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THE CHARACTERISTICS AND VERTICAL ZONE SPECTRUM OF NATURAL DISASTERS IN THE TIANSHAN MOUNTAINS, XINJIANG①

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ABSTRACT: With the mountain elevation increasing and climate condition change, the laws of formation, distribution and development of the various natural disasters, which are caused by the climate, change correspondingly and the vertical zone spectrum of special mountain natural disasters is formed. This research is helpful to finding effective measures to prevent disasters, avoiding and reducing the harm of natural disasters to industrial and agricultural production. There are 12 disasters in Tianshan Mountains, which can be divided into three zones. (1) Base zone (torrential rain collapse zone): types of the various disasters in this zone are caused by suddenly rain in the low-middle mountain of the arid area. The disasters occur mainly from May to August, thus, the frequent periods of their bursts are simultaneous with the maximum period of precipitation in every year. (2) Middle zone (snowmelt water icing zone): most disasters, which happen in the middle-high mountain area, have close relation with variation of temperature. (3) Upper zone (snow drift avalanche zone): the movement of snow mantle creates disaster in this zone. The slope direction and height of mountain greatly influence the frequency of hazards and the formation of vertical zone spectrum of natural disasters. Due to the regional diversities of temperature and precipitation, the vertical zone spectrum of natural disasters in mountains are different in different latitude and longitude zones.

KEY WORDS: natural disaster, vertical zone spectrum, Tianshan Mountains

1 INTRODUCTION

At present, the research of natural disasters has got advances in time sequence, but it develops slowly in space sequence, especially in vertical sequence. With the mountain elevation increasing and climate condition changing, the laws of formation, distribution and development of various natural disasters, which are caused by climate, change correspondingly and the vertical zone spectrum of special mountain natural disasters is formed. Having been working in many mountains, we deeply experienced that it was important to research vertical distribution, especially the laws of the formation and distribution, which are useful in avoiding and mitigating the damage caused by natural hazards to production of industry and agriculture, and helpful in finding out more efficient engineering or other measures to prevent its damage. As a model district where the vertical zone spectrum of natural disasters can be formed there should be two conditions. First, the mountain is high enough to form a fairly integrated vertical zone spectrum of natural disasters. Second, the climate differs greatly between two sides of the mountain, so it can reflect the

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difference of the vertical zone spectrum of natural disasters under different climatic clearly. The Tianshan Mountains, almost in west-east trend, are important geographic boundary in Xinjiang. The climate differs between south and north of the mountains. Simultaneously, the height of the peaks is mainly above 4000 m; and the highest peak (Tuomuer Peak) reaches 7435.3 m. The vertical climate difference is obvious (Table 1). It is an ideal mountain to form the model.

Table 1 Temperature, precipitation and nature landscape on north slope of middle Tianshan Mountains

Altitude (m)	Average annual temperature (℃)	Annual precipitation (mm)	Natural landscape zone
400 - 800	4 - 7	100 - 200	Semi-desert zone in foot of the mountain
800 - 1600	3 - 5	200 - 300	Arid grassland zone in low mountain
1600 - 2800	2 - 3	400 - 550	Forest zone in mountain region
2800 - 3200	- 2 - - 5	450 - 600	Meadow zone in sub-high-mountain
3200 - 3600	- 3 - - 5	400 - 600	Sub-ice and snow zone in high mountain
> 3600	< - 6	400 - 500	Ice and snow zone in high mountain

2 TORRENTIAL RAIN COLLAPSE ZONE (BASE ZONE)

2.1 Water Destruction by Torrential Rain

Eighty percent of rainstorm in Xinjiang is concentrated in the Tianshan Mountains, so the mountain region become "wet island" among desert. Though normal precipitation is little in arid area, a sudden precipitation can occupy 25 % - 40 % of average annual precipitation on the north slope of the Tianshan Mountains and 40 % - 90 % of that on the south slope. Especially in Turpan, which lies on the south slope of the Tianshan Mountains, the longest continuous rainless period is 7 to 10 mouths in a year. But its maximum precipitation can reach 36 mm in 24 hours, corresponding to 2.17 times of its average annual precipitation. Therefore, the flood caused by rainstorm with high intensity in short time often destroys the roads, farmlands, bridges and towns in middle and low mountain zones. In July 1996, the bank of a reservoir was broken by torrent of rainstorm in short time in Fukang City on the north slope of the Tianshan Mountains. It brought about tremendous damage. The rush of the flood even destroyed the old Kuqa Town in 1958, which lay in the south slope of the Tianshan Mountains (Xia, 1985).

