Rockfall hazard identification and assessment of the Langxian-Milin section of the transmission line passage of Central Tibet Grid Interconnection Project

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Abstract. In order to select the location of transmission towers in Central Tibet Grid Interconnection Project and provide hazard prevention strategies for the safe operation of power transmission lines, we used remote sensing technology to carry out the rockfall interpretation, according to which the space distribution for the rockfall hazard was identified. Then, on-site investigation and UAV aerial survey were conducted in the typical section. Using the scoring method, we selected eight factors including topography, lithology, rock structure, slope structure, hydrogeological conditions, vegetation development, historical rockfall, and slope stability status. The results of the study showed that 116 rockfalls were identified in the transmission line passage of Central Tibet Grid Interconnection Project. Since the rockfall linear density of the Langxian-Milin section was greater than that of other sections, this section was selected as a typical survey section, and assessments were conducted in this section. The study area was classified as high serious, serious, medium serious, and low serious four levels.

1. Introduction
Central Tibet Grid Interconnection Project is 860km long, passing through the eastern part of Tibet, crossing the cities of Changdu, Linzhi and Shannan from east to west. The tower elevation ranges from 2125m to 5290m and the average elevation is 3800m. The project is the longest alternating current grid project in Tibet with currently the world's highest altitude and the worst natural conditions interiorly. Due to the complicated geological conditions, strong tectonic movements and frequent earthquakes, the Tibetan Plateau has always been a region with frequent geological hazards threatening project security, one of which is rockfall.

The transmission line passage is distributed along the national road G318 and the provincial highway S306, belonging to the alpine, alpine canyon as well as middle and low hilly landforms in Plateau area. High ridges distribute between deep valleys affected by the subduction of the Indian plate to the Eurasian plate and the strong uplift of the Tibetan plateau.

In recent years, many studies focus on the engineering geological conditions and the distribution of geological hazards along the Sichuan-Tibet Highway. Based on engineering geological survey on site,
Zhang (2004) assessed rockfall hazard at the Basu-Linzhi section on the south line of the Sichuan-Tibet Highway by a new approach proposed. Yuan (2010) studied the development and distribution of geological hazards along the Sichuan-Tibet Highway in the north of the Great Brahmaputra Turns. Chen (2011) used analytic hierarchy process (AHP) to analyse the geological hazards along the Sichuan-Tibet Highway. Li (2017) studied spatial distribution characteristics and potential hazard ways of landslide and rockfall in Kangding to Linzhi section of Sichuan-Tibet traffic corridor by field surveys and remote sensing interpretations.

Since Central Tibet Grid Interconnection Project is special and important, a more detailed investigation of rockfall hazard is required to ensure the safety of the construction. Since the frequency of the rockfall hazard in the plateau mountains is much higher than other types of geological hazards, and the corresponding impact on the project is even greater, the paper mainly focus on the study of rockfall.

2. Methodology

Because of the long-distance characteristics of Central Tibet Grid Interconnection Project, it is necessary to identify the region, segment and mountain scale step by step before the investigation of the rock mass scale can be achieved. Wang (2018) proposed a method for identifying dangerous rock masses by regional engineering geological zoning, zone remote sensing analysis, mountain unmanned aerial vehicle (UAV) photograph and finally rock structure characteristics analysis. With reference to this method, satellite remote sensing analysis was applied to the transmission line passage. A typical research section was identified by remote sensing interpretation and UAV aerial surveys (Figure 1). Rock structure analysis and engineering geology surveys were also carried out in the on-site investigation of rockfall hazard and engineering geological conditions.

The method of remote sensing interpretation was as follows: (1) Remote sensing interpretation marks should be established. Rockfalls are mostly developed on steep slopes. Most of the rockfall walls are usually light or offwhite hue in remote sensing images, where vegetation is scarce. Sometimes cracks are visible on the upper part of dangerous rock masses. The rockfall deposits are rough and mostly fan-shaped or tongue-shaped. (2) Based on GoogleEarth data and GIS platform, the rockfall interpretation of the transmission line passage was finished according to the interpretation marks. (3) On-site verification and improvement of results should be done. Using UAV aerial surveys and traditional engineering geological survey methods, 27 interpretations were verified on-site, 25 of which are accurate, and the accuracy of remote sensing interpretation is 92.6%.

