EARTHQUAKES WITHOUT FRONTIERS

SIMPLE GUIDELINES TO MINIMISE EXPOSURE TO EARTHQUAKE-TRIGGERED LANDSLIDES

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KEY MESSAGES

- Experience in recent large earthquakes provides information on where landslides are most likely to happen, which we use to provide clear and simple guidance for how to minimise exposure to future earthquake-triggered landslides.
- This guidance is targeted at those supporting householder and community decision-making in preparing for large earthquakes, choosing locations for houses or key infrastructure, and dealing with potential future landslide impacts (e.g., local government and NGOs).
- Our guidelines help to identify the safest locations in the landscape:
    - The first and most important guideline to minimise exposure to earthquake-triggered landslides is to choose a location where the angle to the skyline is minimised, and is below 25° if at all possible
    - Second, locations near steep channels (those with slopes of >15°) should be avoided, especially if there are many steep hillsides (>35°) upstream. Any houses or other key infrastructure should be kept at least 10 m away from the banks of such channels, to minimise the chances of inundation by debris flows
    - Third, always seek to minimise the slope of the ground at your location when deciding where to site key infrastructure.
- These guidelines should be used in combination with local knowledge and experience, specialised geological knowledge, and formal hazard assessment where available. In the absence of these other sources of information, these guidelines provide a first approach that can guide decision-making.

SUMMARY

Reducing landslide risk in many mountainous regions is most effectively achieved by reducing exposure to landslides, because landslides cannot be predicted or stopped and engineering solutions are generally impractical or impossible. Because landslide hazard is very site-specific, available hazard maps may not be detailed enough, or contain appropriate and up-to-date information, to inform decision-making.

We use our experience of studying the characteristics of landslides in recent large earthquakes to describe three simple guidelines that can be used to minimise exposure to future earthquake-triggered landslide hazard. The most effective measure is to choose a location that minimises the angle to the skyline, and to keep that angle below 25° if at all possible. It is also important to avoid steep channels (those with slopes of >15°), especially if there are many steep hillsides upstream. Finally, the slope of the ground at your location should always be minimised.

These guidelines do not specify where landslides will occur, but can be used to distinguish between areas which are more or less likely to be affected by landslides in a large earthquake. They can be used to reduce risk before an earthquake occurs by helping to inform decisions on where to situate key infrastructure, such as schools or health posts. They can be used to inform decisions about the locations of houses, markets, or other areas where people are likely to spend considerable periods of time, or for deciding on appropriate types of land use. The guidelines can also be used in disaster preparedness and response planning, by identifying suitable evacuation routes and open spaces for use as evacuation sites or emergency shelters. We provide some brief guidance on what to do immediately after an earthquake in order to minimise exposure to landslides, and discuss the relevance of these guidelines for protecting against rainfall-triggered landslides which may occur more frequently.

THE CHALLENGE

Landslides are a fundamental hazard in mountainous areas like the Himalayas. As well as posing a direct threat to people and property, landslides can impact livelihoods by repeatedly destroying land, limiting access, and disrupting basic services. While landslides are an annual and increasing hazard in mountainous and populous countries like Nepal, they are especially dangerous when triggered by large earthquakes. Experience after the 2015 Gorkha earthquake in Nepal has shown that (1) landslides were a major cause of damage and loss of life in many parts of the 14 earthquake-affected districts and (2) areas that were badly affected by earthquake-triggered landslides in 2015 have been especially prone to further landslides in the subsequent monsoons. Thus, landslides triggered by earthquakes pose both an acute hazard and a persistent threat that can continue for years, and possibly decades, after any large earthquake. Where possible, choosing locations that reduce exposure to such landslides is critically important.

