The Catastrophic Shenzhen Landslide of December 20, 2015

by

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International Geotechnics Symposium cum
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November 14-17, 2016, Hong Kong

中国岩石力学与工程学会
Chinese Society for Rock Mechanics and Engineering

香 港 大 學
THE UNIVERSITY OF HONG KONG

China landslide

Digital Journal

Landslide swept through an industrial park in Shenzhen city on Dec 20

http://www.digitaljournal.com/news/world/china-landslide-leaves-27-missing-sparks-gas-explosion/article/452690

- Dozens of people missing
- More than 30 buildings buried in a sea of mud
- Nearly 3,000 armed police and firefighters deployed to assist with rescue operations

- Landslide ruptured a natural gas pipeline and triggered an explosion *(State media)*
- Landslide caused by improper storage of waste soil from construction sites *(Official paper of Ministry of Land and Resources)*

- **73 fatalities, 4 missing and 17 injured**
- **33 Building collapsed**
- **including 14 industrial buildings, 2 office buildings, 1 Restaurant, 3 factorial residential buildings, other 13 lower story buildings,**

How a Hill of Dirt and Debris Collapsed in a Landslide in Shenzhen

By DEREK WATKINS, DEC. 21, 2015, The New York Times

http://www.nytimes.com/interactive/2015/12/21/world/asia/shenzhen-landslide-maps-photos.html

November 2013, two years ago, it was a **quarry** pit with pool.

The New York Times | Sources: Past imagery by DigitalGlobe via Google Earth. Photo by European Pressphoto Agency.

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November 2014, a man-made fill slope grew as filling of excavated CDV/CDG soils into the former quarry pit.

The New York Times | Sources: Past imagery by DigitalGlobe via Google Earth. Photo by European Pressphoto Agency.

How a Hill of Dirt and Debris Collapsed in a Landslide in Shenzhen

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http://www.nytimes.com/interactive/2015/12/21/world/asia/shenzhen-landslide-maps-photos.html

December 20, 2015, After nearly two years, the fill soil gave way, destroying several buildings as it slid down the low hillslope.

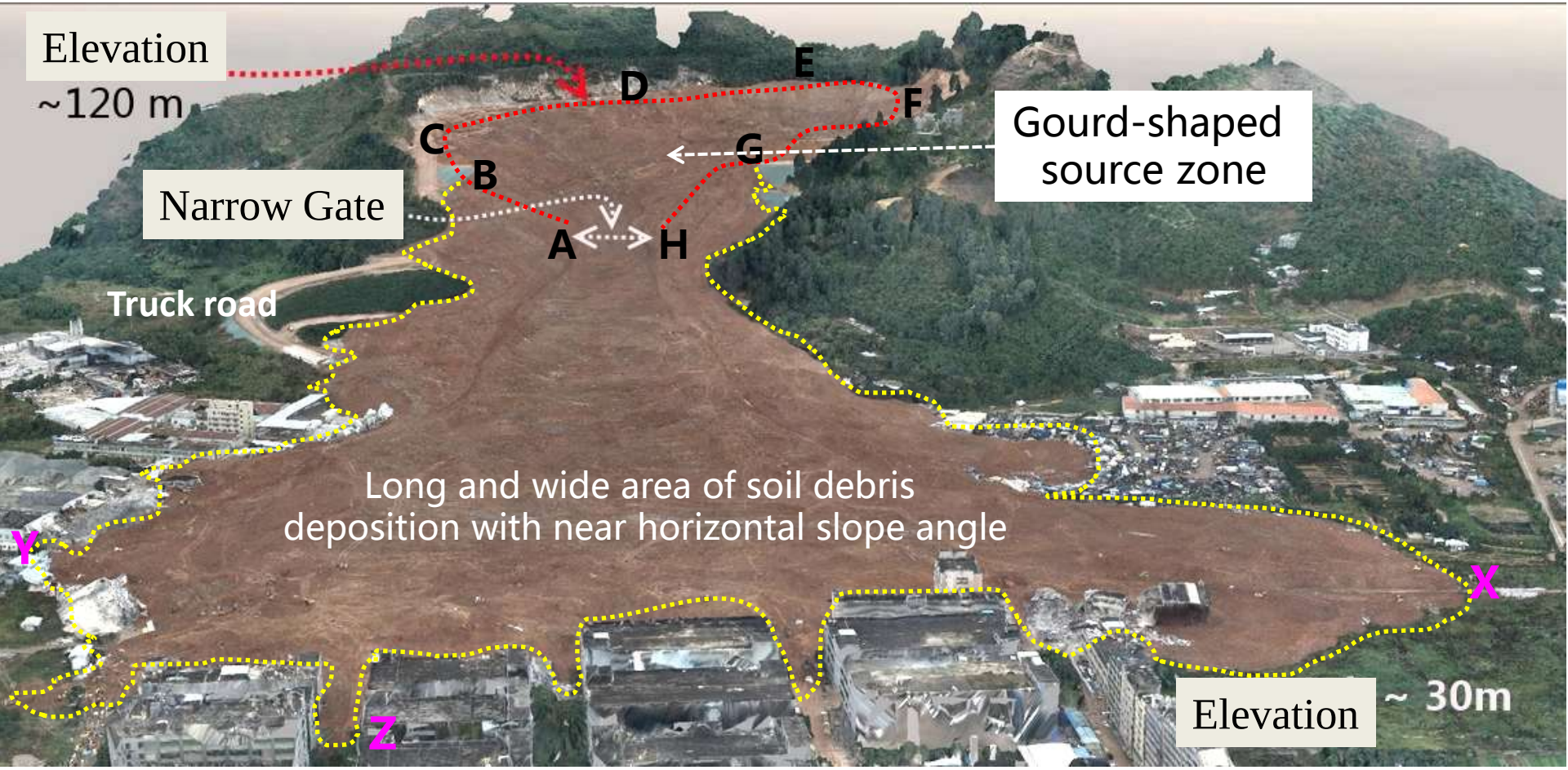
The adjacent natural hill did not slide, according to a geological report issued by the Ministry of Land and Resources on 21 December, 2015.

Site-video by myself on Dec. 23, 2015

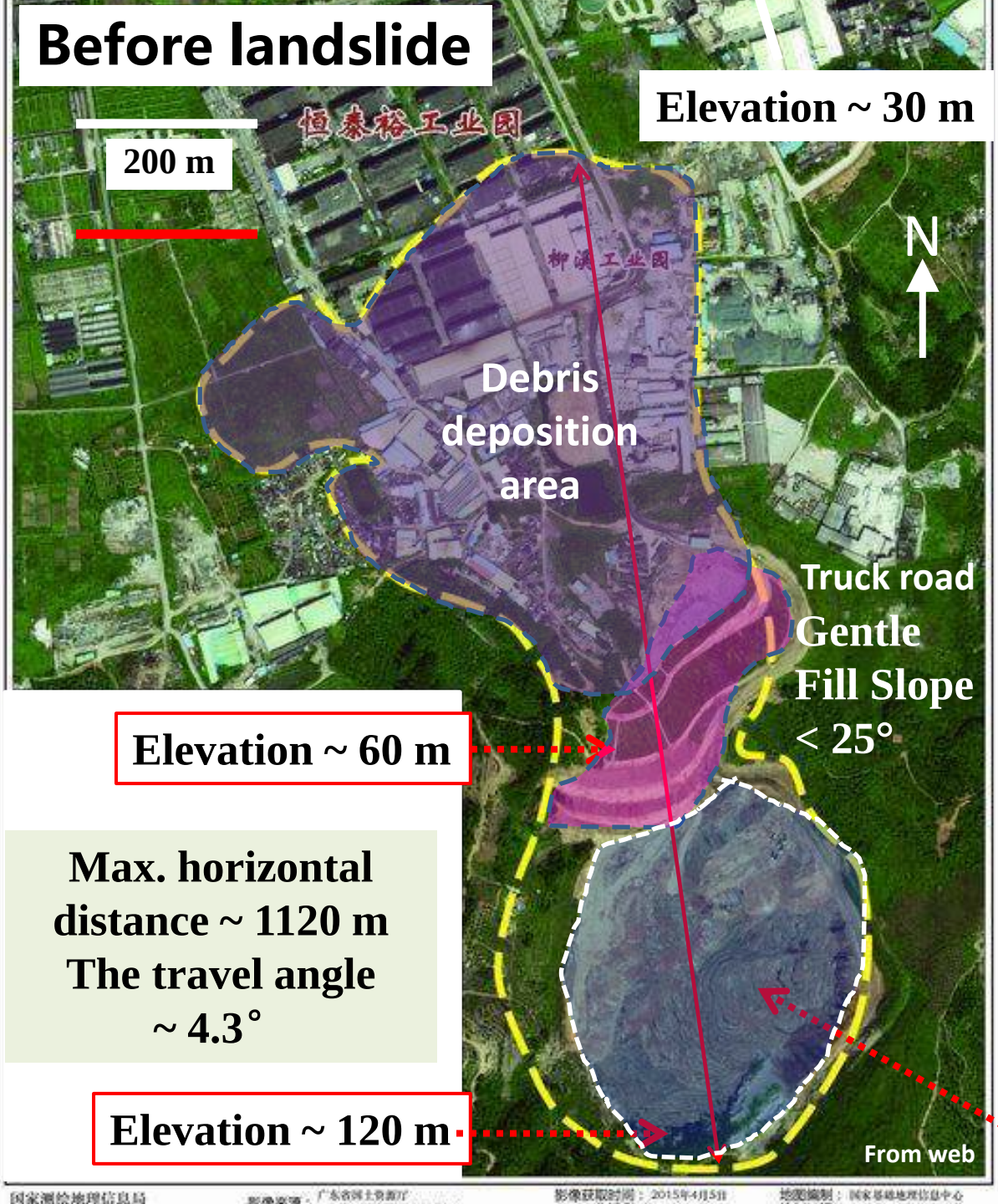
The Source zone

The Debris Deposition zone

A site view from debris toe to the crest of landslide



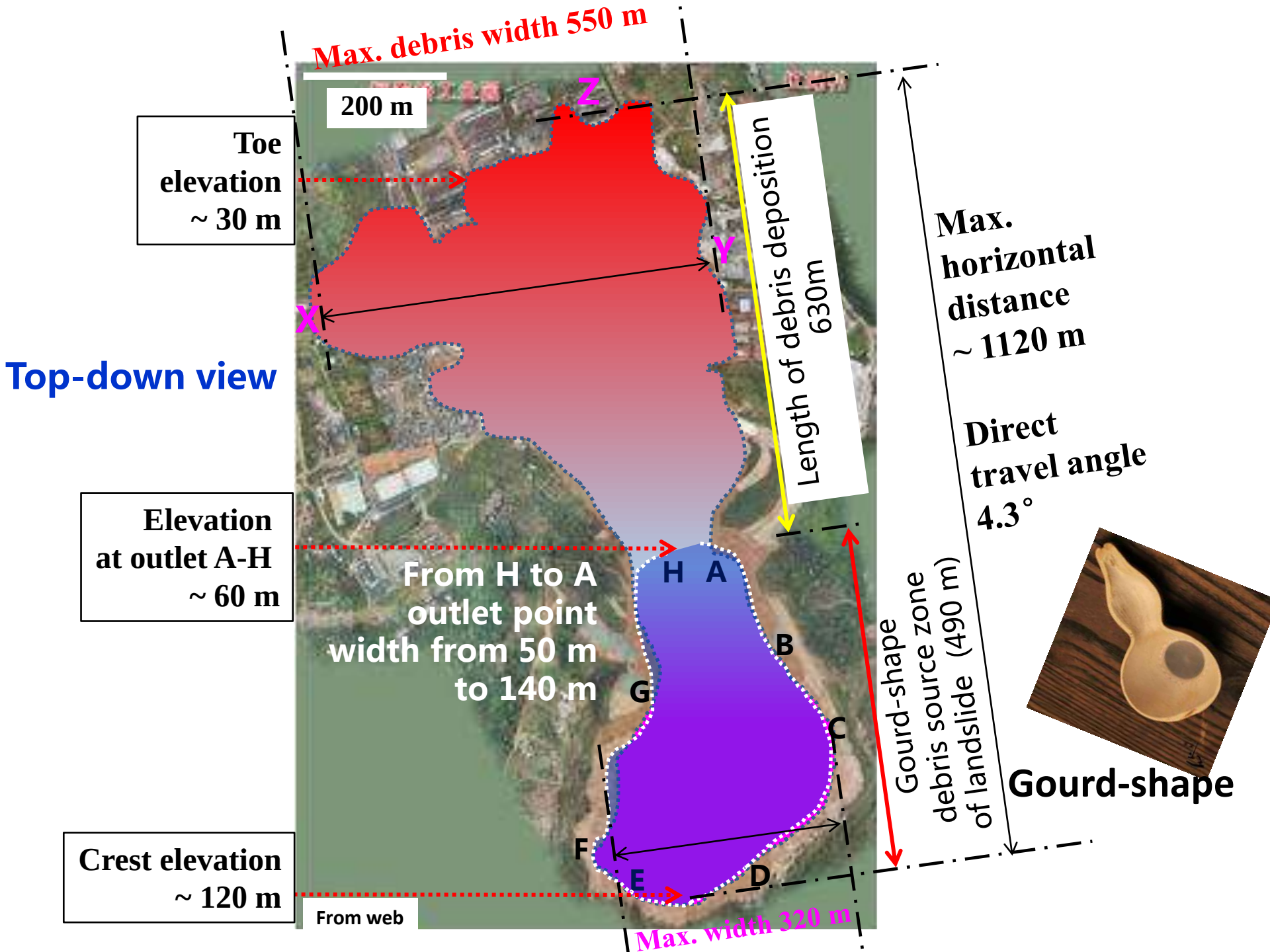
Buildings in front of the debris flow became check-dams against impacting of rapidly moving debris of 10 m thick.

