Debris Flow Risk to Roads and Road Users

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Abstract: Fast-moving, rainfall-induced debris flow events are relatively common in the mountainous areas of the UK. These events present significant hazards to transport networks, particularly roads in remote areas. The latter often follow historic routes that were created without consideration of the extant hazards and their resulting risks. Such risks include the loss of utility of the network and associated damage to the infrastructure, the risk of fatality of road users, and the loss of socio-economic opportunities for the communities that are served by such networks. In this extended abstract and presentation, a brief overview is given of the various risk types.

Keywords: ***Debris flow, Road, Hazard, Risk.***

Introduction

Rainfall-induced debris flow events can present significant hazards to roads that serve remote areas and communities in mountainous areas. Such roads often follow historic routes that were created informally to provide the easiest routes to market with little to no consideration of the hazards and the resulting risks.

Such risks include the loss of utility of the network and associated damage to the infrastructure, the risk of fatality of road users, and the loss of socio-economic opportunities for the communities that are served by such networks. In this extended abstract and presentation, a brief overview is given of the various risk classes; a more extensive treatment is given by Winter (2024).

Semi-Quantitative Risk Assessment

In August 2014 a series of debris flows caused major disruption to the Scottish Trunk Road network (Winter et al. 2006). This led to the instigation of the Scottish Road Network Landslides Study-SRNLS (Winter et al., 2005, 2008) which delivered both a semi-quantitative risk assessment and the development of a landslide management plan and mitigation strategy to allow budget and resources to be focused on areas where debris flow hazards and impacts are most severe and where they can be effectively managed and mitigated to reduce the exposure of road users.

The hazard and risk assessment (Winter et al., 2008, 2013) comprised three phases:

- GIS-based assessment of susceptibility,
- desk-based interpretation and ground-truthing,
- a desk-based exposure analysis.

This pan-Scotland regional risk assessment identified 66 sites with the highest semi-quantitative scores on the strategic Trunk Road Network (TRN).

Quantitative Risk Assessment

In addition to allowing the wide-ranging implementation of exposure reduction measures such as static and early-warning signs, the regional risk assessment identified the sites of highest risk at which further work was required. This allowed the development of a methodology to determine the fatality risk to users of the TRN at both the personal and societal levels (Winter and Wong, 2020). This methodology was extended to include those users that stop at informally developed tourist car parks built on debris fans (Winter et al., 2024).

The original methodology developed was applied to the A83 Rest and be Thankful and the A85 Glen Ogle and this and the extended methodology to the A82 Glen Coe. Space prohibits showing detailed results herein, but the personal risk was shown to be within broadly acceptable levels in all cases. The societal risk levels were elaborated on the F-N diagram and show results that are generally 'As Low as Reasonably Practicable' (ALARP) for Glen Ogle and mobile road users at Glen Coe. For the Rest and be Thankful the results were in the 'Unacceptable' zone for lower numbers of fatalities although once mitigation measures extant as at the time that the work was undertaken this returned to ALARP. In contrast, for road users in the car parks at Glen Coe the risk for higher numbers of fatalities was in the 'Unacceptable' zone.

In addition, to allowing the very highest sites to be identified and subject to QRA, the regional risk assessment also allowed appropriate more detailed assessments of other high-risk sites. A programme of such assessments was instigated in 2022 and to date around 15 sites have been assessed with varied outcomes as to the required mitigative actions.

Socio-Economic Risk

The socio-economic impacts of landslides are both significant and complex. Roads in Scotland, for example, provide vital communication links to remote communities and the severance of access to services and markets has significant economic and social consequences. Employment and education opportunities may be lost and health, welfare and social activities restricted.

Winter and Bromhead (2012) categorized the economic impacts of a landslide event that closes a road, or other form of linear infrastructure, as follows:

- Direct economic impacts: The direct costs of clean-up and repair/replacement of lost/damaged infrastructure in the broadest sense and the costs of search and rescue.
- Direct consequential economic impacts: 'disruption to infrastructure' and loss of utility. For example, the costs of closing a road (or implementing single lane working with traffic lights) for a given period with a given diversion.
- Indirect consequential economic impacts: due to the dependence upon the transport network on incoming and/or outgoing goods, and for the transport of staff and visitors as well as any associated longer-term impacts. How confidence in, and the ongoing viability, and credibility, of local businesses are affected if a given route is closed for a long period.

The economic impacts of road closures and restrictions caused by landslides (and floods) were quantified for both direct and indirect consequential economic impacts by Winter et al. (2019).

For indirect consequential economic impacts, the data acquired was found to be inconclusive and open to alternate modes of interpretation. However, it did provide some very important insights into the effects of such events on local businesses. The impacts for single, non-recurrent events were of lower impact and descriptors that relate to hazard were used by survey respondents: 'landslide', 'flooding' and other words that describe the event itself are also to the fore. In contrast, for areas subject to repeated and significant events the impacts were greater, and survey respondents used descriptors that described the impacts such as 'road', 'closed', 'staff', 'visitors', 'due', 'access', 'tourism'.

Infrastructure Risk

Here the focus is on the risk to the infrastructure and assets rather than on that to the road users and their socio-economic activities. An important facet of this is the development of fragility functions that relate flow volume to damage probabilities and thus quantify the physical vulnerability of the asset.

Vulnerability curves were developed by Winter et al. (2014) for both high-speed and local (low speed) roads at Limited, Serious and Destroyed damage states. These were calibrated against known magnitude and damage levels from events in Scotland and South Korea. More recent work considers the vulnerability of systems, rather than individual-assets (Argyroudis et al., 2019).

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