So, what can be done to reduce this risk? Our experience of working in Nepal has shown that most landslides are impossible to prevent or to stop, and that the mitigation tools that are commonly available for use by government and NGOs – such as gabions, retaining walls, and bioengineering measures – are often of very limited use. Instead, efforts to mitigate landslide risk should focus on reducing exposure, by identifying places where landslide hazard is relatively low. Unlike many other hazards, landslide hazard is extremely site-specific; small distances can make a very large difference in both the exposure to landslides and to their impacts. Decisions about where to build a house, school, or health post, where to site emergency supplies, or how to identify safe evacuation routes, involving choices of only small distances (c. 100 m), can thus be vitally important. Communities have been making such decisions for generations and have a wealth of local knowledge and experience to build upon. However, a large earthquake presents a new and rapidly evolving set of hazards that most people have never experienced, raising questions about how to prepare for a future earthquake and how to rebuild afterwards.

Ideally, decision-making would rely on detailed and up-to-date landslide hazard maps, widely available and prepared with a consistent and agreed approach in all landslide-prone areas. Unfortunately, suitable landslide hazard maps are not always available, and even where they exist they may not contain the detailed information that is needed to support decision-making. Such maps are also unlikely to be available to and accessible by everyone who needs this information. It is also important to remember that, for some householders and communities, relocating houses and other key infrastructure is impractical or even impossible. If damaged houses and infrastructure are to be rebuilt following an earthquake, however, then there may be a window of opportunity to re-consider the location of infrastructure and houses to reduce exposure to landslides.

Efforts to mitigate landslide risk should focus on reducing exposure, by identifying places where landslide hazard is relatively low.

In this policy brief, we use landslide research undertaken at Durham University to define some simple guidelines that can be used to minimise exposure to earthquake-triggered landslides. These guidelines have been distilled from a large body of research into landslide occurrence in earthquakes, and represent the best available scientific information on where earthquake-triggered landslides are most likely to occur in the landscape – and thus, how they can be avoided in future earthquakes. The guidelines have been designed to be understandable, communicable, and memorable; to require no prior knowledge, skills, or equipment to evaluate; and to identify areas of high landslide hazard as effectively as possible. They are not a replacement for local knowledge of an area, specialised geological knowledge, or formal and detailed hazard assessment. Instead, they should be viewed as a first approach for minimising exposure, especially where no other information is available, and should be combined with all other forms of knowledge about landslide hazard.

GUIDELINE 1: MINIMIZE THE ANGLE FROM YOUR CURRENT LOCATION TO THE SKYLINE

The single most effective way to reduce exposure to earthquake-triggered landslides is to minimise the 'skyline angle': the steepest angle from your location to the skyline (Figure 1). By reducing this angle, you minimise the number of potential locations that landslides could start from and reach your present location. This is a more effective measure of landslide risk than the local slope (the angle of the ground surface at your location), because it accounts for the fact that landslide material moves downhill and can affect locations far downslope of where the landslide begins. Skyline angles to key locations should always be kept as small as possible.

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Figure 1. Landslide-prone houses in Sindhupalchok District, Nepal, showing the difference between the maximum angle to the skyline and the local slope of the ground surface.

A good rule of thumb is that landslide hazard increases dramatically when the maximum skyline angle is greater than about 25°. This angle can be estimated by holding your arm horizontally and comparing the height of the skyline to the distance between your thumb and little finger (Figure 2). If the skyline is higher than this distance, then there is a greater than average chance that the point where you are standing will be affected by a landslide in the next large earthquake. If you are considering where to locate a building or other key infrastructure, consider moving to a different site if that is feasible.

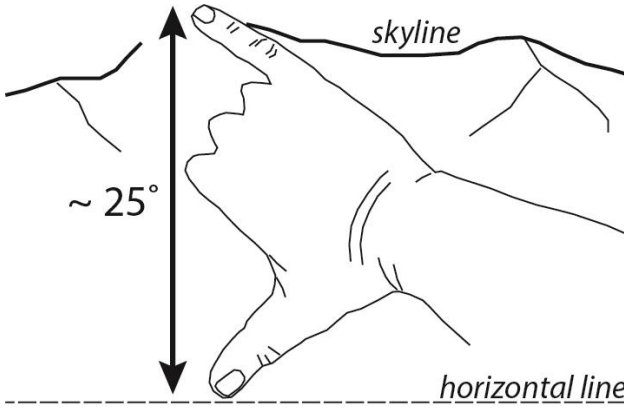

Figure 2. A skyline angle of ~25° can be estimated by extending the thumb and little finger and holding your hand at arm's length. Landslide exposure increases dramatically for sites with skyline angles that are greater than this value.