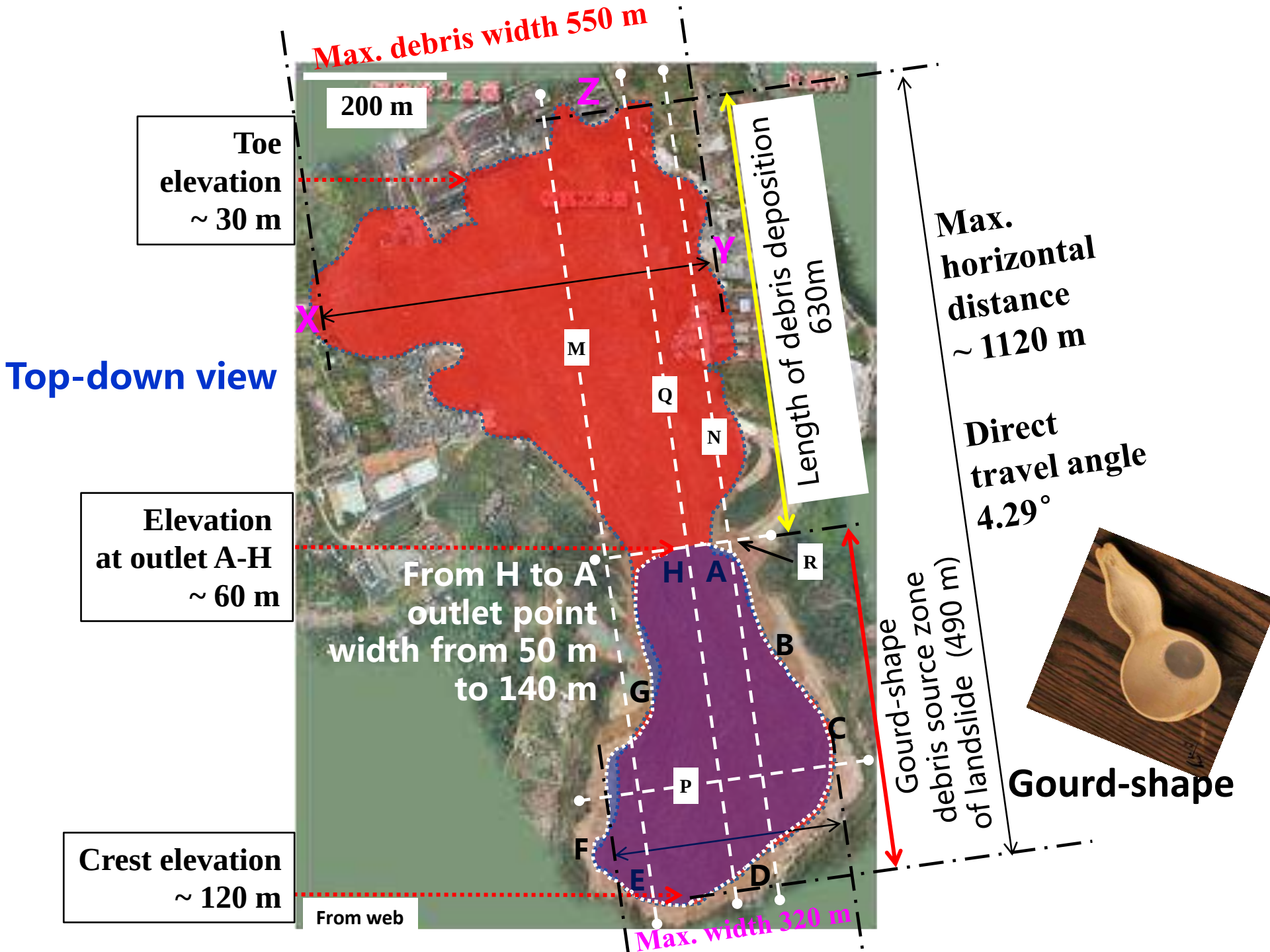


葫蘆瓢

Gourd-shape

The fill pit platform


Max. debris width 550 m
200 m
Z
Y
X
Toe elevation ~ 30 m
Top-down view
Length of debris deposition 630m
Max. horizontal distance ~ 1120 m
Direct travel angle 4.3°
Elevation at outlet A-H ~ 60 m
From H to A outlet point width from 50 m to 140 m
H
A
B
G
C
F
E
D
Gourd-shape debris source zone of landslide (490 m)
Gourd-shape
Crest elevation ~ 120 m
From web
Max. width 320 m


Max. debris width 550 m
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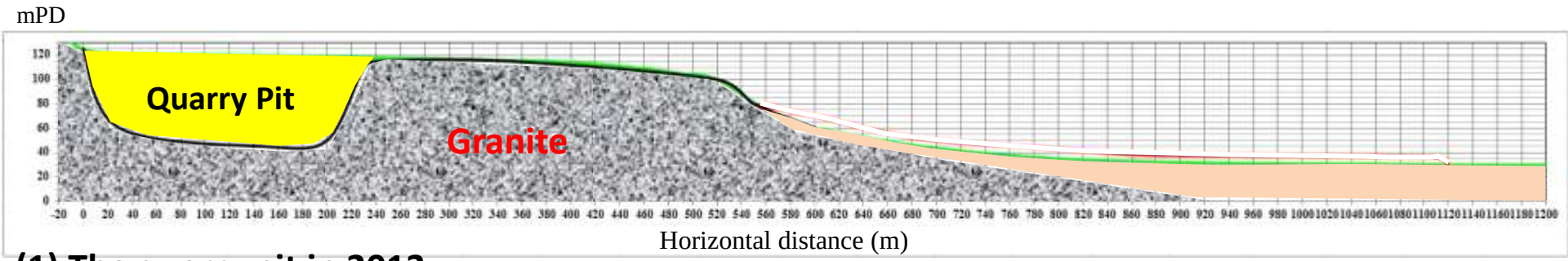
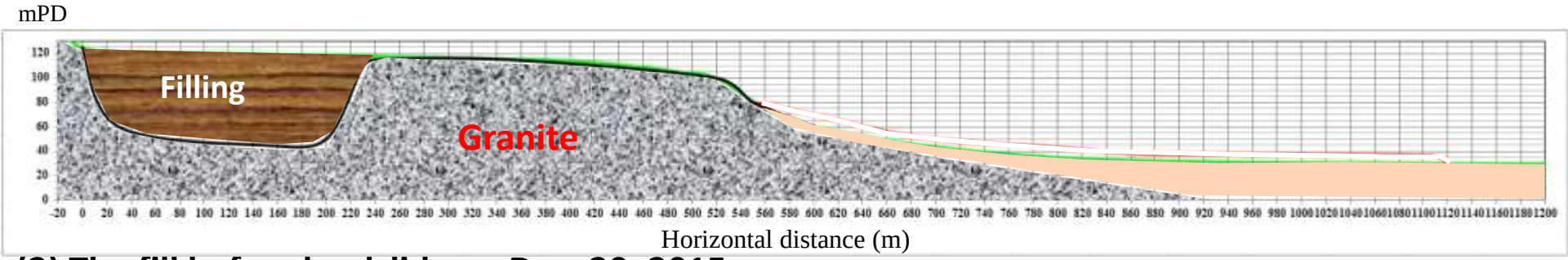
Length of debris deposition 630m
Max. horizontal distance ~ 1120 m
Direct travel angle 4.29°
Gourd-shape debris source zone of landslide (490 m)
Max. width 320 m
Gourd-shape

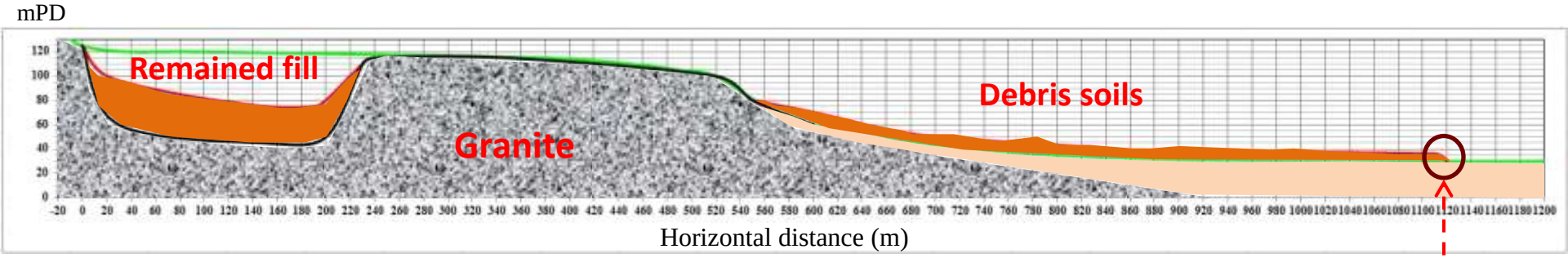
Longitudinal Section M on West



(1) The quarry pit in 2013

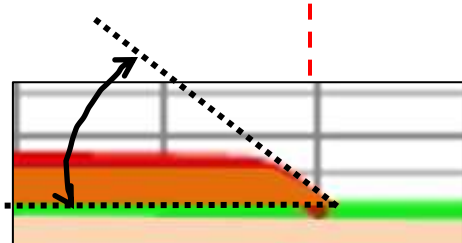


(2) The fill before landslide on Dec. 20, 2015

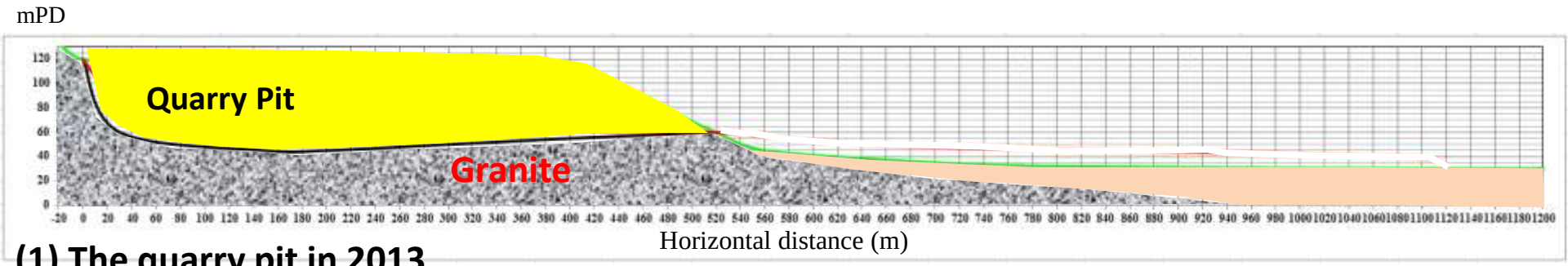


(3) The failed slope after landslide on Dec. 20, 2015

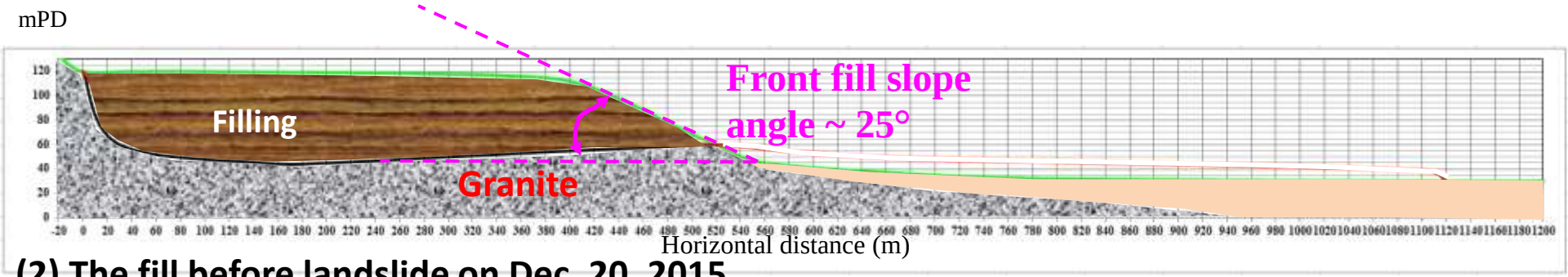
Angle of repose $\lambda > 20°$
of debris deposition



