Transcript: METEOR Introduction to landslides

Introduction Slide (Slide 3)

In this introduction to landslides I'm going to cover: what is a landslide, how landslides are classified covering different classification schemes, I'm going to give a few examples of landslides. Moving on to what causes landslides. And then, how landslide can be captured in landslide inventories and then how these landslide inventories can be can be used to produce landslide susceptibility maps and the different techniques that can be used and the considerations you need to take into account before choosing your technique.

Slide 4

So what is a landslide? 'Landslides' is an umbrella term that covers a wide variety of processes, but simply put: It is a type of mass wasting commonly defined as a downslope movement of soil and rock under the influence of gravity. There are a number of definitions used in the literature that this one by Cruden (1991) is often quoted.

The block diagram on the left shows a range of geological and geomorphological settings that are subject to landslides; high mountains, submarine slopes as well as coastal cliffs. A number of different types of landslides are shown: rockfalls, debris flows, rock slides and river bank collapses, also rock landslides and soil landslides.

All of these are captured by the term landslide but this variation show highlights the need for a classification scheme, so that all these different types of movement and processes are clear.

Slide 5

Classification schemes help us to use common language to be able to effectively communicate the process we are referring to. It provides internationally recognized terminology. Landslides can be classified by the type of movement, the rate of movements (the speed or velocity), the age or activity of movement.

And this diversity of classification reflects the diversity of processes that we saw in the previous block diagram. There are a number of classification schemes in the literature, including: Varnes, Hungr and Sharp and they are all subtly different.

Hungr recently built on the commonly used Varnes definitions scheme.

Slide 6

This is a relatively simple classification scheme based on type of movement showing five main types, we have fall in the top left where material is detached from a cliff steep slope and then rolls falls or bounces. These are common on cliff's, mountain slope's or river banks and the size is very variable from a few blocks to thousands of meters cubed.

Then we have topple on the top right, this is characterized by a forward rotation of the unit of material. The access of movement is below the centre of gravity. It's common in columnar jointed volcanic rocks, cliffs and stream banks.

We move down a row to slide, this is a downslope movement on a defined surface of rupture or shear surface and there are two main types: rotational (which we see here), where the surface of rupture is curved upward and translational slides which have a planar shear surface, with little rotation or tilting compared to the rotational slide. Translational slides can be quite ubiquitous in the environment and occur widely in a whole range of materials and settings.

Then we have flows. A Flow resembles a viscous fluid with shear surfaces very short lived or not present. There is a gradation of slide to flow with increasing water content and mobility. They occur on steep slopes and gullies around the world, and can comprise: rock fragments, granular material or mixes of debris and water

And then we have our bottom type, which is Spread. Now unlike some of the other types of landslides these occur in gentle, flat terrain and generally with a stronger rock on top of a soil or weaker rock. It involves extension of the stronger rock and often liquefaction is, a cause.

Slide 7

In this classification scheme by Varnes we've also added the type of material. This can add valuable information in our description if we specify rockfall or soil fall and it gives more context and information for our user. Material is divided into: bedrock, debris - which is less than 80% sand and finer and a minor and earth – more than 80% sand and finer.

So we can now say whether our fall is a rockfall, debris fall or an earth fall. Complex landslide has also been added at the bottom of this classification and it involves two or more of the above landslide types combined together, so in this instance they have given the example of a rock avalanche or an earth slide.

Slide 8

In this classification, velocity has been used rather than the type of landslide. So we have on the left our rock landslides, and we have on the right, the unconsolidated material landslides.

Now velocity is important when considering the impacts of a landslide and evaluating hazards. Our landslides range from one centimetre a year (now, these are things like creep, which is in the flow category) and we also have earthflow and slumps, to our moderate velocity landslides. These are one kilometre an hour with a high water content, so debris flows, mud flows and also rock slides and debris slides. And then we have fast landslides, five kilometres an hour or more with a high air content so these are rock avalanches rockfalls and debris avalanches.

