Gaining new knowledge from the catastrophic Zhaojiagou landslide on January 11, 2013 in dry season

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ABSTRACT

The catastrophic Zhaojiagou landslide suddenly occurred at about 8:20 am on January 11, 2013 in dry season in Zhen-xiong County, Yun-nan Province, southwestern China. The landslide debris rapidly arrived and instantly buried 14 village homes and partially damaged 2 homes of the matured Zhaojiagou village. A total of 63 house-rooms, 31 pig-cattle-sheds and toilet rooms, 46 people, 59 pigs, 5 cattle and 100,000 m² arable land were buried. Two people were injured. At the time of landslide, 46 people were in their 16 homes and totally buried. They were 27 males and 19 females including 11 boys, 8 girls and 7 elders of age above 60 years. Starting at 8:30 am, the local government organized the urgent rescues and mobilized ~1000 people, and used many excavators, loaders, tractor shovels, spades, and search and rescue dogs. Because of up to 13 m thick soil-rock mixture debris covering large village area, however, the rescue progress was very slow. Until noon of the second day, the 46 buried bodies were found and all dead. All the researchers except the author who investigated this landslide had the consensus that this catastrophic Zhaojiagou landslide was triggered/cause by rainfall or soil liquefaction. This paper presents data and phenomena that cannot be described and explained with the rainfall cause hypothesis and for gaining new knowledge and lessens of originality from this disaster.

1 INTRODUCTION

1.1 Investigation and conclusion by others

In the afternoon of the second day after the disaster, the local geological hazard prevention and mitigation team announced the landslide disaster and its cause (Jinghua Times 2013). The failed slope was about 120 m long, 110 m wide and 16 m thick. It consisted of soil and rock mixtures of a total volume of $21 \times 10^4$ m$^3$. The debris rapidly run downward. After passing a flat platform, they turned, jumped and rushed into Zhaojiagou village, instantly buried the village over a flat area of 10,000 m$^2$. Four factors caused the disaster (Xinhuanet 2013). The landslide area had steep slopes which were unfavorable to slope stability and provided effective space for sliding. Secondly, the failed slope consisted of a Quaternary colluvium that was mainly clay soils, had large thickness and lower stability, which was the internal factor. Thirdly, the continuous raining and snowing weather was the direct triggering factor. Fourthly, the M5.7 earthquake in Yiliang County on September 7, 2012 had certain effect to the occurrence of the landslide. This rainfall triggering hypothesis was accepted by many researchers including Yin et al. (2013; 2017), Yao et al. (2014), Yin et al. (2015) and Zeng et al. (2016). Yin et al. (2017) concluded that this landslide was a rapid and long-runout catastrophic disaster triggered by prolonged low-intensity rainfall.

1.2 Investigations and findings by the author

The author had a doubt about the above cause hypothesis of rainfall. To address the doubt and to gain more knowledge, he left Hong Kong for the site on January 15 and arrived there in the evening of January 17, 2013. He investigated the landslide on January 18 and 19, 2013. Because of little rainfall and government protection, except the buried village area near the front toe of the debris flow, the failed natural hillslope and the upper to
middle to lower debris flow-pass and deposition surfaces kept almost the original conditions. He observed many phenomena that were not consistent with the hypothesis of rainfall cause/triggering (Kang 2013; Yue 2013a). He then carried out a NSFC research project. The project title is “Investigation of Fatal Zhaojiagou Landslide of Rapid, Long and Wide Run-out in Zhen-xiong County, Yun-nan Province.” He investigated the landslide in details, covering literature review, ground investigation, laboratory soil testing, slope stability analysis, and numerical simulation of the long-runout with 2d-Debris Mobility Model (2d-DMM). Some results are presented below for gaining new knowledge.

2 FACTUAL DATA AND PHENOMENA OF THE LANDSLIDE

2.1 Topography of the landslide

The general conditions of Zhaojiagou landslide are shown in Figure 1. The zone from Points A to B is the failed hillslope for the source of the landslide debris. The zone from Points B to C, D and E is the debris deposition zone. The failed village is the area before the debris toe Point E. The GPS for A is about 27°33.038’N and 104°59.077’E at elevation 1810 m. The GPS for E is about 27°33.211’N and 104°59.500’E at elevation 1560 m. The distance from A to E is ~850 m and the vertical drop is ~250 m. The surface area of the source zone is about 10,000 m² (about 130 m long and 75 m wide). The surface area of the debris deposition is about 130,000 m² (about 850 m long and 150 m wide). The catchment area of the hillslope above the failed slope is about 9,000 m², which is relatively small comparing to the large areas of the failed slope and deposition zones. The failed natural hillslope has a gentle angle increasing from 5° at toe to 30° at crest. The failed volume is 20×10⁴ to 40×10⁴ m³. The debris thickness is 0 to 13 m and the mean 2 to 3 m.