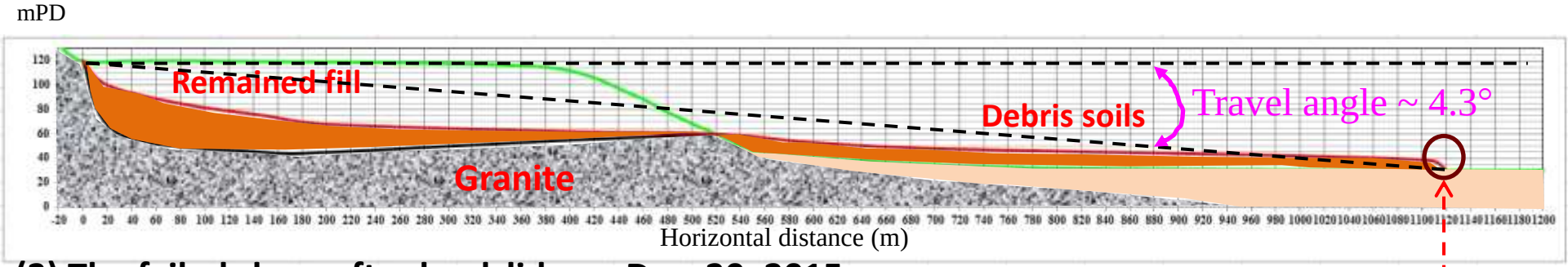
Longitudinal Section Q at Centre



(1) The quarry pit in 2013



(2) The fill before landslide on Dec. 20, 2015



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Angle of repose $\lambda > 20°$
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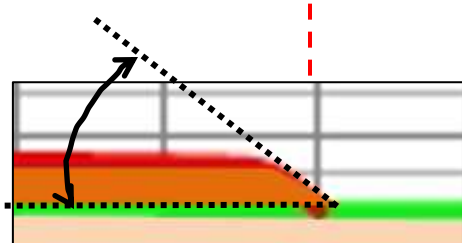
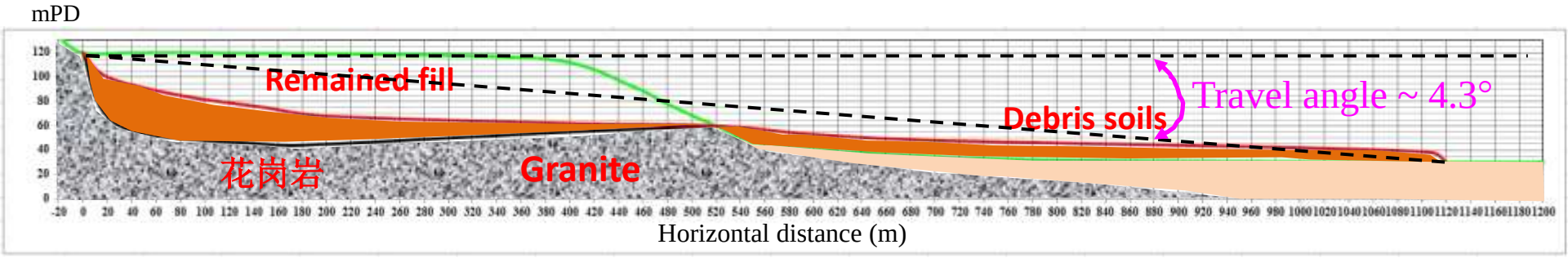
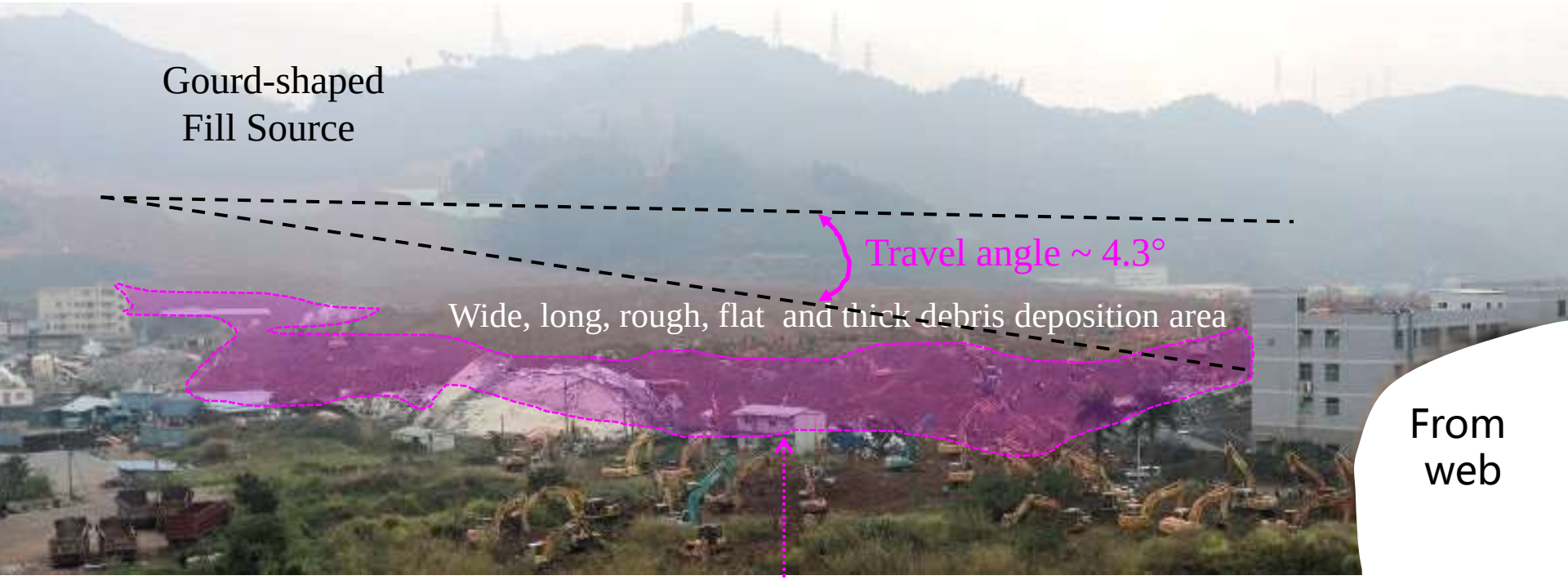


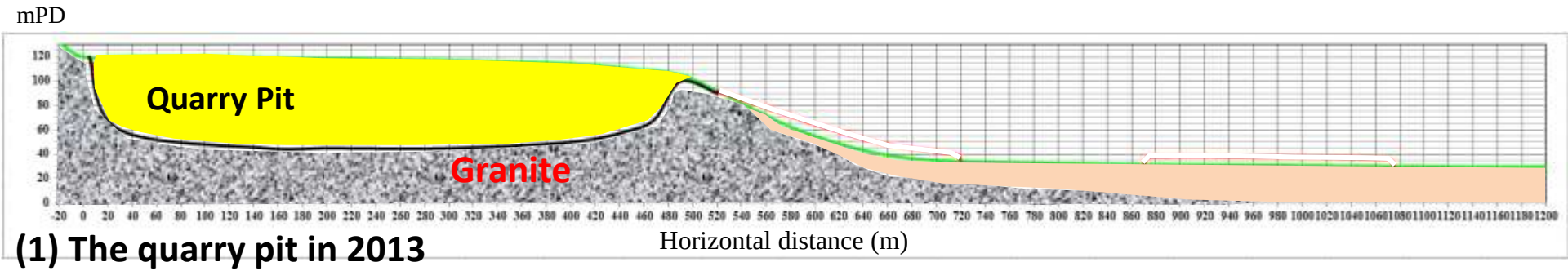
Longitudinal Section Q Versus Site Photograph



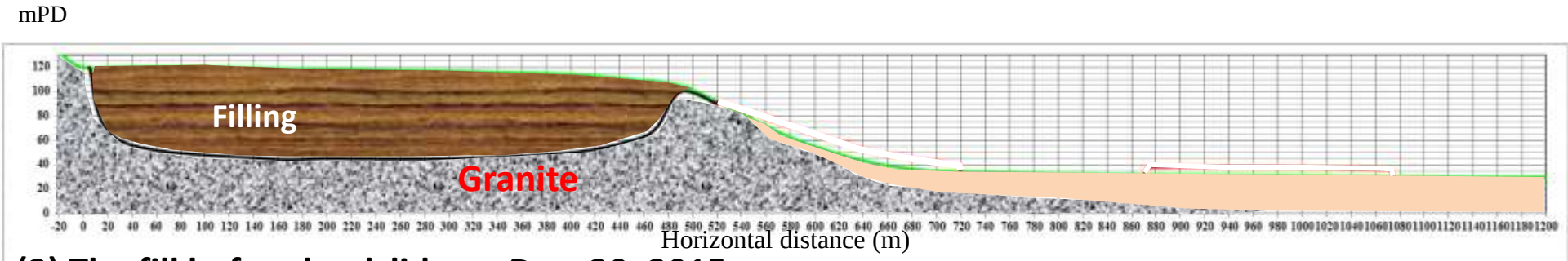


Angle of repose λ> 20° of the side and front toes of thick debris deposition

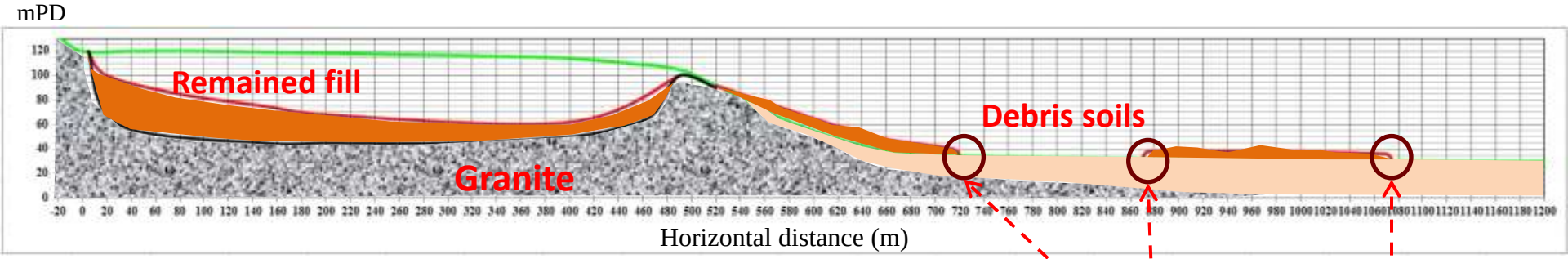
Longitudinal Section N at East



(1) The quarry pit in 2013

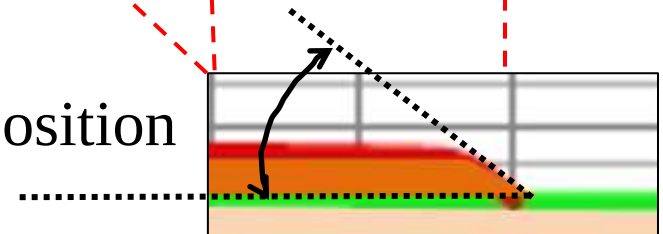


(2) The fill before landslide on Dec. 20, 2015



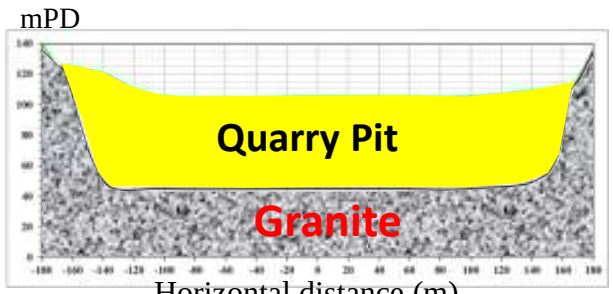
(3) The failed slope after landslide on Dec. 20, 2015