2.2 Collapse

Under the influence of the external factors, avalanche sheer precipice form collapse suddenly. It blocks traffic and ruins various architectural installation. According to the statistics from 1983 to 1987, collapses with the quantities of more than 3000 m^3 added up to 25 times at 110 km section of Duku highway of the north slope of the Tianshan Mountains. Collapse mainly occurred in middle mountain, 2000 to 3000 meters high, where relative altitude difference is obvious, rock is tattered and slope is precipitous. Simultaneously, rainstorm often occurs in middle mountain zone, it is usually the main factor to touch off collapse in summer. According to statistics (Table 2), from May to August, the times of collapse are 84 % of that in the whole year, and the quantity of collapse is 92.7 % of that of the whole year. Contrasting with Fig. 1, it is shown that the period of the violent collapse times and quantity is virtually consistent with the period of the high precipitation.

2.3 Debris Flow by Torrential Rain

From the representative data of the precipitation on the north slope of the Tianshan Mountains (Fig. 1), it is found that from May to August, the continuous

Table 2 Collapse situation from 1983 to 1987 in Duku Highway of the Tianshan Mountains

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Frequency of collapse (times)	0	0	0	2	2	8	8	3	0	1	1	0
Monthly frequency (%)	0	0	0	8	8	32	32	12	0	4	4	0
Quantity of collapse (m^3)	0	0	0	710	3850	19804	9610	2420	0	600	1800	0
Monthly quantity (%)	0	0	0	1.8	9.9	51.1	24.8	6.2	0	1.6	4.6	0

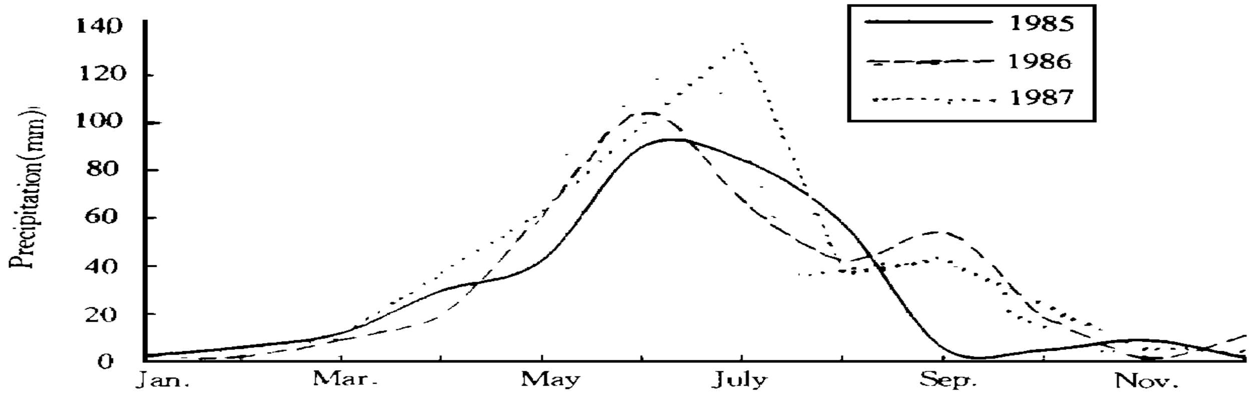


Fig. 1 The annual variation of average surface precipitation in the Urumqi River basin

four months with maximum precipitation, the high precipitation zone appeared in the middle mountain, 2300 to 3500 m high and the annual precipitation reached 590 mm. Through the analysis of relationship between the precipitation data and every month's cleared quantity of debris flow and collapse in Houxia highway of the Urumqi River basin lying on the north slope of the Tianshan Mountains from 1986 to 1988 (Fig. 2), it is shown that the frequent period of the debris flow keeps pace with the period of the maximum precipitation. Every summer, the roads in the Tianshan Mountains are destroyed or blocked by debris flow.

3 SNOWMELT WATER ICING ZONE (MIDDLE ZONE)

3.1 Destruction by Thawing Snow Water

The destruction by thawing snow water mainly happens in accumulated snow area of mountain. The temperature rises suddenly and the accumulated snow is melted quickly in later spring and early summer. At that time, engineering protecting drainage installation, such as culvert and escape canal, can't drain the water because of being filled with freezing ice.