During the assessment of the rockfall hazards, the method of selecting assessment factors and scoring according to site conditions was adopted. According to UAV aerial survey and site investigation, within the 100m area on both sides of the typical survey section, the topography, lithology, rock structure, slope structure, hydrogeological conditions, vegetation development, historical rockfall, slope stability status were selected as assessment factors of the rockfall hazard.
3. Characteristics of rockfall hazard in the typical study section

3.1. Selection of the typical section
Due to the study focused on the distribution of the rockfall hazards, the remote sensing interpretation of
the rockfall hazards in the whole transmission line passage was carried out according to the established
interpretation marks. 116 historical rockfalls were interpreted in the entire line and the average linear
density was 0.14 per kilometre. These historical rockfalls were mainly distributed on the Langxian-Milin
and Bomil-Basu sections, and the linear density was 0.26 per kilometre and 0.18 per kilometre
respectively (Figure 2).

The Langxian-Milin section with the largest rockfall linear density was taken as a typical section,
where on-site investigation and confirmation were carried out. This section is roughly distributed along
the highway and the Yarlung Zangbo River. Rockfalls threaten the transmission tower, as well as
highways, pedestrians and passing vehicles. It may also pose a risk of blocking the river. There were
few previous studies on this section and the working degree was relatively low. Therefore, it was
difficult but necessary to investigate the rockfall.

3.2. Regional geological background conditions
The typical section is mainly located in Linzhi City. It is in the southeast of Tibet and middle reaches of
the Yarlung Zangbo River. Affected by the topography of the plateau region, the vertical differentiation
of the climate is typically significant. The precipitation is less, and the glacier is widely distributed. The
average annual temperature is 8.2°C and the average annual precipitation is about 600 mm. Precipitation
is mainly concentrated in the Yarlung Zangbo River and its tributary river valleys.

The research area is located between the Sierra Tanggula Mountain and the Himalayas. Influenced
by plate movements, this area is mostly an alpine valley. The relative altitude is 2200m. The slope angle
is generally above 50° and the maximum is up to 90°.

The study area is mainly located in the Himalayan and the Gangdise-Nyaintangtangura sub-region
of the Gondwana stratigraphic realm. Quaternary(Q4), Paleogene(E), Cretaceous(K), and
Proterozoic(PT) strata are found in the area.

The study area is located at the Yarlungzangbo deep fault, which is the boundary zone between the
Gangdese-Nyainqentanglha plate and the Indian plate of the Indian Tectonic Domain. The
Yarlungzangbo deep fault is the main fault of the Tethyan fault system(Huang, 1980) and the remnant
of the closing of the new Tethys (Ma, 1998), also known as the Yarlungzangbo suture zone. As a whole,
the central Tibet Plateau is dominated by horizontal tectonic stress, and its stress regime is thrust. While
on the eastern edge of the plateau, the stress regime is mainly thrust, and part of it is a strike-slip(Guo,2017).

3.3. Characteristics of rockfall hazards
Rockfalls usually have large scales and high frequencies in the typical section. The accuracy of the
earthquake zone division in the rockfall area is relatively low and can only be considered as the same
intensity zone currently. In this area, the slope height varies 50 to 1500 meters, and the slope angle is
generally greater than 40°, which provides a good dynamic condition for the rockfall. The lithology is
mainly granite and conglomerate.

Hu (1989) summarized the deformation and failure modes of rockfall hazards as toppling, pull-
splitting, sliding, and staggered rockfall. Pull-splitting and sliding are the main modes in the typical
section. The pull-splitting rockfall in the section mainly develops on steep slopes, which are cut by
several groups of structural planes and one of them is nearly horizontal. Free face is under the dangerous
rock mass, the upper part of which is fractured. As a result, the block falls from the bottom to the top.
In the sliding mode, a group of structure plane that has the same trend to the slope dominates the
development of rockfall. Tensile cracks appear in the trailing edge that cause the blocks to fall, and the
lower part of the slope generate depressions, thus forming a dangerous rock mass on the upper part.
The faults and joints of the rock mass is dense in this area and the cutting effect is strong because of the collision between the plates. Rockfall occurs frequently in the slope of cataclastic and loose structure, and the structural planes are usually flat with the same trend to the slope. Thirty-nine groups of structural planes were counted and three groups of dominant joints could be identified, namely $220° \angle 75°$, $320° \angle 20°$, and $60° \angle 50°$ (Figure 3).

![Figure 3. Isogram of structural planes.](image)

The precipitation is less in the rockfall development area, but the freeze-thaw weathering effect is obvious. The vegetation in the eastern part of the section is generally developed, while the western is scarce or not developed. The historical rockfalls are mainly centralized in the middle and the scale of the rockfall deposits ranges from 500 to 2000 m$^3$ (Figure 2). Most slopes are stable or relatively stable currently and some are unstable or relatively unstable. Under unfavourable conditions such as rainfall, the rock mass may lose stability, which provides a material basis for large scale rockfall and threatens the transmission towers on the slope. What’s more, national roads, provincial roads and village roads are built at the foot of the slope, which often become rockfall accumulation areas. As a consequence, the safety of vehicles and pedestrians are threatened by rockfalls as well.