GUIDELINE 2: AVOID STEEP (>15°) CHANNELS WITH MANY STEEP HILLSIDES (>35°) UPSTREAM

Landslide debris is very commonly washed down river channels during or after heavy rain, often as a slurry-like mass called a debris flow. Debris flows can be extremely destructive to people and property within or near the channel, but their occurrence is hard to predict. As a rule, however, debris flows are more likely to happen in river channels that are both steep (>15°), and where there are steep hillsides (>35°) within the upstream river basin (Figure 3). This is because debris flows need (1) landslides to occur upstream, to supply sediment to the river channel, and (2) a steep river bed to allow the debris flow to move downslope.

Impacts from debris flows can be devastating but are typically limited to a narrow zone along the

channel. Locations directly on, inside or below the channel banks should always be avoided. Areas outside of the channel banks can still be affected by large flows that spill over the banks. The width of the zone that is likely to be affected can be estimated by looking at the naturally-occurring vegetation and evidence of debris from older flows: large flows will remove even established trees or thick shrubs and will often leave behind large boulders. Any areas within this zone should be avoided. In the absence of any other information, our experience in Nepal has shown that a minimum buffer of 10 m should be established around channels that have a history of debris flows (Figure 3). Even this small step can lead to a major reduction in exposure to debris-flow hazard.

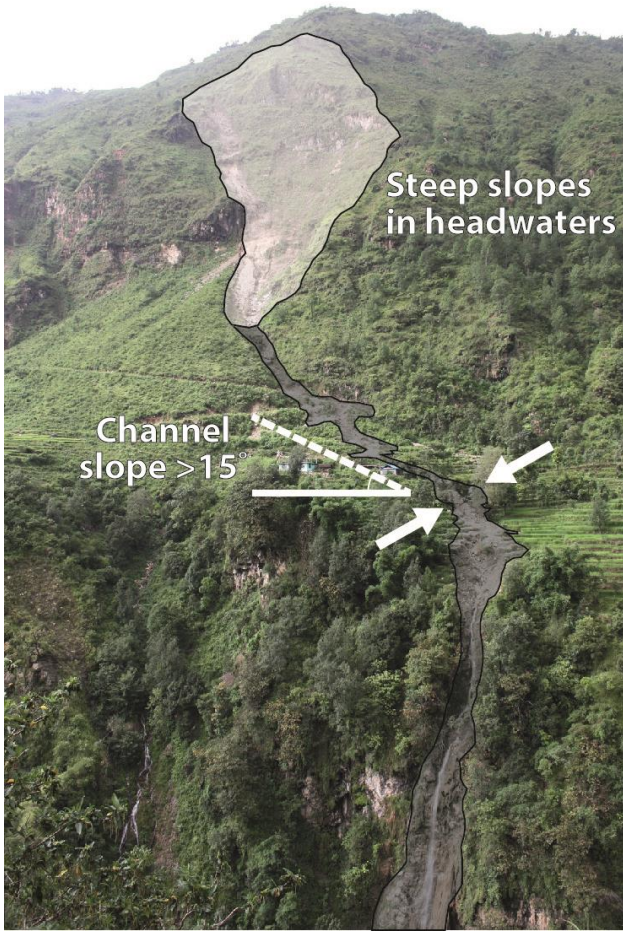

Figure 3. Debris-flow channel in Sindhupalchok District, Nepal, showing (1) channel slope of >15° and (2) steep hillsides in the channel headwaters. The white arrows show the width of the zone that has been disrupted by recent debris flows. This can be estimated by the distance between established vegetation on both banks.