Angle of repose $\lambda > 20°$ of debris deposition

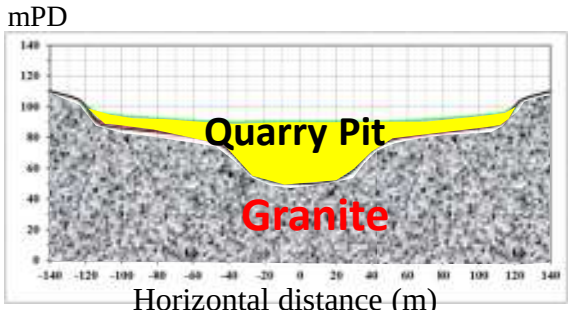


Longitudinal Section N at East

The widest section P



The narrowest section R



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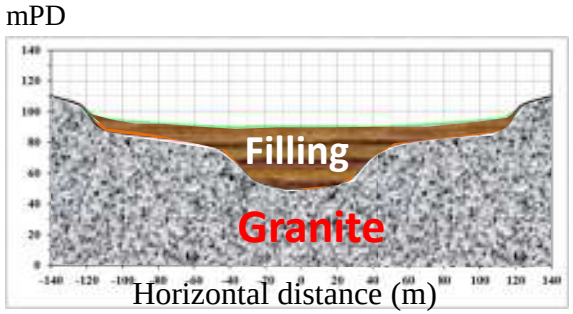

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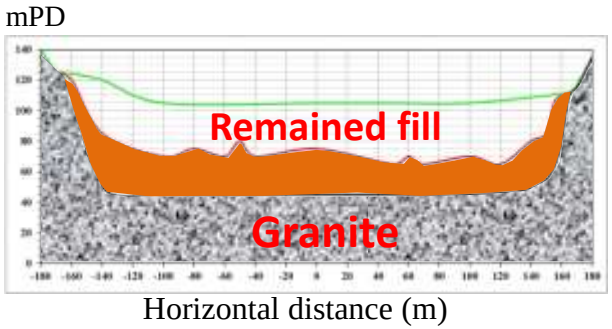
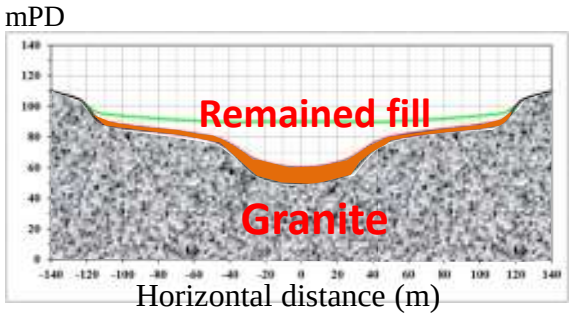
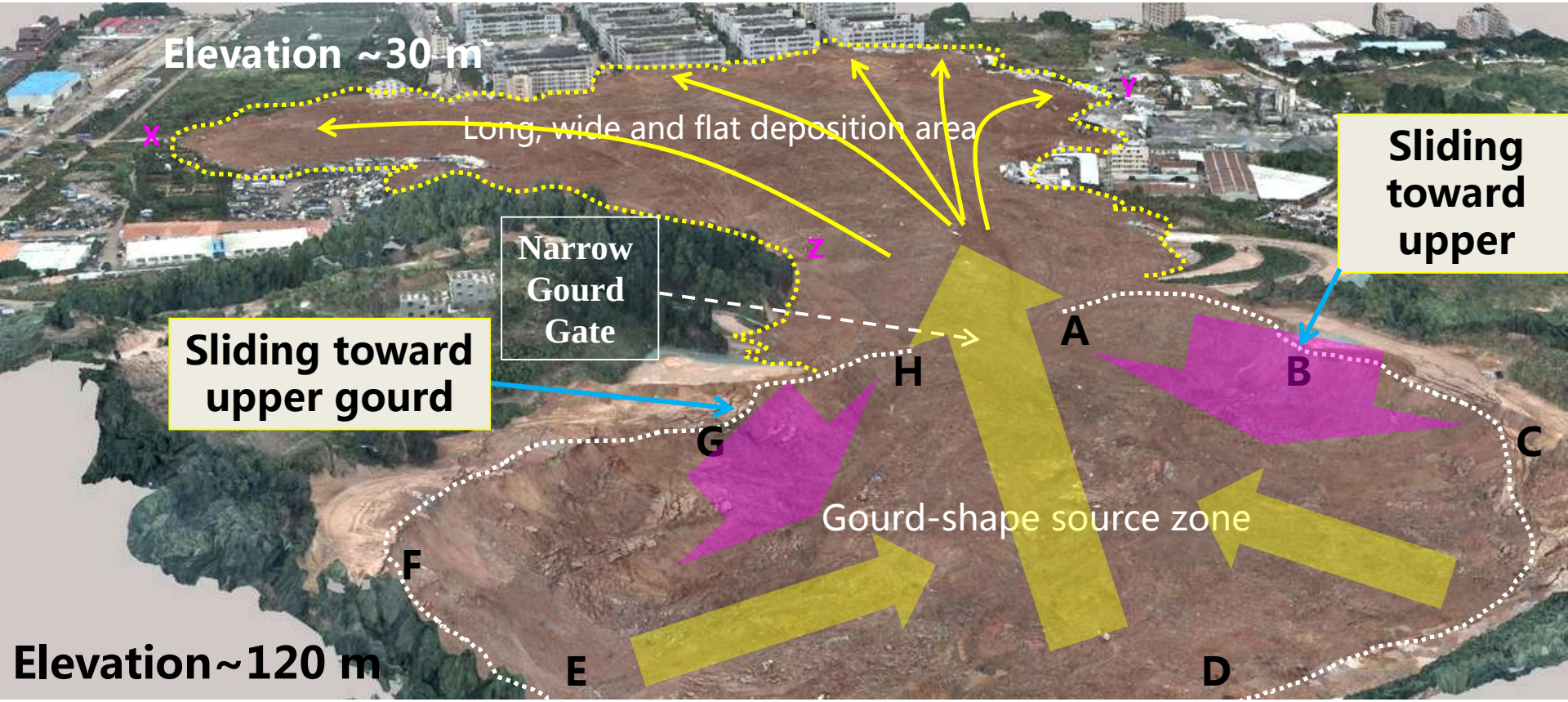




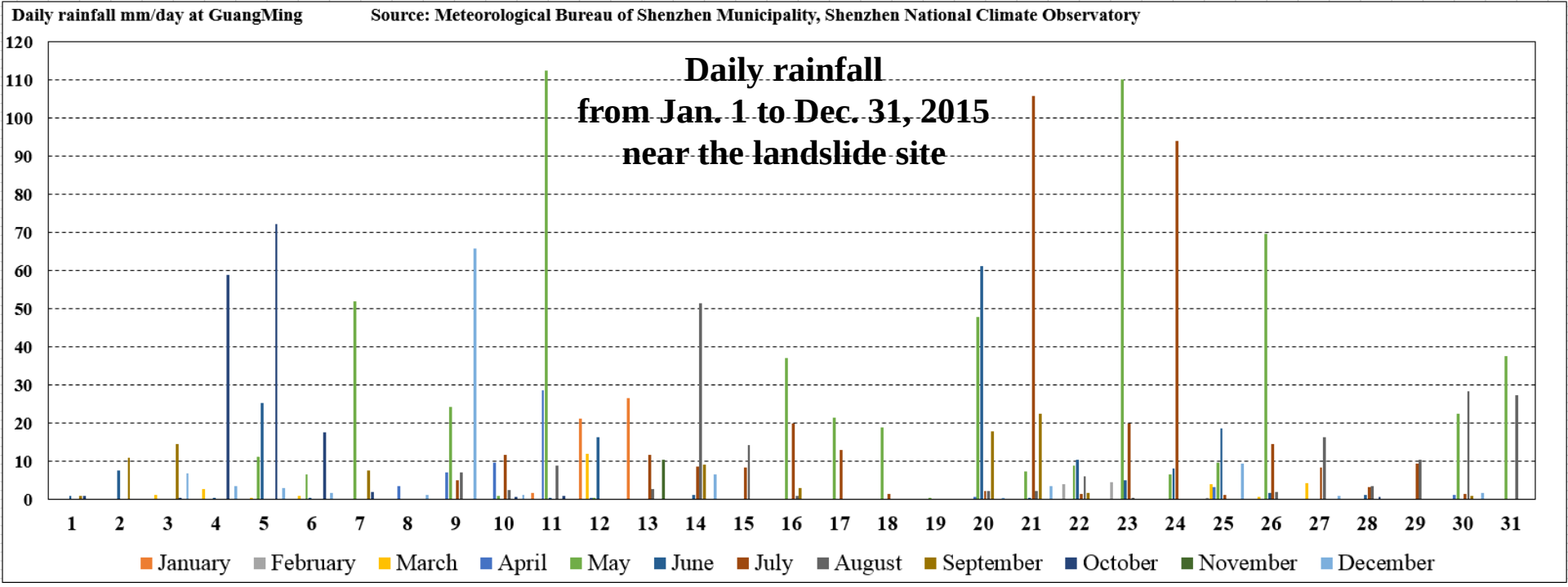
(3) The failed slope after landslide on Dec. 20, 2015

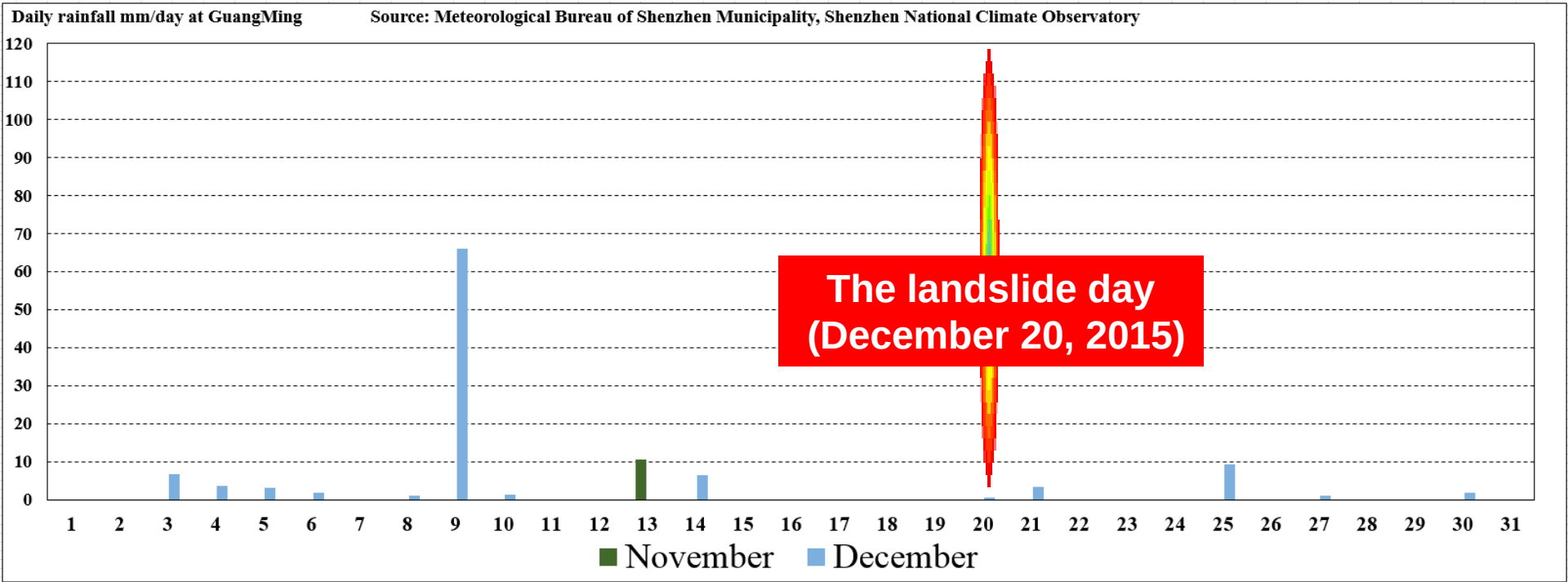
The way of large amount of fill soil mass
rapidly moving out of the gourd-shape source zone
via a narrow gate
then rapidly flowing down over vast gentle/flat area and
impacting and destroying the buildings



Downward View from Crest to Toe

???