4. Assessment and zonation of rockfall hazard in typical section

4.1. Principle of assessment and zonation

Eight assessment factors, namely topography, lithology, rock structure, slope structure, hydrogeological conditions, vegetation development, historical rockfall, and slope stability status, were selected for the rockfall hazard assessment of the typical section. The factors are detailed as follows:

1. Topography

   Including height and slope angle of slopes, it was obtained through DEM data. The steep slope is necessary for the formation of rockfall and dangerous rock. When the slope is steeper, the more likely it is to rockfall. According to the principle of entropy increase of the system, the steep slope must be transformed to be gentle, that is, the direction of effective energy reduction (Yin, 2012). The dangerous rocks on high slope have great potential energy, and will transform into kinetic energy during the rockfall process, which will cause great destructiveness.

2. Lithology

   The lithology along the typical study area is mainly phyllite, granite, and conglomerate, and is graded according to the degree of rock rockfall. Since phyllite has a phyllitic structure, it usually takes the form of a landslide rather than rockfall when it is destroyed. Granite is hard and brittle with obvious cutting of primary structural planes and weathered structural planes, so the possibility of rockfall is relatively large. Conglomerate is also more prone to rockfall due to the differential weathering of gravel and cement.

3. Rock structure

   This factor mainly includes rock structure type and structure plane state. The rock structure type includes the overall massive, layered, cataclastic and loose structure. In the overall massive structure, the block is large in volume, with few structural planes and good stability, where rockfall is not easy to occur. Beddings are distributed in layered structure rock. In the giant thick and thick layered structure
rocks, the depth of stratum is much greater and the rockfall is easier to happen than that of medium thick and thin layered structure rocks. Cataclastic and loose structure rock masses are strongly cut by the structural plane or bedding, and the rock mass is very broken, with poor stability, and it is very easy to rockfall. The state of the structural plane is an important factor that affects the strength and stability of the rock mass. When the structural surface is rough and irregular, the anti-sliding force of the rock mass moving along the structural surface is the largest, while the structural surface filled with clay or rubbed traces is the smallest. The anti-sliding force of the undulating and flat structural surface is between the two, and the latter one is much smaller.

(4) Slope structure
The slope structure is mainly a representation of the spatial relationship between the structural plane and the slope, which is very important, since different combinations have different structural plane control effects and deformation failure modes. When the trend of the structural plane is the same as that of the slope, and the dip angle is smaller than the slope, the rockfall is easy to occur. The failure mode usually shows a pull-splitting rockfall. When the strike of the structural plane is consistent with the slope and nearly erect, the possibility of rockfall is slightly reduced. Rockfall happens less frequently in other situations.

(5) Hydrogeological conditions
The existence of fissure water has great influence on the stability of dangerous rock. Therefore, the rainfall intensity and the water-bearing state of the slope are very important. In addition, the altitude of the study area is generally above 3000m, and the freezing and thawing effect has a great impact on crack propagation. It should also be included in the assessment. In spring and autumn, the temperature difference between day and night is large, and the temperature fluctuates up and down at 0 °C. When the temperature decreases, the fissure water freezes, leading to the obvious riving effect and the increasing of the crack tension. When the temperature rises, the ice melts and the water pouring into the crack caused mudding and seepage effect, which leads to further reduces the shear strength of the structural surface in the slope and accelerates the occurrence of rockfall.

Table 1. Scoring table of rockfall hazard assessment.

| Factors                     | Scoring standards and scores |
|-----------------------------|-----------------------------|
| Topography                  |                             |
| Height/m                    | 3                           |
| Slope angle/°               | 9                           |
|                             | 27                          |
|                             | 81                          |
| Lithology                   |                             |
| Phyllite                    | 3                           |
| Conglomerate                | 9                           |
| Granite                     | 27                          |
| Rock structure type         |                             |
| Massive structure           | 81                          |
| Giant thick and thick layered structure |               |
| Medium thick and thin layered structure |           |
| Structure plane state       |                             |
| Rough and irregular         | 81                          |
| Undulating                  |                             |
| Flat                        |                             |
| Filled with clay or rubbed traces |               |
| Slope structure             |                             |
| Structure planes have different trend with the slope, or close to horizontal | 81 |
| Structure planes have the same trend with the slope and the dip angle is larger than the slope |     |
| Structure planes are nearly erect |               |
| Hydrogeological conditions  |                             |
| Low to moderate precipitation; | 81 |
| Moderate precipitation or short |                             |
| High precipitation or long  |                             |
| High precipitation and long | 81                          |
Vegetation development

| Vegetation development | Developed | Relatively developed | Scarce vegetation | None vegetation |
|------------------------|-----------|----------------------|-------------------|-----------------|
| Historical rockfall    | Number    | <2                   | 2-3               | 3-5             | >5              |
|                        | Scale/m³  | <100                 | 100-500           | 500-1000        | >1000           |
| Slope stability status | Stable    | Relatively stable    | Relatively instable| Instable        |

*Score 10 items, with a total score of 837.

