Failing slopes
Modelling how rock cliffs and slopes can collapse

Slope failure by toppling and slipping

Rocks with horizontal bedding tend to be fairly stable, but when they dip at an angle they are less stable, particularly if they have vertical fractures or joints. The type of collapse usually depends upon the rock type and thickness of the beds.

Cliffs and slopes of sedimentary rocks can collapse in several ways, but two of the most common are toppling failure (Figs 1 and 2) and bedding plane slip (Fig 3).

Figure 1. Toppling block failure where blocks of Chalk rock have fallen from the cliff top. Hunstanton Cliffs, Norfolk, UK.

Figure 2. Alternating sandstone/shale sequence, where large and small blocks of sandstone topple and fall. The beds are dipping towards the camera. Mam Tor, Derbyshire, UK.

Mam Tor is formed of a Carboniferous age sandstone/shale rock sequence and is sometimes called the ‘Shivering Mountain’ because of the sandstone blocks which regularly topple and rain down onto the scree slopes at the foot of the face.

The effect of bedding plane slip is clear in Fig 3, where a massive block of Torridonian Sandstone has slid down the bedding plane, probably on a thin layer of mudstone.

Figure 3. Bedding plane slip. The rock shaped like a shark’s fin has slid down the bedding plane and into the sea. Clatchtoll, Sutherland, Scotland.

The bedding plane slip process can be seen ‘in action’ where road cuttings cut through dipping rocks (Fig 4). Often the rocks have to fixed in place (stabilised) using rock bolts or netting (Fig 5).

Figure 4. A road cutting through rocks which are dipping from right to left. The rocks on the right could easily slide down the bedding plane but the rocks on the left are relatively stable as they dip into the hillside.

Figure 5. Rock bolts and netting being used to stabilise rocks on a slope in the A5 Ty Nant Cutting, North Wales.

Modelling slope failure – competent materials
Rocks behave in a competent way when they move as one mass.


Figure 6a. Modelling failure in competent rocks – sliding.

- Make a clinometer like the one shown in Figure 6a or use a clinometer you have available.
- Attach the clinometer to a board, e.g. by using a bulldog clip.
- Place the box of cards flat and to one side of the board.
- Gently raise this end of the board and record the angle at which the box begins to slip, as in Figure 6b. Take at least four measurements and use these to calculate the mean angle of slip. Record the results in Table 1.
- Repeat, putting the box of cards in different orientations, e.g. on its long and short sides both perpendicular to and parallel with the direction of slope. Record the results in the table.
- Stick a piece of sandpaper to the board and repeat the investigations.


Figure 6b. Modelling failure in competent rocks – sliding.

Modelling slope failure – incompetent materials
Rocks move in an incompetent way when they break up and/or flow during movement.


Figure 7b. Modelling failure in incompetent rocks – sliding.

- Remove the stack of cards from the box and repeat the investigation to model how incompetent rocks fail.
- Repeat using the stack of cards with the empty box on top.
- Stick a piece of sandpaper to the board and repeat the investigations.


Figure 7b. Modelling failure in incompetent rocks – sliding.

Key questions
Ask your pupils to answer these questions using the results recorded in the Table.
- What are the differences between the angle of slope failure for the different situations?
- Is there any difference between the angle of slope failure when the sandpaper is used?
- Why may this be? (*The sandpaper has increased the frictional force between the board and the objects)*
- In a real life situation, what effect might water have? (*It might reduce friction and encourage failure)*
- What other factors may influence the failure of slopes in the real world? (*Frequency of bedding planes, joints and other fractures; roughness of bedding plane and joint surfaces; direction of a cutting in relation to the direction and amount of dip of the beds).*

Experiment	Smooth board		Board with sandpaper	
	Angle of failure °	Kind of failure	Angle of failure °	Kind of failure
Box of cards flat				
Box of cards on long end perpendicular to slope				
Box of cards on short end perpendicular to slope				
Box of cards on long end parallel to slope				
Box of cards on short end parallel to slope				
Stack of cards				
Stack of cards and with the box on top				

Table 1. Blank table for recording the results of the different experiments.

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The back up

Title: Failing slopes

Subtitle: Modelling how rock cliffs and slopes can collapse

Topic: Investigating the factors which affect the angle of slope at which materials fail and slip.

Age range of pupils: 11 - 18

Time needed to complete activity: 30 minutes

Pupil learning outcomes: Pupils can:
- take a series of measurements using a clinometer;
- look for patterns within their measurements;
- understand some of the ways in which competent and incompetent rock slopes may fail;
- explain how friction may influence the angle at which failure of rock masses occurs.

Experiment	Smooth board		Board with sandpaper	
	Angle of failure °	Kind of failure	Angle of failure °	Kind of failure
Box of cards flat	20	Bedding plane slip: competent beds	52	Bedding plane slip: competent beds
Box of cards on long end perpendicular to slope	14	Toppling failure: competent beds	10	Toppling failure: competent beds
Box of cards on short end perpendicular to slope	5	Toppling failure: competent beds	5	Toppling failure: competent beds
Box of cards on long end parallel to slope	25	Bedding plane slip: competent beds	45	Bedding plane slip: competent beds
Box of cards on short end parallel to slope	17	Bedding plane slip: competent beds	28	Toppling failure: competent beds
Stack of cards	6	Bedding plane slip: incompetent beds	8	Bedding plane slip: incompetent beds
Combination of cards and box	5	Bedding plane slip: competent & incompetent beds	8	Bedding plane slip: competent & incompetent beds

Table 2: Mean angles obtained from an actual investigation.

Context:
The activity could be used in a lesson on slope failure itself, or as an application of the physics of friction. Results obtained from an actual investigation are shown in Table 2.

Following up the activity:
Try other related Earthlearningidea activities, e.g. Sandcastles and slopes: Landslide through the window: Dam burst danger.
Look for real examples of potential rock failure, or for preventative measures in your own locality.

Underlying principles:
- Beds of rock are referred to as "competent" when the bedding planes are widely spaced, e.g. >30cm, and the rock is relatively strong, e.g. many sandstones.
- "Incompetent" beds are much more thinly bedded and they readily slip over each other, or become soft when they get saturated with water, e.g. shale.

Thinking skill development:
Investigating the movement of the objects involves skills of constructive thinking. Cognitive conflict arises when pupils find that angles of failure are not what they expected. Applying the investigation to real slopes requires bridging skills in pupils' thinking and may have an impact on their daily lives.

Resource list:
- clinometer – see note below
- large board, (preferably smooth board/plastic)
- box of playing cards
- sheet of sand paper
- large bulldog clips to attach the clinometer and sand paper to the board

Note: A clinometer can be made from a photocopy box lid (or similar). Draw a semicircle onto the lid, as shown in the figures. Pierce a very small hole through the box at the centre of the horizontal. Add the angles in degrees (note that the clinometer shown in the photos is different from most school protractors, which have 90° at the midpoint – here the mid-point has a dip of 0°). The plumb line is made from thin string and a large nut/washer. Thread the string through the hole from front to back. Tie the string to a paperclip on the reverse of box to prevent the knot coming through the hole and use sticky tape to fix it into position.

Useful links:
http://www.bgs.ac.uk/landslides/
http://www.geolsoc.org.uk/Geoscientist/Archive/June-2013/2012-Landslide-year
http://landslides.usgs.gov/

Source: This activity was devised by Hazel Clark, Liverpool John Moores University. All photographs by H.E.Clark.