Daily rainfall mm/day at GuangMing
Source: Meteorological Bureau of Shenzhen Municipality, Shenzhen National Climate Observatory
Daily rainfall
from Jan. 1 to Dec. 31, 2015
near the landslide site
January
February
March
April
May
June
July
August
September
October
November
December


Daily rainfall mm/day at GuangMing
Source: Meteorological Bureau of Shenzhen Municipality, Shenzhen National Climate Observatory
The landslide day
(December 20, 2015)
November
December

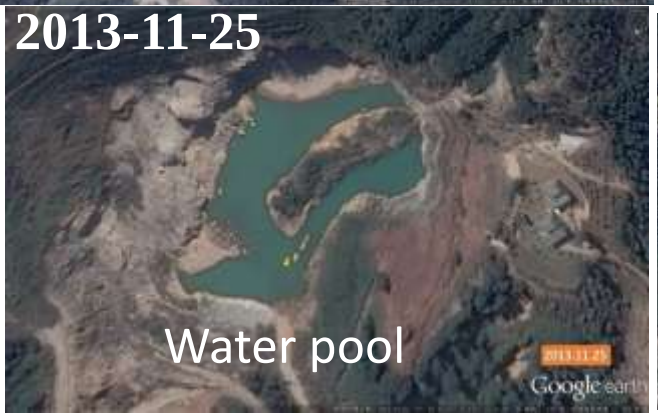
Little free water and no mud/slurry at front of thick debris toe

> 20° slope angle at thick debris far toe

Water on roof due to heavy rainfall on Dec. 9, 2015

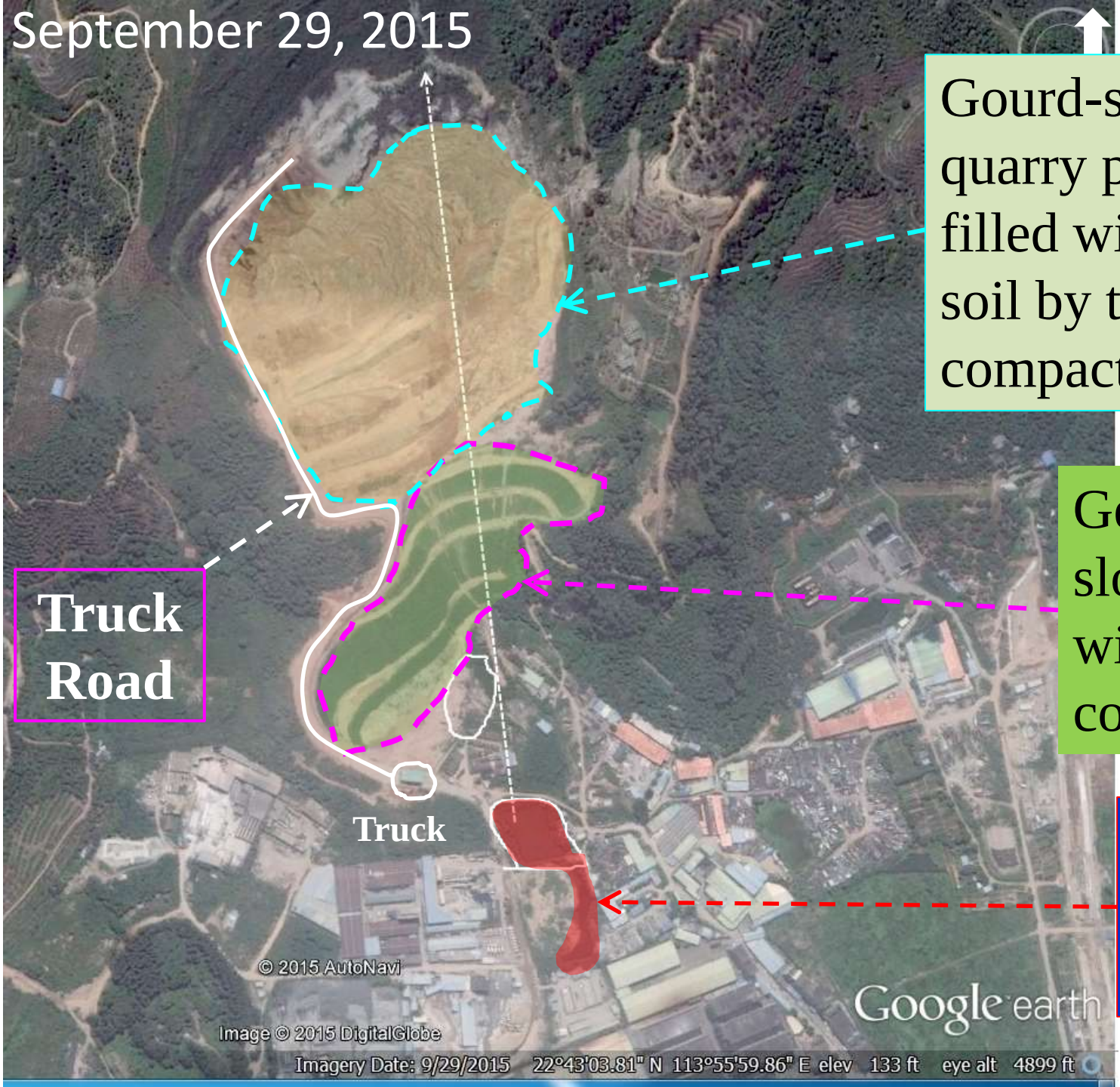
From Quarry Pit for Granitic Aggregates to Water Pool to Excavated Soil Fill Slope

http://blog.sciencenet.cn/blog-39317-945912.html; 2015-12-25 23:22

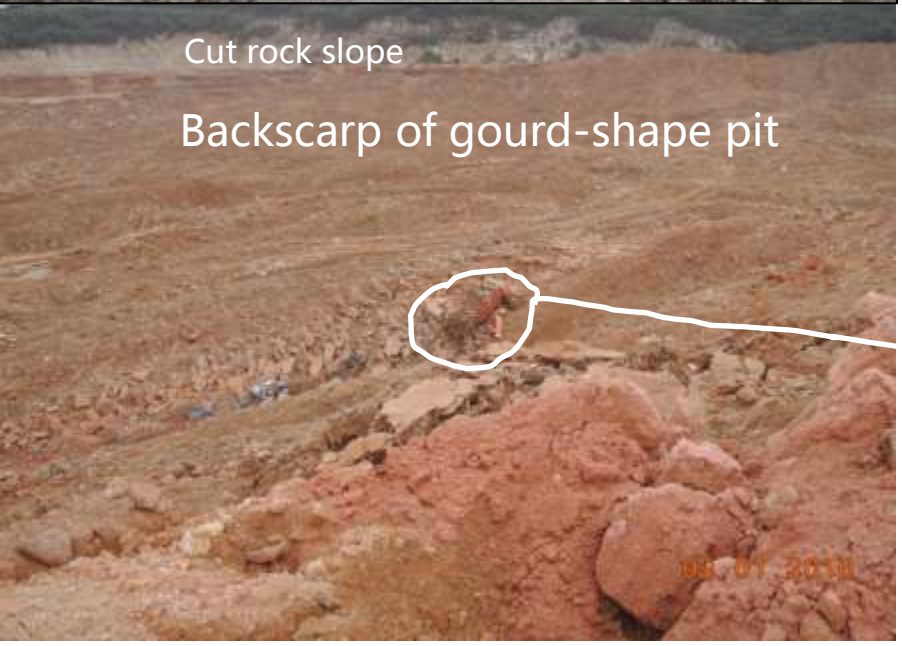


The granitic bedrock for quarry of quality aggregates

Samples and cores of drillholes in failed fill pit in Jan. 2016


September 29, 2015
Gourd-shaped quarry pit being filled with excavated soil by trucks and compaction
Truck Road
Gentle fill slope (< 25°) with vegetation cover
Truck
Water pool see the water later
© 2015 AutoNavi
Google earth
Image © 2015 DigitalGlobe
Imagery Date: 9/29/2015 22°43'03.81" N 113°55'59.86" E elev 133 ft eye alt 4899 ft

Pit Platform Filling Method of Layer by Layer

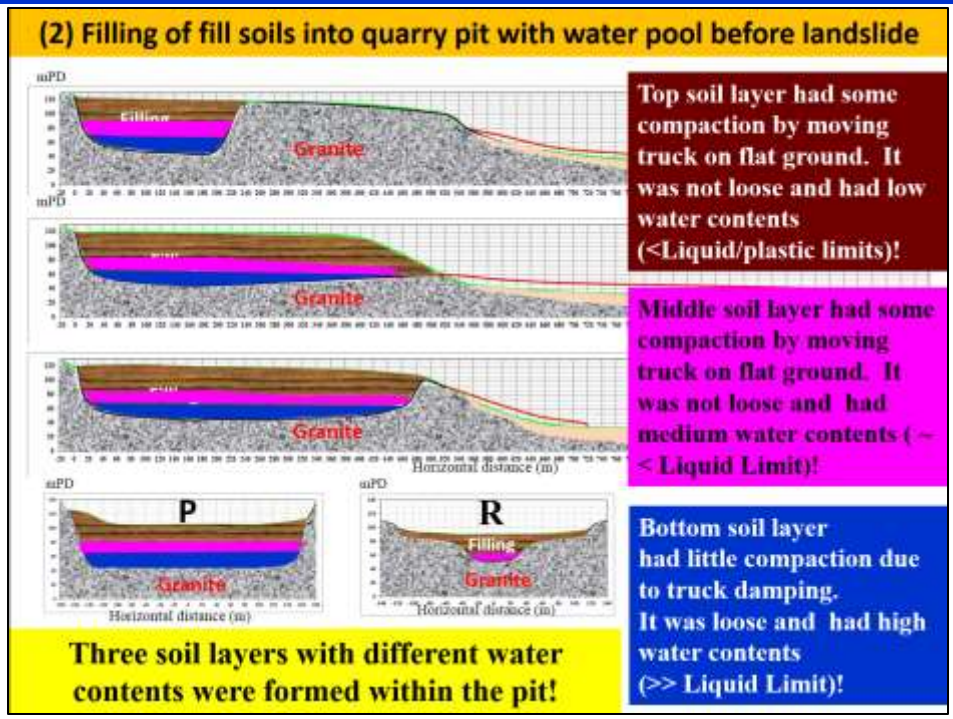


Convex Curves of Flow Wave Lines Showing High Viscosity

Lava Flow Lines

For they had high/good viscosity and mobility, the fill soils should have an adequate amount of water (lubricants) and non-zero cohesion (clay).

Permanent Underground Water



1) The permanent underground water in bottom/lower portion of loose fill soils should be an important factor causing the landslide.
2) It could be a confined aquifer of high pressure due to the upper high mountain and lower permeability of the soil fills.
3) However, the amount of water should not have any sudden increase since it was in the middle of dry season of the year. Or it should keep constant or be slowly reducing due to seepage.
4) It could not have any substantial abrupt change causing or triggering the huge devastating landslide.