Slide 9

In this classification, the activity of the landslide this shown. So active is straightforward, the landslide is currently moving, whereas a suspended landslide have moved in the last 12 months but it's not currently active. A reactivated landslide are those that are active, but had previously been inactive, so we can see in the reactivated landslide, we have our block that’s fallen down into the river or the sea from the bluff and then we have a reactivation, another block falling onto of it.

Then we move into are inactive category, so our inactive slides haven't moved in the last 12 months. Now they can be dormant, so inactive but could be reactivated by the original cause, so here we have our block material that’s fallen into the water now if this was eroded away then we could see how the landslide could be reactivated again. Then we have abandoned, so this is no longer affected by the original cause, so maybe water levels have changed and it's no longer being undercut. Then we have stabilized landslides, now these have been protected by remedial measures, so they might have been pinned or toe protection might have been added.

And then we have relict, so these are inactive they've developed under different geomorphological or climatic conditions, and you can see how this one's been re-vegetated by trees and with a much more subdued topography. We have many of this type of relict landslides in the UK that were active during the quaternary when climatic conditions were very different.

Slide 10

Okay, so a couple of pictures here of actual landslides that have happened in Nepal. I've started off with rainfall trigger landslides and these happened in the monsoon. These are on obviously very steep slopes in more unconsolidated material and we're looking at shallow landslides, debris flows and debris sides, and these have been both confined within channels and gullies which you can see but also opens failures as well.

Slide 11

In this slide we're looking at failures in rock and these have been triggered by earthquakes. So we have rockfalls on the left, we can see all the individual blocks of varying different sizes, that have fallen down or rolled or bounced onto this road and damaged these cars and the houses. On the right hand side, we have a rock slide which has blocked the river.

Slide 12

Just like in the previous slide this landslide has blocked the river. This is the Sunkoshi landslide which occurred in August 2014. And what I put this in for is, I wanted to highlight the fact that sometimes an event can lead to a cascade of hazards. So in this case heavy rain or an earthquake can trigger a landslide which dams a river which when breached leads to an inundation of downstream areas.

This is to highlight the fact that it's not always possible to study landslides in isolation, we will need to consider what triggers the event and also the consequences.

Slide 13

We're moving on now to what causes landslides, now ultimately that's gravity, all slopes are under stress and within the slope there are forces promoting movement downslope and opposing forces resisting that movement. If the resisting forces are greater then the slope is stable. If the destabilising forces are greater then movement will take place. Let's imagine a block of material, like in the diagram, resting on a slope, which gravity is acting on, normal stress is pushing the block into the hillside and resisting movement down slope. Shear stress is acting to push the block down the hill. The greater the normal stress the greater the frictional resistance. The greater the stress parallel to the slope, the greater the shear stress.

In this example the angle of the slope increases in the right hand side of the diagram thus increasing the shear stress once this over comes the normal stress movement occurs.

The forces resisting movement, are grouped together a shear strength, which include: frictional resistance and cohesion. These two factors are affected by: soil, rock type, weathering, presence of week surfaces and pore pressures within the slope.

We use the term factor of safety, to express the balance of resisting and driving forces. Shear strength divided by shear stress gives us a factor of safety. Factor of safety of more than one and the slope is stable, less than one and the slope is unstable and factor of safety will be one at the point of failure. Factor of safety can vary over time.

Slide 14

So what are the actual processes that can cause a landslide? These can be divided in a number of ways.

We think first about factors that precondition a slope to failure, these influence the inherent stability of a slope so examples would be: a very weak plastic geological material making up the slope.

There are then the preparatory factors that reduce the stability over time, so an eroding river or vegetation removal. These are tipping the balance towards the driving forces but it's not enough yet to trigger the failure.

Then we have the triggering event so heavy rain or strong earthquake these initiate failure. Terzaghi differentiated between internal changes that reduce the shear strength and external causes that increase the shear stress. Often a landslide will have have multiple causes, but only one trigger.

Slide 15

When considering these different causes it is useful to think of our slope in one of three different states: stable, marginally stable and actively unstable.

So, imagine a stable slope with intact, strong rock at a relatively low angle. It's unlikely a trigger such as an earthquake or heavy rain will initiate failure. If this slope was a bit steeper, though, and the rock slightly weaker with more discontinuities it's easier to imagine how a trigger (that’s big enough) could initiate a failure and slope would become actively unstable.

