Real-time rockfall monitoring for hazard assessment along road corridors (Ref IAP2-18-46)

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Rockfall, hazard assessment, geomorphological monitoring, roads

Overview
In September 2017 large rockfalls on El Capitan in Yosemite, USA resulted in loss of life and major socio-economic disruption. This event headlined in the World media and illustrated the devastating and unpredictability of rockfall events. In the UK rockfall is also recognised as an important geomorphic process conditioning the long-term development of hillslopes, (Hinchcliffe and Ballantyne, 2009), determining rates of coastal retreat (Vann Jones et al. 2015) and is a significant hazard along roads and highways (Nichol, 1999). However, research into this important process has tended to concentrate on hard rock coastal cliffs and mountain talus development - there have been remarkably few contemporary process studies in the UK uplands (Johnson and Warburton, 2002).

Understanding the conditions leading to rockfall in UK upland environments is important due to risks posed to road infrastructure, upland communities and the recreational public. Castle Rock in Thirlmere (Cumbria) is an excellent example of hazard setting where rock-mass instability in the upper part of the rockface threatens a busy road, a local community and recreation users (Figure 1a). This is a unique opportunity to study the pre-failure behaviour of such an event, which can be set into the wider context of rockfall deposits in the Lake District, most of which are presumed to be periglacial, representing debris accumulated over 1000s of years.

Cracking of the upper rockface, in the form of a horizontal crack running in a in a SW-NE direction, was first noticed in August 2011 and has been monitored thereafter (Figure 1b and 1c.). The volume of rock affected by this is approximately 18 x 15 x 5

Figure 1. Castle Rock, Legburthwaite, Thirlmere, Cumbria. (a) View of the upper buttress showing the location of the fracturing. (b) Detail of crack showing the site of manual measurement and the in-situ gauge plates. Photographs courtesy of Dave Bodecott.
m (1350 m$^3$) which corresponds to a mass of around 3375 t.

We have been given access to a unique data set of direct observations of crack widening, recorded since May 2012 on a ~ two-monthly basis (Figure 1b and 2). The data clearly show a very strong trend in continued crack widening but also illustrate a fascinating pattern of movement which shows a slight seasonal closure along the long axis measurement in springtime each year probably due warmer drier conditions.

![Figure 2. Historical measurements of crack widening at Castle Rock. Measurements are shown for displacement in two dimensions along a short axis (x) and long axis (y) with reference to the fixed plates shown in Figure 1c. Approximately 30-45 mm of widening has been observed over the 4 year period. Source: Dave Bodecott.](image)

The study has seven main objectives: (1) use an online data logger and time-lapse cameras to provide a continuous record of crack movements and local temperature, rainfall and solar radiation on the rock face which can be monitored remotely; (2) Monitor the area of instability and surroundings using repeat terrestrial laser scanning (~ 1 month intervals) to quantify the spatial patterns of movement, and provide a baseline for a rockfall inventory; (3) Using drone derived Structure from Motion (SfM) photogrammetry map the discontinuities in the rock face and relate this to potential failure volumes and viable release mechanisms; (4) Model probable rockfall trajectories in both 2D and 3D using existing numerical codes to determine the potential impacts of the failure on the valley; (5) Carry out a regional hazard assessment of roadside cliffs in the Lake District to determine other sites susceptible to potential failure, and those undergoing similar deformation pathways (this will also be informed by reports from the BMC and local climbing clubs); (6) Assess rates of rockfall debris accumulation by using lichenometry, historical records and direct 14C dating to date valley-wide talus accumulations; (7) Relate variations in movement and any rockfall activity to climate data and establish likely failure timescales and appropriate alert thresholds.

**Methodology**

The main methods employed include:

1) **Field survey** of Castle Rock including detailed topographic mapping using differential GPS, terrestrial laser scanning (TLS) and Structure-from-Motion photogrammetry from Unmanned Aerial Vehicles; geotechnical analysis of rock structures from the captured imagery.

2) **Statistical analysis** of the temporal trends in the crack widening database. This will include descriptive statistics, time series analysis, graphical presentation of results and simple empirical modelling to predict the failure of the rock face. This is based on archive data, and the online data-logging system currently deployed at the site. This will be critical in evaluating the key role of temperature regime in governing failure and distinguishing the contribution of recoverable and irrecoverable strain in rock mass deformation.

3) **GIS / spatial modelling** of rockfall susceptibility. GIS tools will be used both at the local and regional scale to integrate geological and topographical data to predict the susceptibility of the cliffs to rockfall. InSAR data can be used to identify other potential failure sites in the region.

4) **Numerical slope stability modelling** will be undertaken to analyse the critical conditions for determining rock mass failure. This will involve 2D and 3D modelling of the rock mass and runout analysis.

5) **A hazard mapping approach** will be developed which draw on the results of the talus dating analysis, GIS and numerical modelling approaches.

**Timeline**

**Year 1**

i) Maintain the online data logger and promote the online portal to stakeholder communities (O1).

ii) Establish ground control and monitor the area of instability using repeat terrestrial laser scanning (~ 1 month) (O2)

iii) Capture UAV imagery and begin structural analyses of the rock face (O3)

**Year 2**
i) Continue monitoring the area of instability using repeat terrestrial laser scanning (~ 1 months) (O2)

ii) Complete structural analyses to establish parameters for numerical modelling (O3, O4)

iii) Model the potential impacts of the failure on the valley (O3, O4)

iv) Carry out a regional hazard assessment of roadside cliffs and date talus accumulations (O5 & O6)

**Year 3 and 3.5**

i) Complete monitoring the area of instability using repeat terrestrial laser scanning (O2)

ii) Relate variations in movement to climate data from the AWS located at the foot of the crag (O7)

iii) Predict the timing of potential failure of the rock mass instability (O7)

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**Training & Skills**

Training is fundamental to the development of postgraduate research students and, together with the DTP, University and Department we provide a substantial training programme. Priorities for training are determined from the ‘Training Needs Analysis’ carried out in the initial supervisory meeting with the student.

Departmental training in (a) research skills and techniques and (b) research environment are provided through four mechanisms: (i) a programme of taught modules; (ii) internal training ‘workshops’ that focus on key geographical research skills and techniques; (iii) input from supervisors; and (iv) departmental seminars by visiting speakers and presentations by postgraduate students themselves. Physical geography research postgraduates normally take the taught departmental module ‘Implementing Research Design’ during their first year. The aim of this module is to help students put University training in research design into practice specifically in relation to physical geography research both generally and with regard to the student’s own project work. Students receive instruction in data collection and the scientific method, contextualizing and problematizing research in physical geography, planning for field- and laboratory work, and team and group working in physical geography. Assessment of students in this module is formative. In addition to generic training offered by the University, the Department also provides training through a series of in-house ‘workshops’. These workshops offer the opportunity to gain both experience and knowledge with a number of tools in a specifically geographical disciplinary context and to gain an understanding of some of the wider structures and practices which make up academic life. This programme has been developed in response to postgraduate requests and is open to ALL postgraduate students irrespective of degree or year of study.

Research training continues through the second and third years, and is based around a number of themes: Recognition and validation of problems; Demonstration of the original, independent and critical thinking, and the ability to develop theoretical concepts; Knowledge of recent advances within research field and in related areas; Understanding relevant research methodologies and techniques and their appropriate application within research field; Ability to analyse and critically evaluate findings and those of others; and Summarising, documenting, reporting and reflecting on progress.

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**References & Reading**


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**Further Information**

Further information can be obtained by contacting Jeff Warburton.