Fill Soils

1) In recent years, Shenzhen has been undertaking massive construction of civil infrastructure (e.g., MTR tunnels) and buildings.
2) The excavated soils are about 36 million m^3 per year.
3) Similar to Hong Kong, Shenzhen soils are mainly weathered volcanic and granitic rocks (i.e., CDV and CDG).
4) Therefore the huge and deep gourd-shaped pit of the abandoned quarry site was quickly filled up in less than 2 years.
5) The filling of excavated soils by trucks might not be well compacted.
6) The fill might be loose but should not be very loose since it could support the running and loading of many heavy trucks.

Dec. 23, 2015 on debris

The fill soils should be typical CDG/CDV soils

Further photographs showing the fill debris conditions in dry/wet seasons

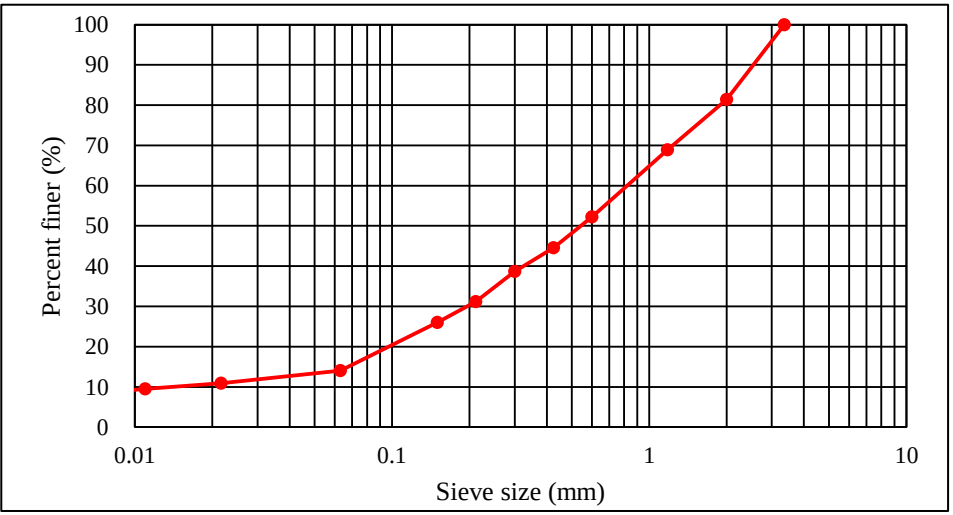
Loose and dry CDV or CDG soils with gravels on Dec. 23, 2015 in dry season

Wetted and dense CDV or CDG soils on April 8, 2015 in wet season
These soils were the landslide debris and removed to stockpiling nearby their original deposition areas

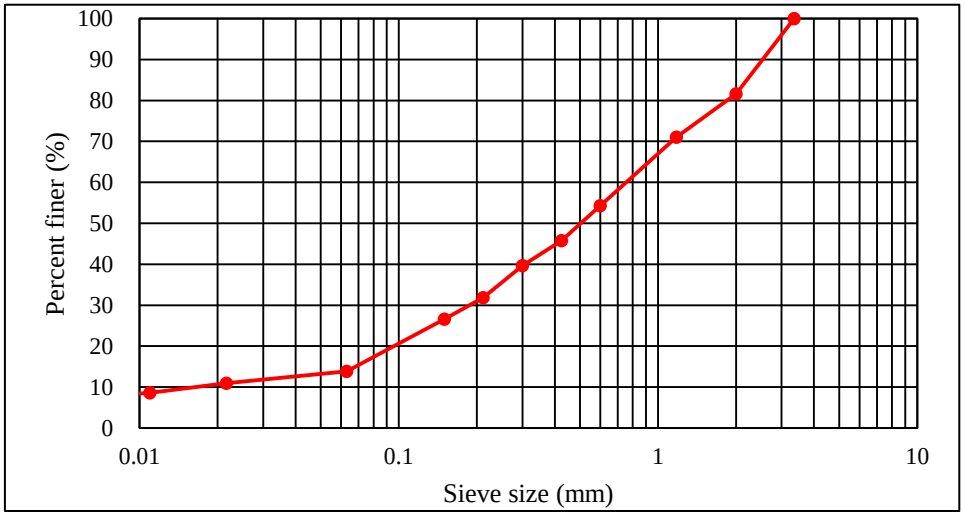
Further site video showing the conditions of landslide debris during the excavation and removal of the soils for rescuing on Jan. 9, 2016

The debris soils were not wetted and liquefied. There were almost no mud/sully or very wetted soils over the entire debris deposition areas except the former water pool area.

PSD for Soil Sample A



PSD Soil Sample B



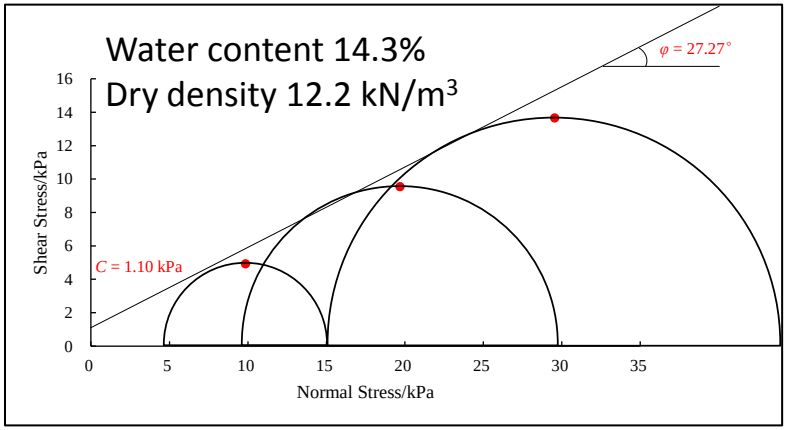
Clay contents about 7%

Well graded clayey silty sand with gravels

For particle size < 0.425 mm
Plastic limit = 25.2% or 21.8%
Liquid limit = 32.2% or 29.5%
Plastic index = 7

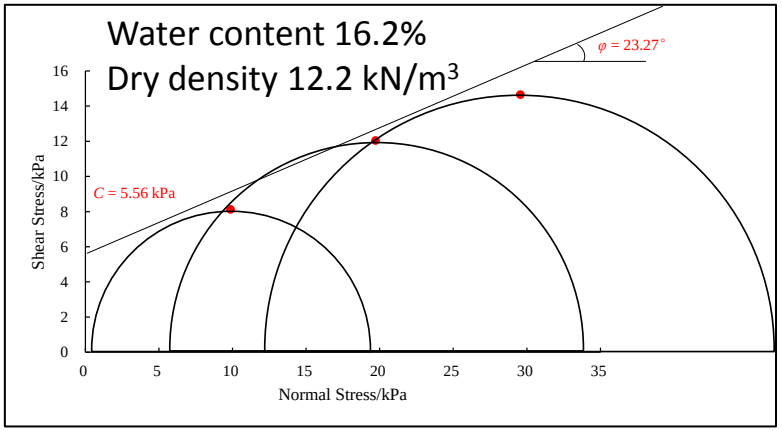
For all soil particles
Plastic limit = 14.9% - 12.1%
Liquid limit = 22.0% - 18.7%
Plastic limit = 7

Direct shear test for soil samples at loose condition



c =1 kPa, φ = 27°

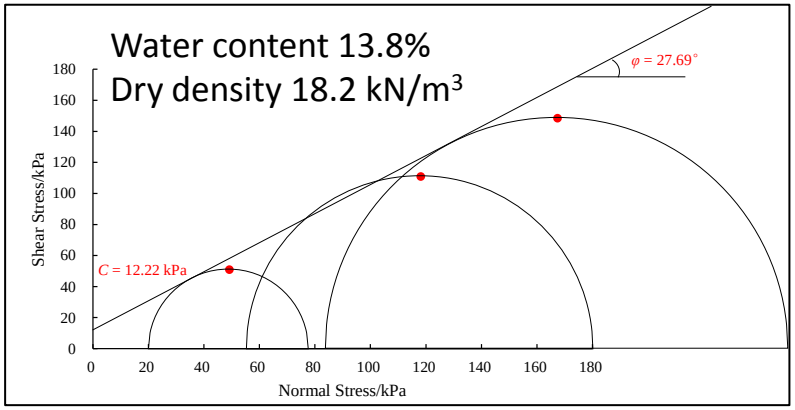
Initial shear modulus 2 – 10 MPa



c =6 kPa, φ = 23°

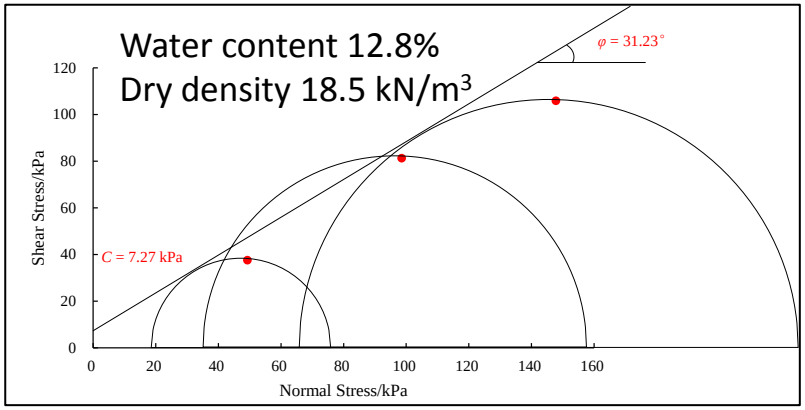
Initial shear modulus 1 – 2 MPa

Direct shear test for soil samples at maximum dry density



c =12 kPa, φ = 28°

Initial shear modulus 7 – 43 MPa



c =7 kPa, φ = 31°

Initial shear modulus 2 – 13 MPa

Summary of the findings

1) The fill soils are regular and typical CDG/CDV soils of adequate strength for deformation and failure.

2) There was very limited water in comparison with the huge amount of landslide soil debris.

3) Hence, there had to have an unusual factor that could have a substantial abrupt change and power to cause or trigger the huge devastating landslide.

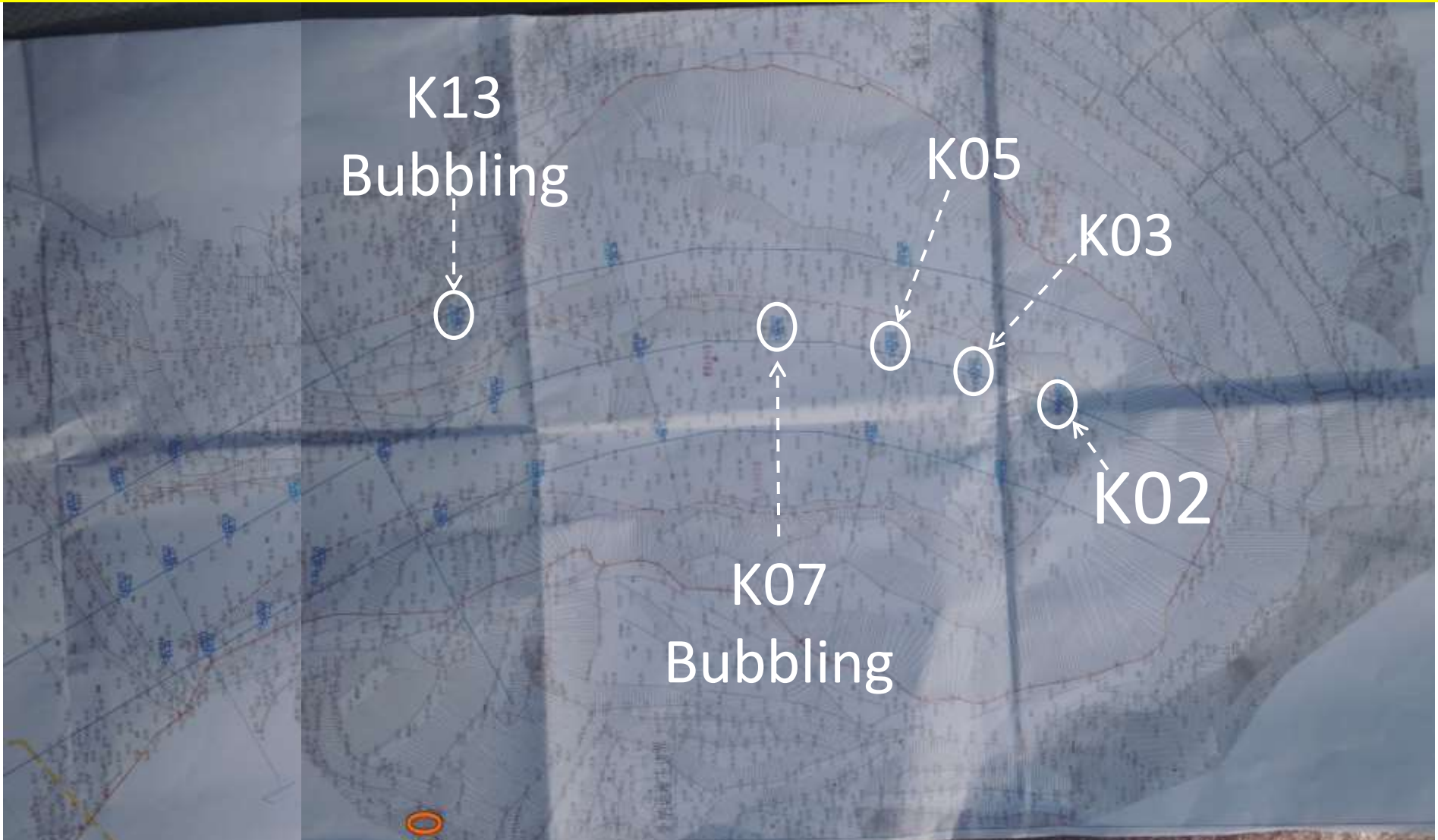
What was the factor ?