Figure 1: The Zhaojiagou landslide site: (a) Google image before the landslide; (b) Satellite image after the landslide ground covered by thin snow; (c) Geological cross-section

2.2 Rainfall conditions and question

According to Yin et al. (2013), the average monthly rainfalls for Zhen-xiong county from 1957 to 2000 were 14.7, 15.6, 23.9, 53.0, 109.3, 149.5, 173.3, 167.1, 113.6, 58.8, 29.2 and 15.1 mm for January to December, respectively. The maximum monthly rainfalls were 32.5, 41.2, 60.9, 134.1, 313.0, 238.6, 355.0, 336.0, 251.3, 128.4, 64.6 and 38.9 mm, respectively. The average and maximum annual rainfalls were 923.6 and 1427.7 mm, respectively. The average rainfalls in December 2012 and from January 1 to 10, 2013 were 12.1 and 3.7 mm, respectively. The rainfalls at the Da-shui-yu station of 20 km west to the landslide site were 66.4 mm in December 2012 and 3.3 m from January 1 to 10, 2013. Hence, the landslide occurred during relatively long days of extremely low rainfall. A question must be examined. Why did the typical natural hillslope fail catastrophically in a dry season with extremely low rainfall instead in a wet season with heavy rainfall?

2.3 Witnesses accounts
The witnesses accounts can be summarized as follows. 1) The geological team of the local governments had identified hundred sites for monitoring and preventing landslide hazards, but, did not include this Zhaojiagou landslide site. 2) Such huge and catastrophic landslide disaster was the first case in a winter (dry) season of Yun-nan province. Because of dry-season, the governmental weather pre-warming media-announcement of rainfall induced geological disasters was closed on November 21, 2012 as usual. 3) From December 2007 to January 2008, the site had prolonged heavy snowing for 50 days but no landslides. The site had small snowing in January 2013, but occurred such huge disaster. 4) None huge or noticeable landslide occurred during the past 70 years at this area. 5) Tension cracks were observed on the hillside slope before the landslide. 6) Immediately before, white smoking rose from the hillside. 7) Many local people heard a big sounding “Hong”. The duration from this big sounding to the debris burying of the village houses was less than 2 minutes. 8) “At that time, the hillslope looked like a volcano eruption, suddenly burst out. … Evidently felt a big and powerful gas flowing out of the hillslope”. “Huge dust suddenly appeared in the hillside and the mount collapsed and buried the village like a truck pouring its sands.” 9) A coal-truck driver saw the landslide was powerful and had flying speed for long distance, shouted loudly, run but failed to inform the villagers because of rapid arrival of the soil and rock debris. 10) On the steep slope below Point D in Figure 1, some trees and grasses were not damaged at all. 11) The landslide might be related to the outburst of coal-gases due to an underground tunneling coal mine nearby. These observations and descriptions clearly indicate that a) the failed hillslope was a typical natural slope covered with dense vegetation and shrubs. It had been stable for more than 70 years; b) the landslide was clearly an unexpected, sudden and rapid, dramatic, horrible, catastrophic and powerful event in relatively dry days; c) it did not involve any noticeable groundwater or rainfall water but it might involve a powerful gas outburst or eruption from the ground.

2.4 Speed and travel angle of debris flow

Average speeds of the debris flow were 6.8, 11.6 and 16.7 m/s. They were estimated by Zeng et al. (2016), Yao et al. (2014), and Yin et al. (2017), respectively using the witness account, empirical bend-channel equation and DAN-W modeling. These debris-flow speed values are much greater than the upper limit rate of 5 m/s for extremely rapid landslide defined by IUGSWGL (1995). The travel angle of the debris flow is ~16° and much less than the normal frictional angle 30°, showing a long-runout of the debris flow.

Yue (2013a) reported the phenomena observed on January 18 and 19, 2013 (Figure 2). The adjacent hillslope angles increased from 5° to 30° from the toe to the crest of the failed zone. Debris were composed of soil and rock mixtures including silty clay and rock blocks of various sizes. They were spread over up to the vast deposition area of 210 m wide and 700 m long flat, gentle or steep slope surfaces. They were in loose and unpacked state and had low water contents. The broken rocks in the debris included argillaceous siltstone, siltstone, fine-sandstone and mudstone. Occasionally, block masses of mud or fully saturated soft silty clay were found in isolated state among the vast loose and low water content debris. The debris did not show any water flow or seeping or liquefied mud features. The original ground surfaces with grasses were observable beneath the loose deposits. Striations and steps on the original ground above the Point D showed strong impacting and rapid frictional slipping. No entrainment features were found.
3 CONCLUDING REMARKS

These data and phenomena evidently show that Zhaojiagou landslide is a catastrophic rapid long-runout and vast-spreading landslide in dry season. They are inconsistent with the cause hypothesis of rainfall or groundwater although this hypothesis was the consensus of many researchers. Mostly importantly, the landslide was strongly lack of the noticeable presence of free water or substantial amount of liquefied mud soils. They demonstrated that Zhaojiagou landslide was triggered/caused by the eruption of highly compressed underground gas (Kang 2013; Yue 2013a). They can be consistently and logically described and explained with the gas cause hypothesis (Yue 2013b; 2014; 2015). Because of the existence of two different cause hypotheses, further investigation of Zhaojiagou landslide can allow us to gain new knowledge and learn more lessons of originality for landslide prevention and mitigation in this region and elsewhere.

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REFERENCES


