].

Table 1: Steps used to implement the MoSSaiC methodology from 2008

Steps	Sample Evidence
1 International agencies engage with MoSSaiC in the Eastern Caribbean	2008 - MoSSaiC projects in communities visited by World Bank, Caribbean Development Bank and USAID in St Lucia and Dominica, and UNDP in St Vincent and Bequia. Agencies and Governments provide ~US$6M for drain construction for MoSSaiC projects [b].
2 World Bank incorporates MoSSaiC methodology in disaster mitigation projects	World Bank funds St Lucia Second Disaster Mitigation project 2009-2011, incorporating MoSSaiC approach to landslide risk reduction in a further six communities [b].
3 World Bank incorporates MoSSaiC as a case study in annual report	Inclusion of methodology in World Bank, *World Development Report* 2010; 'Climate Change and Development' [c] and featured in the World Bank's *Aid Effectiveness Showcase* in Washington DC, 2011 [d].
4 World Bank publishes book on MoSSaiC as an accepted methodology suitable for widespread uptake	Publication of book: M.G. Anderson and E.A. Holcombe, 2013. *Community-based landslide risk reduction: Managing disasters in small steps.* 455pp, [a].

Details of the beneficiaries

Since 2008, the MoSSaiC methodology has benefitted 12 communities, totalling approximately 3000 inhabitants, across St Lucia, Dominica and St Vincent and the Grenadines. In 2011, it was introduced to Jamaica through a programme of community-based projects costing US$2.37M, funded by the World Bank and implemented by the Office of Disaster Preparedness and Emergency Management [e].

Details of the nature of the impact and indicators

The methodology works: there have been no reported landslides in any of the communities in which MoSSaiC interventions have been completed [2]. The Latin America and Caribbean Regional Disaster Risk co-ordinator at the World Bank comments: "*In the aftermath of Hurricane Tomas (October 2010), there were numerous landslides in St. Lucia due to the extreme rainfall. None were reported in any of the communities with MoSSaiC interventions. This positive proof of the powerful results... has motivated St. Lucia to scale-up the initiative nationwide, and to institutionalize it"* [f]. In addition, it has been noted that these communities "*used to be affected by substantially weaker events in the past*" [g].

The methodology pays: it has a benefit-cost ratio of 2.7:1 [2,h]. In this study, the development and application of an integrated landslide risk assessment and cost-benefit analysis methodology was grounded in data acquired at this community scale – overcoming some of the methodological issues regarding scale, data availability and process representation and allowing the degree of landslide risk (and risk reduction) to be quantified. Conducting a survey of community benefits, using both revealed preference and stated preference (contingent valuation) methods, allowed estimation of indirect project benefits. These indirect benefits to the community were shown to be significant and included: lower water bills through the harvesting of intercepted rainwater from rooftops; improved access to and from the community due to reduced flooding and associated debris on footpaths; and therefore fewer days of work missed and less time spent clearing debris. In St Lucia, these benefits were valued at EC$12,705 annually [2]. In addition, over 80% of programme funds were spent in the communities [c] with, for example, 25 local people employed on the project.

The methodology is being scaled up by The World Bank: Funding was awarded for development of the functional and technical specification of an online interface to MoSSaiC resources. The interface will give structured access to the MoSSaiC book, and technical and project management tools; allow development agencies and governments to design and deliver landslide risk reduction projects; provide training modules for the local teams delivering the landslide hazard reduction measures; and include relevant calculators and tools for slope stability assessment and drainage design. The combination of the ePractice user mode, user types, content and functionality are particularly novel and innovative. It is anticipated that the interface will become a template for other resources in the field of Disaster Risk Management knowledge transfer both at The World Bank and elsewhere. The specification was completed and signed-off in June 2012 and will be built by and hosted with World Bank funding (for which an agreement is in place). Creating a state-of-the-art interface for all MoSSaiC resources, bespoke for each audience type at a site funded and hosted by the World Bank, will enable global reach of the methodology, and maximise impact in the period 2011-2014 beyond the current levels of recognition [b].

In addition, the World Bank is translating the book into Spanish (in 2013) and is establishing a 'community of practitioners' in Latin America and the Caribbean to roll out the methodology within the region. The World Bank comments that "g*iven this context of apparent success* [in St. Lucia], *the World Bank sees the potential to encourage uptake of the methodology more widely. To that end the Bank is publishing in December 2012 the book 'Community-based landslide risk reduction – managing disasters in small steps'... [and] a Spanish translation of the book will later be published by the Bank"* [f].

CHASM software recognition: CHASM software is recognised internationally as 'industry standard', with the US-based Scientific Software Group marketing the software since 2000 [i], achieving CHASM sales in more than 17 countries worldwide. In 2010, CHASM was awarded the Grand Prize at the *Random Hacks of Kindness#1* software event at Microsoft, Washington DC [b].

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

[a] '*Community-based landslide risk reduction: Managing disasters in small steps'.* Malcolm Anderson and Elizabeth Holcombe. Book published by the World Bank, 2013, 456pages. ISBN 978-0-8213-9456-4, https://openknowledge.worldbank.org/handle/10986/12239

[b] Latin America and Caribbean Regional Disaster Risk co-ordinator, World Bank.

[c] World Development Report 2010: Climate change and development. MoSSaiC included as a case study on page 327.

[d] Aid effectiveness showcase, World Bank Main Complex, Washington DC, October 2011. http://www1.worldbank.org/operations/aideffectiveness/Showcase4.html (see Saint Lucia: "Community-based Landslide Risk Reduction" link to presentation slides).

[e] Jamaica: Jamaica Observer article *Landslide risk reduction project coming*, 26th October 2011.

[f] Latin America and Caribbean Regional Disaster Risk co-ordinator, World Bank – letter, October 2012.

[g] World Bank, Results in Action web article *Saint Lucia: From Landslides to Stability*, 2011.

[h] Vice-President for sustainable development, World Bank, uses MoSSAiC example in her speech at the TEDx event in Sendai, Japan 2012. http://www.youtube.com/watch?v=cWYcXhMhJF4&noredirect=1, start time 7.08.

[i] Scientific Software Group CHASM sales page on www.scisoftware.com