The unusual factor could be the gas in the fill soils


September 29, 2015
December 23, 2015
Bubbling of gas
?
Water pool see the water later
23.12.2015
DigitalGlobe
Imagery Date: 9/29/2015 22°43'03.8

Video showing the bubbling of gas in the water pool of an deep excepted pit in the debris soils at the original water pool (video taken on Dec. 23, 2015, 3 days after the landslide)

A Shenzhen geo-company made 28 drillholes in the gourd-shaped source zone. Basically, each drillhole had soil collapse cases. 8 drillholes had bubbling of gas and water. 11 drillholes had water table reaching the ground surface in the failed pit.



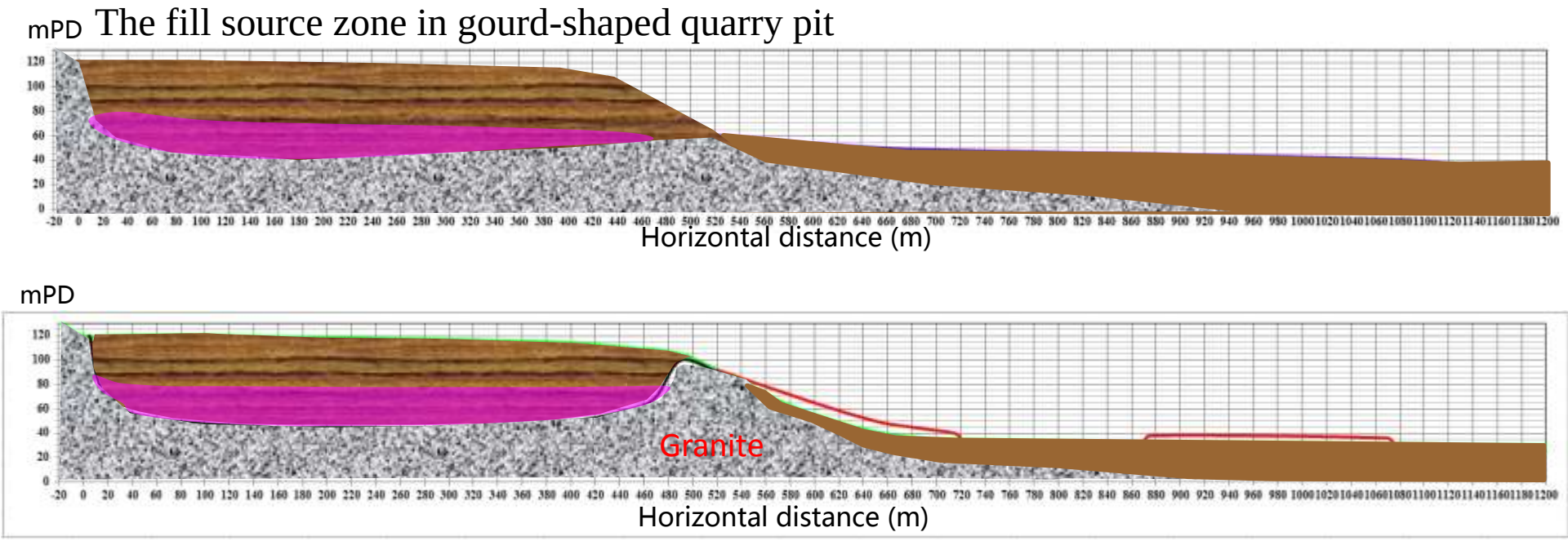
Video showing bubbling in K02

Drillhole No. K13 on Jan. 9, 2016

The gas out of the drillhole had strong odour or foul smell.

Likely mode and sequence of the landslide

Likely mode and sequence of the landslide



1)

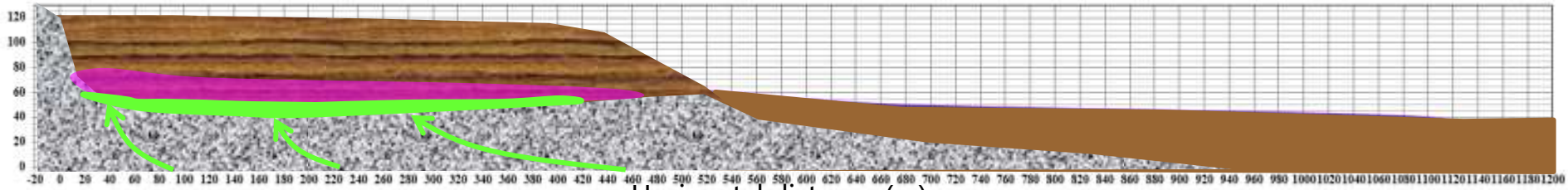
The fill soils are well graded clayey silty sand with gravels excavated from CDG or CDV sites in Shenzhen. They are loose, low permeability.

Water can be stored and accumulated in the bottom of the filled pit due to very low permeability of the granitic bedrock.

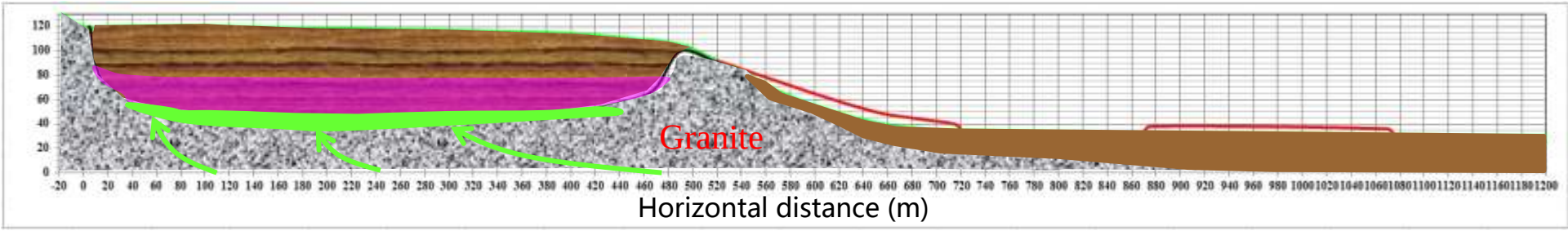
Water made the loose fill at the bottom wetted, softened and easy deformed, which gradually affected the middle part. The upper part remains loose.

Likely mode and sequence of the landslide

mPD The fill source zone in gourd-shaped quarry pit



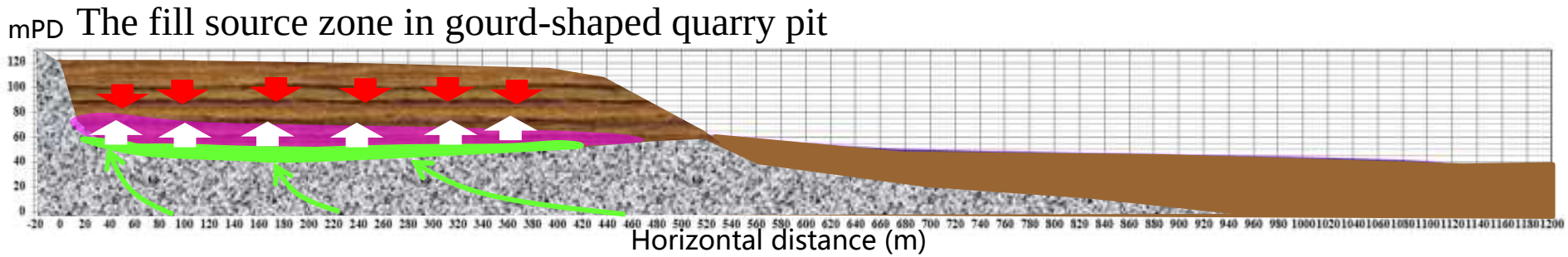
mPD

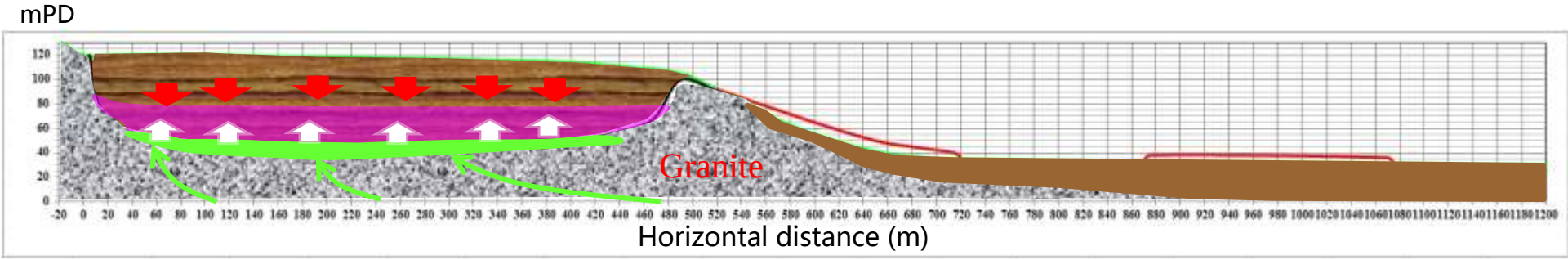


2)
The leaking and seeping of the highly compressed natural gas into the bottom part of the fill. The gas accumulated there.

The mass and pressure of the gas increased with time due to the overburden pressure of the fill weight.

Likely mode and sequence of the landslide

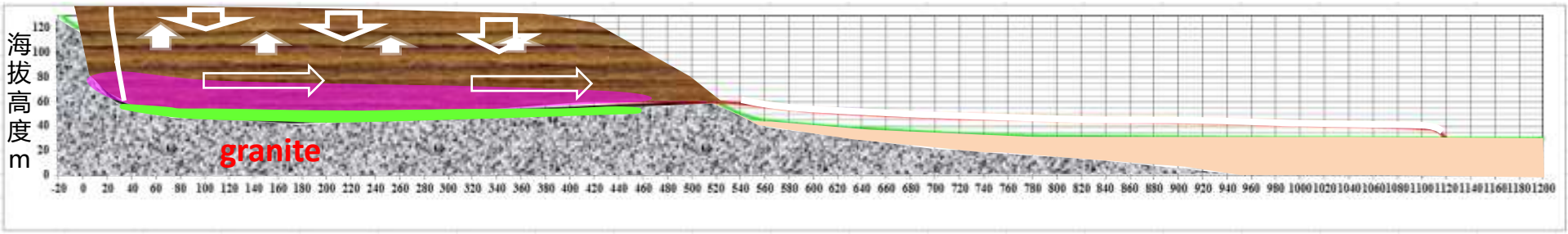




3)
The expanding of the compressed gas was uplifting the middle and upper loose fill.

The weight of the fill confined and restricted the gas uplifting.

So, the middle soil was compressed accordingly.