6. Vegetation development

The development of vegetation affects the retention position and energy attenuation of the rockfall block. The denser the slope vegetation, the more the block energy is reduced, and it has a blocking effect on the stone.

7. Historical rockfall

This factor includes the number of rockfalls and the size of the rockfall deposits. The number of rockfalls characterizes the number of historical rockfalls per 10 km, and the size of the deposits represents the scale of each historical rockfall. The larger the size of the rockfall deposit, the larger the number of rockfalls in the same place or the larger the volume of rockfall. It can be considered that the slope is in a geological environment conducive to rockfall, and the more likely it is to rockfall again.

8. Slope stability status

The slope stability status has reference significance for predicting the development of dangerous rock masses. It’s preliminarily evaluated by the natural environment, geological environment and slope deformation.

After scoring each factor, the score $G$ is determined according to equation (1):

$$G = \sum_{i=1}^{n} F_i (i = 1, 2, ..., n)$$

In the formula, $F$ is the assessment factor of the zoning for the assessment of rockfall hazards and $i$ is the number of assessment factors.

The study area was classified as high serious, serious, medium serious, and low serious four levels.

4.2. Results of zonation

The high serious zone (I) accounts for 19.6% of total length and is divided into 6 sub-regions (Figure 4). $G$ is 441, 477, 459, 513, 406 and 513 respectively for each sub-region. The topography of the these sub-regions is basically a vertical upright slope, the main lithology is granite. The rock mass is broken, with a fragmented structure, and the quality of the rock mass is poor, and many dangerous rocks have been cut by multiple sets of structural planes. Slopes are various from relatively instable to instable, where historical rockfalls are frequent.
The serious zone (II) accounts for 25.6% of total length and is divided into 9 sub-regions. G is 369, 387, 351, 327, 351, 351, 333, 327 and 351 respectively for each sub-region. In these sub-regions, slopes are steep, and the main lithology is granite. The rock masses are broken or relatively broken, whose structures are basically massive structures and layered structures. The dangerous rocks are cut by multiple structural planes and the slope is in a relatively stable or relatively unstable state in the present situation, and it will be in an unstable state under the action of rainfall and weathering. Historical rockfall and block falling often occur.

The medium serious zone (III) accounts for 44.6% of total length and is divided into 5 sub-regions. G is 261, 291, 237, 261 and 219 respectively for each sub-region. Slopes are high with small slope angle in this zone. The vegetation is developed and the main lithology is granite. The rock mass is relatively complete, the structure of which is basically a massive structure, and the quality of the rock mass is poor or good. The slope is in a relatively stable or relatively unstable state in the present situation, under the influence of rainfall, weathering, etc., will be under stable or unstable state.

The low serious zone (IV) accounts for 10.2% of total length and is mainly located in Zhaxilin Village to Langxian County. G is 147. There are basically gentle slopes and dense vegetation in this zone. The main lithology is conglomerate and phyllite. The rock mass is relatively complete and basically massive and thin layered structure. The Quaternary deposits are mainly weathered residual soil accumulation. The overall quality of the rock mass is good, and the slopes are in a stable state. Under the induced action of rainfall and weathering, slopes will be in an unstable state, and some hidden rockfall dangers will occur in some locations, mainly monolithic stones.

5. Conclusion

(1) The rockfall is well developed along the transmission line passage of Central Tibet Grid Interconnection Project. Remote sensing interpreting marks were established and applied to obtain the characteristics of the rockfall spatial distribution. The Langxian-Milin section with the highest linear density of rockfall was selected as the typical study section.

(2) According to the actual situation of the study zone, eight factors including topography, lithology, rock structure, slope structure, hydrogeological conditions, vegetation development, historical rockfall, and slope stability status were selected for the rockfall assessment of Langxian-Milin section. Medium serious zone accounts for the majority, followed by serious zone and high serious zone. The length of low serious zone is the shortest, mainly distributes in the Zhaxilin village to Langxian section.

(3) The rockfall hazard assessment of the typical section provides the basis for the work in the later stage of the Central Tibet Grid Interconnection Project. The transmission line passage should avoid the very serious and serious zone while selecting the tower site. The design of hazard prevention and mitigation should be carried out for the existing tower of the project, which ensures the safe and smooth operation of the national lifeline.
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