So now we're going to have a look at this graph here, which is imagining a slope over time and it uses factor of safety to track the change in state. Our slope is stable, but it’s gradually reducing the factor of safety due to weathering. Heavy rainfall leads to a drop in the factor of safety, but this is then recovered when the slope dries out. Our slope is still stable. Now imagine an intense erosion event which leads to a big drop in the factor of safety, this is considered our preparatory factor. Our slope is now marginally unstable and it's also being impacted by continuing rainfall. Once a trigger event occurs, so in this case overloading of the upper slope, failure occurs and our factor of safety is one at this point and our slope becomes actively unstable.

Slide 16

The working party of the world landslide inventory grouped causes into those that were: ground conditions, geomorphological processes, physical processes and anthropogenic processes. In this slide I’ve highlighted the preconditioning factors in read, all of which fall under ground conditions.

Slide 17

These factors in red are preparatory factors
. There is: erosion, deposition, vegetation removal and excavation. Earthquake can be both a preparatory and a trigger. Some factors can also be preconditioning and preparatory factors.

So slope for example is a preconditioning factor for all landslides but a change in slope, by erosion, for example is considered a preparatory factor.

Slide 18

Those factors shown now in red are our triggers, and these are the ones which actually start the movement of the landslide happening. So we're looking at things like intense rainfall, snow melt or earthquakes (with the earthquake, increasing the shear stress) of the slope.

Slide 19

I'm now going to focus on two triggers that are important to the METEOR work. The first is rainfall triggered landslides.

Triggering rainfall can take different forms, intense short duration events or periods of prolonged rainfall, such as during the monsoon. In soils the type of landslides triggered by rainfall can be influenced by these characteristics of intensity and duration. Shallow slides and flows triggered by shorter duration intense events (often) and larger deeper seated failures, which will require a build-up of antecedent rainfall.

During a storm, rainfall rapidly infiltrates this slope leading to a saturation of the soil and a temporary rise in pore water pressure, which can trigger these shallow landslides. The water in the slope acts to oppose normal stress, a resistant force, and reduces the effective normal stress of the slope. Water also increases the mass of material on the slope and, in turn, the gravitational pull. We've seen evidence for intense rainfall triggering debris flows in materials with high permeability in the sub-Himalayan zone of western Nepal.

Slide 20

Next we will look briefly at earthquake triggered landslides. Earthquake induced landslides can occur due to: ground shaking, liquefaction or shaking induced dilation of sediments which allows rapid infiltration of water. Earthquakes trigger different styles of movement but its predominantly falls, soil slides and rock slides and we also saw different types of landslides for different slope angel so rockfalls or soil rock slides on steeper slopes and earth spreads or slumps triggered on gentler slopes.

The intensity of earthquake triggered landslides depends on the magnitude of the earthquakes, the higher the magnitude, the greater the lands on intensive may trigger. Studies also suggest that most landslides are triggered by earthquakes of a moderate to high magnitude and that most of these landslides do not occur beyond a certain distance from the source of the earthquake.

Slide 21

Moving on from what causes landslides to how we record them. So a landslide inventory map, captures the location of landslides and a study area. These can either be a point usually recorded at the highest point of the landslide, on the back scar or a polygon depicting the outline of the whole landslide mass. So, ideally, you want to capture extra information rather than just the location, so you might want: the date, the activity state and also the type of landslide.

Numerous ways exist to create a landslide inventory and the techniques used will be dependent on the scale of a study area and its subsequent use. Techniques commonly used include stereo-air photo mapping, satellite image interpretation – obviously suited to capturing the outline of events over larger areas. As well as direct field mapping, which is obviously suited to a smaller study area unless there's considerable resources available. We've also seen a rise in the use of social media citizen science and harvesting of news reports. These can offer information if you want to keep updating an inventory without direct mapping or if you don't have access to multi temporal imagery.

Some authors differentiate the style of imagery based on how the events have been mapped, so an archive inventory will have been produced through searches of archives, such as reports newspapers and journals.