GUIDELINE 3: MINIMISE THE LOCAL SLOPE, BUT NOT AT THE EXPENSE OF INCREASING SKYLINE ANGLE (GUIDELINE 1) OR EXPOSURE TO STEEP CHANNELS (GUIDELINE 2)

In the absence of any other information or guidance, seek to minimise the slope of the ground at your location when making decisions about where to build key infrastructure. Slope is the most important control on where landslides happen, and steep slopes are much more likely to experience landslides than shallow slopes. Thus, an effective way to reduce exposure to landslides is to move to a site with a gentler slope.

Note that sometimes, moving to a site with a lower slope means moving upslope to a ridge crest, rather than down on to a valley floor. Ridge tops often have low landslide hazard, especially if they are broad and fairly flat.

HOW TO USE THESE GUIDELINES

These guidelines do not specify where landslides will occur. Instead, they summarise observations from previous earthquakes that can help to distinguish between areas which are more or less likely to be affected by landslides in any future earthquake. Because landslide hazard varies so much from one location to another, these simple guidelines provide guidance about locations that are best to avoid. Key infrastructure, such as schools or health posts, should ideally be located in areas where landslide hazard is minimised according to Guidelines 1-3. The same consideration should be used for siting houses, markets, or other infrastructure where people are likely to spend considerable periods of their time, or for planning suitable evacuation routes and open spaces for use as evacuation sites or emergency shelters. Of course, this isn't always possible and householders and communities may, understandably, prioritise other concerns relating to livelihood security and wellbeing over landslide exposure. Nonetheless, these simple guidelines provide additional information about hazards that may not have been

directly experienced by a community, enabling a more comprehensive assessment of future risk.

While these guidelines may exclude many areas for development, areas where the guidelines suggest higher landslide hazard – for example, areas with skyline angles of 25° or more, or areas near the banks of steep channels – need not be abandoned or set aside completely. Instead, they can be used for activities that don't require permanent or valuable infrastructure, and that aren't occupied by people for considerable periods of time. For example, these areas could still be useful for agriculture or grazing, or for storage of non-essential goods. The key consideration is to limit exposure to the absolute minimum necessary for sustainable and safe livelihoods.

WHAT TO DO IMMEDIATELY AFTER AN EARTHQUAKE

During an earthquake, it is unlikely that people will be able to move considerable distances to reduce their risk to landslides. When the earthquake shaking stops, however, it is important to reduce exposure to landslides that may happen in the following minutes, hours or days. This is especially important in the first 48 hours after a large earthquake, when powerful aftershocks are most likely, and during heavy rain, when damaged slopes are likely to move or release more rocks and debris. Our research shows that following Guidelines 1-3 above can also decrease exposure to landslides after the earthquake. Even small changes in location (100 m or less) can make a very large reduction in landslide hazard.

In general, after the shaking stops it is best to move as quickly as possible to locations that minimise both skyline angle (Guideline 1) and local slope (Guideline 3) and to stay well away from channels particularly during and immediately after rainfall (Guideline 2). Broad, flat valley floors can be safe, as can broad ridge tops. The guidelines can also be used for identifying suitable open spaces for use as evacuation sites or emergency shelters.

DO THESE GUIDELINES APPLY TO RAINFALL-TRIGGERED LANDSLIDES?

Available evidence from Nepal, as well as other areas affected by recent large earthquakes such as Taiwan and China, shows that the locations of earthquake-triggered landslides provide a good indication of the locations of subsequent landslides triggered by heavy rain. That is, areas affected by earthquake-triggered landslides should be expected to be hit repeatedly by landsliding in later rain storms and wet seasons. It is not yet clear, however, whether these guidelines are a good guide to landslide hazard in areas where no major earthquake has occurred (i.e. in areas susceptible to rainfall-triggered landslides only). Minimising skyline angle (Guideline 1) and staying clear of steep channels (Guideline 2) are important considerations in any steep landscape that experiences landslides. There are important differences, however, between areas that are prone to earthquake-triggered and rainfall-triggered landslides. For example, the latter are more common along river banks and near the base of steep hillsides, whereas the former typically occur higher on hillsides. Again, the guidelines in this briefing note should be used only as a first approach for minimising exposure, especially if more detailed information is not available.

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