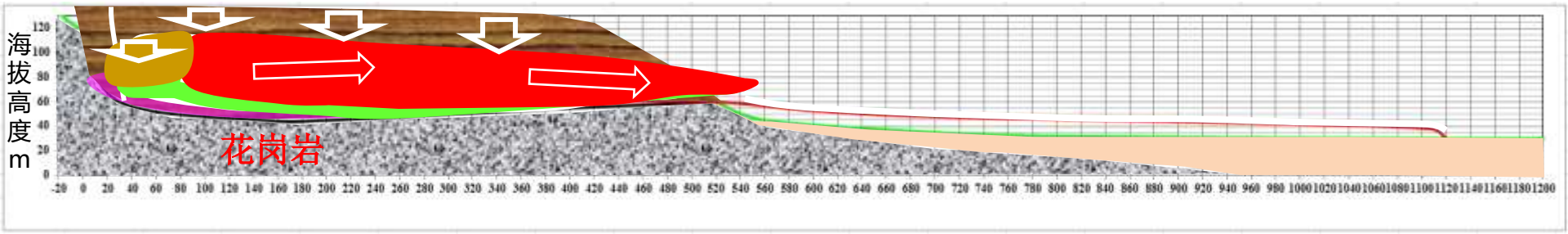


4)

Before 11:42, December 20, 2015, there was suddenly increasing in the gas pressure in the pipeline. The leaking of the gas also was increasing. Much more gas mass was accumulated and the gas pressure in the fill soils also increasing.

The force equilibrium and the deformation compatibility were broken. The expanding gas uplifted, tilted its upper soil layers and ruptured fill soils around the gourd-shaped pit.

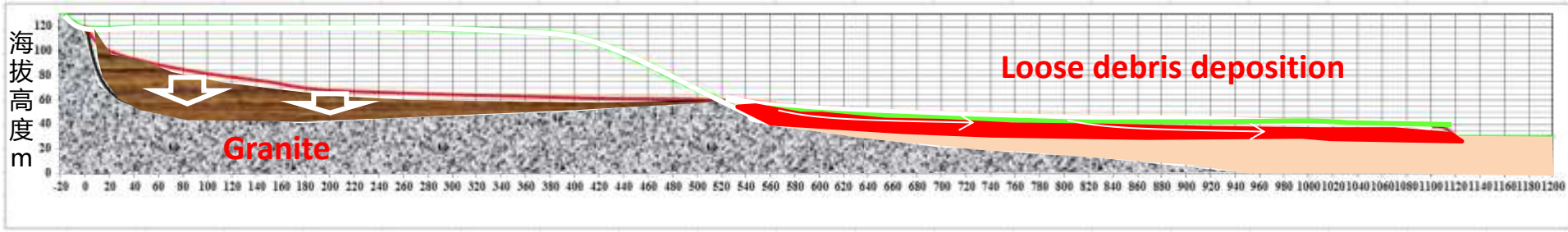
So, the isolated above fill soil layers were moved upward significantly.



5)
The expanding gas uplifted its upper soil layers and also moved them laterally.

Due to the loose linkage between the upper loose fill layer and the middle fill layer, their interface ruptured and delinked.

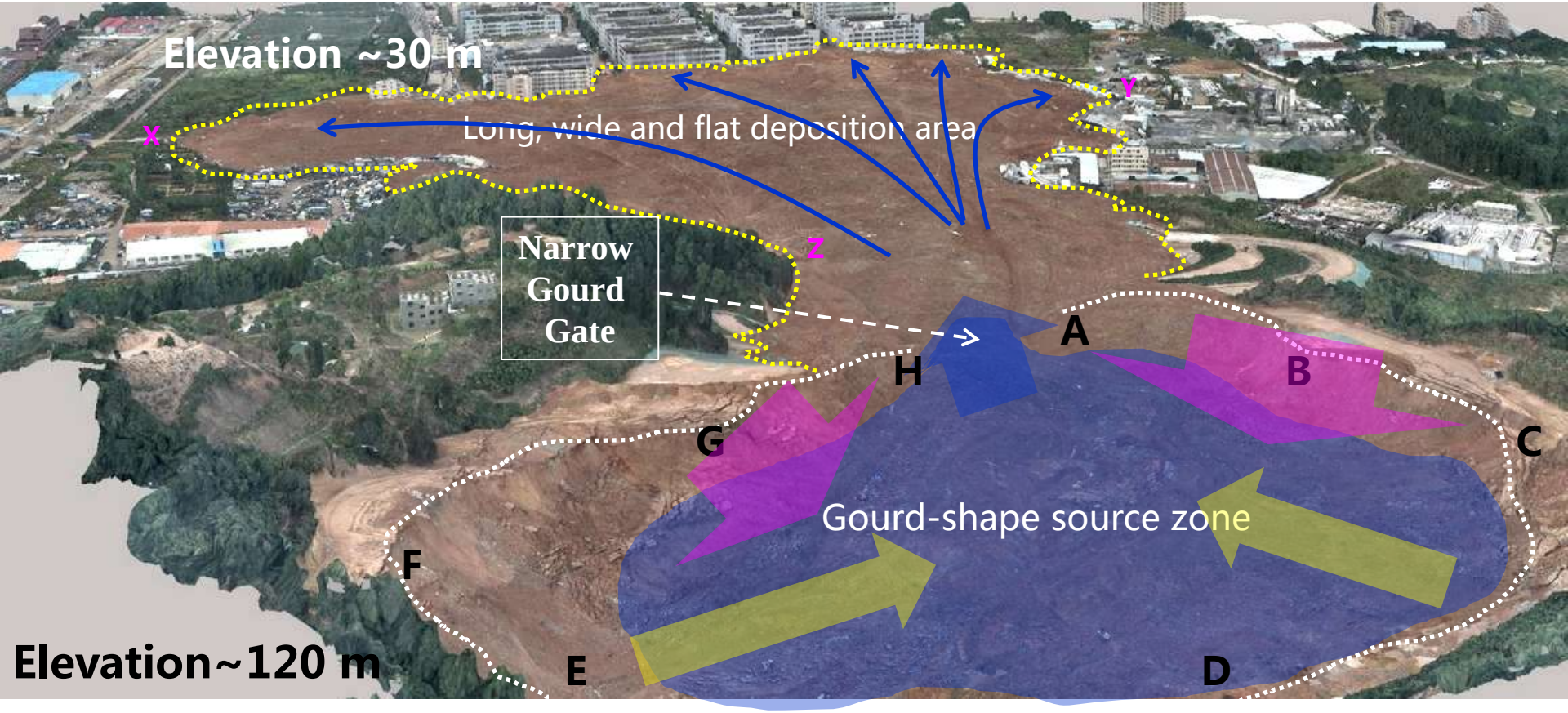
Subsequently, the expanding gas, the wetted/gassed soft bottom layer and the middle layer, like water, slipped and flowed out of the narrow gate (outlet), and rapidly flew down the gentle slope.



6)
The soil debris, saturated with water and gas and uplifted by compressed gas, slipped out the outlet like water.
They rapidly flowed and spreaded over the vast flat ground.
They strongly and forcefully destroyed, impacted and buried houses and buildings on their rapid moving/flowing path.

7) In the meantime, the upper loose soil layer and the surrounding soils sunk and collapsed into the suddenly empty space due to the rapid leaving of the middle soil layers and that was originally occupied by the debris soils.

The way of large amount of fill soil mass
rapidly moving out of the gourd-shape source zone
via a narrow gate
then rapidly flowing down over vast gentle/flat area and
impacting and destroying the buildings



Downward View from Crest to Toe

On May 18, 1980, debris 3×10^6 m^3 flowed/slipped 27 km into Columbia River.

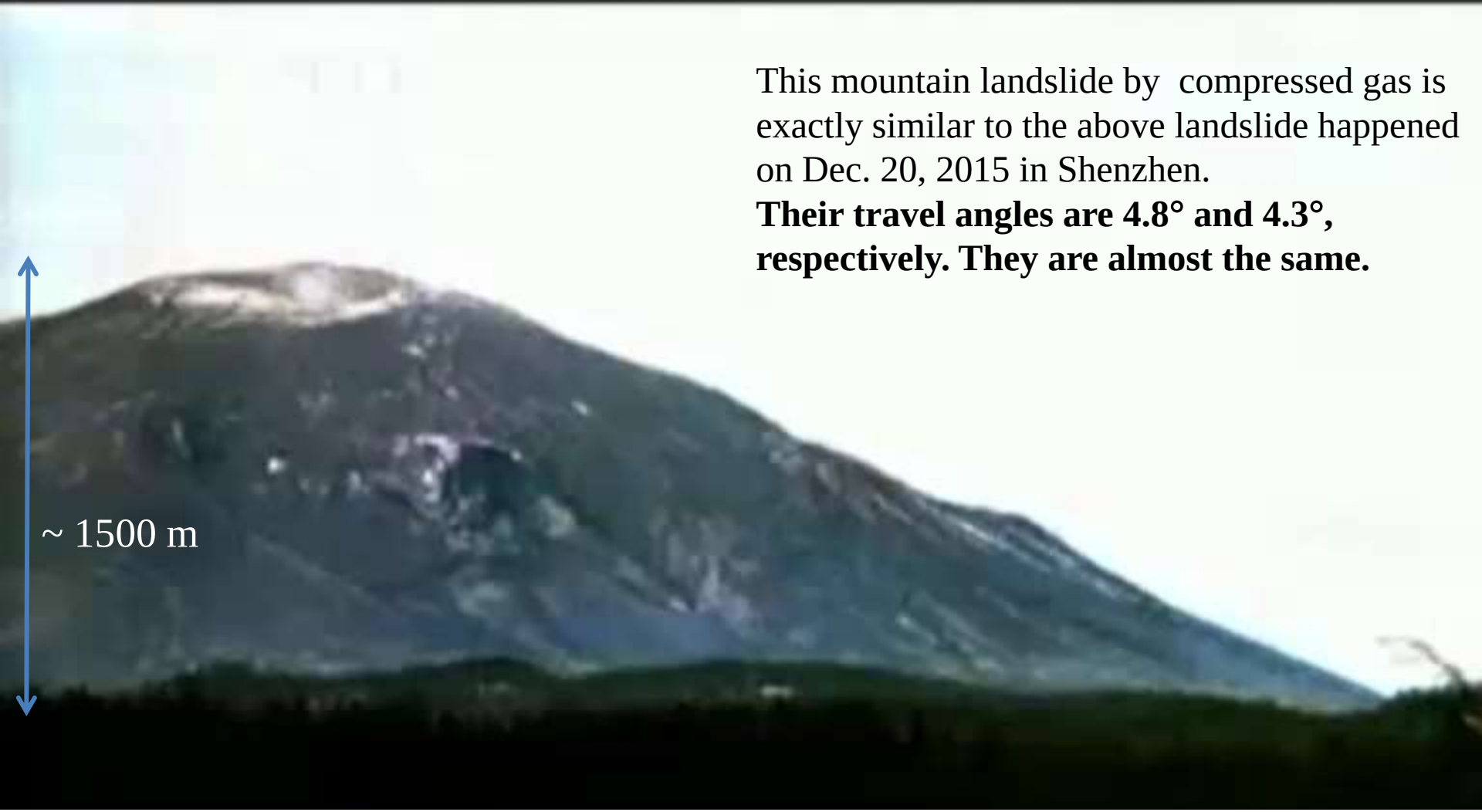
Elev.300 m
Columbia River

27 km long runout distance

$\alpha = \tan^{-1}[(2550-300)/27000]$

$\alpha = 4.8°$

Elev. 2550 m



This mountain landslide by compressed gas is exactly similar to the above landslide happened on Dec. 20, 2015 in Shenzhen.
Their travel angles are 4.8° and 4.3°, respectively. They are almost the same.

Video, Power of compressed gas expansion causing mountain slope sliding and throwing.
The expanding gas mass uplifting and carrying and pushing the gasified rock and soil mass, like water to rapidly move, flow and slide down the slope.
The eruption of black gas was appearing.

Concluding Remarks

Two Steps for Landslides in General

1) Initiation for slope to change from stable state to motion state with initial velocity.

2) Movement for debris to slide, flow, run or fly over various distances with various travel angles

The Three Basic Causes of Landslides

Baseline Cause

Gravity force in slope mass

Additional Cause A

Water on and under ground

Additional Cause B

Gas in ground & with Pressure

Their Three Combinations