Geomorphological inventories have been created using direct mapping techniques and capture events either historically, so all landslides regardless of age, or they can capture events associated with the monsoon or a single trigger event.

Slide 22

Brabb defined multiple uses for inventory maps which I will flag up, before focusing on susceptibility maps. So, inventory maps can provide valuable information on the distribution, type and pattern of landslides, in an area, which is really useful information for planning purposes or for civil contingency.

Inventories form part of the study of the evolution of an area by mass wasting and are a preliminary first step towards susceptibility, hazard and risk assessment.

Slide 23

So landslide susceptibility here is defined as the quantitative or qualitative assessment of the spatial distribution of landslides which exists or potentially may incur in an area. Susceptibility shows the likelihood of an area being subject to landslide, sometimes described as the spatial probability. It gives use the ‘where’ for hazard assessment, but not the ‘when’ or the magnitude of future failures and it can be expressed qualitatively: high, medium, moderate, low susceptibility. Or quantitatively.

So our susceptibility takes our inventory map and it moves it a step on and it expands it to fill in the gaps to depict areas where landslides could occur but either haven't been mapped yet or haven’t occurred yet. Susceptibility is determined by correlating the predisposing factors of an area such as: geology, slope, elevation, distance roads with the inventory of past events. It is therefore important if you're using an inventory to create a susceptibility map to have a detailed and spatially representative inventory.

Landslide susceptibility mapping is founded on the principle, the past is the key to the present and it assumes a level of static conditions. If there is active quarrying, forestry or road bulding, or even climate change then this should be taken into account

Slide 24

There are various techniques for producing a landslide susceptibility map and there is a wealth of scientific literature on this matter. What I’ve tried to do here is to separate the methods into qualitative and quantitative, so the different types there in the blue circles and then all around them are some of the things that you need to take into account when deciding on the technique that you will use in your study.

So your chosen technique will be influenced by the size of your study area. So, are you looking at national scale study, or is it regional, local or site. Now all of those will need to be taken into account when you're choosing your methodology, because not all of these different methods as suitable to be used at every single scale.

You also want to look at the type of landslide that you're looking at. So, do you need to look at the initiation of the landslide as well as the runout. So will, you need to look at both of those in your susceptibility. You also need to look at the objectives of the study, do you require a level of objectivity about the results. And also how complex is the study area and how varriable are the factors and how do they change spatially. If there is not a lot of spatial variability it will be less useful for some of the statistical methods that can be used.

Data availability also plays a significant role as some of the techniques are data intensive. Resource availability, such as computing power and time are also a factor in considering what method you will be choosing. So if we have a look now at the qualitative methods we have heuristics (index based) and geomorphological mapping.

Heuristic methods rely on the expert assigning weights to the thematic data which reflects their knowledge of an area and of a process. There's quite a high level of subjectivity and both of these methods. In geomorphological mapping the susceptibility is assigned directly based on geomorphological evidence of instability features.

In our quantitative methods these are less subjective and they involve less reliance on expert judgment and based more on the data. Deterministic approaches model the process and can be very data intensive requiring a lot of input data on geotechnical and hydrological properties, and they often use slopes stability software. In statistical approaches a combination of landsat occurrence and predisposing factors is carried out, statistically. This can be used as either bivariate or multivariate statistical techniques. Analysis of inventories can be carried out through creation and landslide density maps, for instance.

Slide 25

As well as an inventory of landslides and a detailed knowledge of your area and also the landslide types and process that are occurring it's also necessary to have thematic data to input into your susceptibility model. There is a tendency to use any data which can be generated or gathered and it's important that the data that you choose is relevant to your study area and also to your landslides. In a review by Reichenbach all the thematic data which had been used in susceptibility models published in the literature were looked at and analyzed and it was grouped together in this grid that I've put on this side.

Now the thematic data was grouped by five different types: geological, hydrological, land cover, morphological and other different types.

This really gives you a feel for the diversity of factors which have been included in many susceptibility maps, but also the common themes and the common landside thematic data which has been used.

So we can see here that slope and geological lithological factors are by far the most common, as you would expect, and then also we have things like: aspect, land cover, curvature and elevation as well.