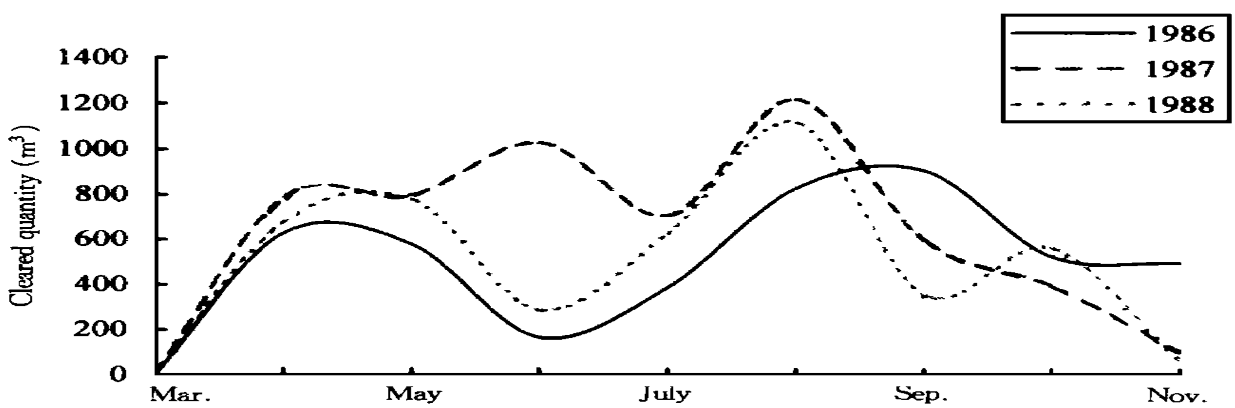


Fig. 2 The cleared quantity of debris flow and collapse in Houxia Highway

A great quantity of thawing snow water flows swiftly and violently to low-lying land, and destroys the buildings and roads in mountainous area. For instance, in the accumulated snow section, only about 30 km long, of north part of Duku Highway, the thawing snow water destroyed tens of the road surfaces and thousands of cubic meters of engineering quantity. Hundreds of thousands of RMB yuan lost every year. The injury extent of this kind destruction is mainly determined by the quantity of accumulated snow in winter and the temperature when spring is changing into summer. The thicker the accumulated snow is in winter, the higher the temperature is in thawing season, the larger the snow water runoff is, and the greater the damage is. Otherwise the damage is small. If the destruction of rainstorm and thawing snow water are in harmony with each other in early summer, the damage is more serious.

3.2 Icing Damage

Icing damage refers to the ice formed on the road of cold area in autumn and winter. It is caused by groundwater in frozen area, presents different shapes and is distributed at the altitudes of 2500 to 3600 m. The temperature changes greatly over a year in frozen area and the seasonal characters of icing damage formed on roads are different (Bai, 1987). Every year, from later October to early December, ice layer is thin and relatively gentle because of the large and quick flow. From December to February of the next year, the ice is characterized by great thickness, slow development and the steep slope. From February to late March, at the beginning it is thick and steep; as the temperature rises, the flow is larger gradually, the ice grows rapidly and becomes gentle. The development of icing damage blocks up the traffic, makes the vehicle turned over on the ice and crushed into the valley.

3.3 Glacial Debris Flow

There are many modern glaciers in the Tianshan Mountains. Every summer under the condition of continuous high temperature, glaciers and snow are in strongly thawing state. Large quantity of thawing water flows into the till in the bottom of glacial valley and other kinds of deposit. When the broken slacks in full of water approach or reach the liquid limits, they will rush down along the valley under gravity and form special glacial debris flow. From 1984 to 1985, debris flow occurred 8 times, 7 times of which were caused by high temperature (Table 3) on the section of Duku Highway near the Sancha River. The glacial debris flow was mainly formed in June in 1984. According to the climatic data of Dushanzi (Table 4) with an altitute of 730 meters, the time about 26, June 1984 when the extreme high temperature appeared was just the period of the strongly glacial debris flow. The debris flow occurred in all three high temperature days. In 1985, the debris flows were all caused by high temperature and occurred mainly in July. About 3 July, the extreme high temperature caused two times of debris flow.

Table 3 The occurring conditions of glacial debris flow in Duku Highway

Time		Debris deposits on highway (m^3)	Percentage of debris deposit in yearly total (%)	Cause
19:00 - 21:00	1 June 1984	3500	32.71	Rainstorm
20:00 - 23:00	24 June 1984	2000	18.70	High temperature
18:00 - 4:00	25 June 1984	3200	29.90	High temperature
18:00 - 4:00	26 June 1984	1000	9.35	High temperature
20:00 - 2:00	13 July 1984	1000	9.35	High temperature
19:00 - 22:00	13 June 1985	1500	20.00	High temperature
20:00 - 0:00	1 July 1985	2000	26.70	High temperature
19:00 - 0:00	2 July 1985	4000	53.30	High temperature

Table 4 The temperature elements of Dushanzi in 1984 - 1985

Year	Extreme high temperature		Average highest temperature in summer (℃)		Average monthly temperature (℃)	
	Date	℃	June	July	June	July
1984	26 June	39.0	29.6	31.0	23.4	24.5
1985	3 July	37.8	29.6	32.6	23.0	26.4

Glacial debris flow has the following characteristics: 1) The mainly formative cause is the high temperature. 2) It occurred mostly in June and July. 3) The occurring times and the accumulation quantity are large when the extreme high temperature appears. 4) Commonly, the temperature reaches the high extreme from 15:00 to 16:00, usually it occurs after 18:00. The temperature is low, so a few debris flow can be formed in the morning. 5) The possibility of occurrence is greater if the high temperature and the rainstorm occur simultaneously.

3.4 Glacial Lake Burst

Water is often accumulated on the surface or edge of glaciers and formed lakes in glacial area of high mountain zone. Trigged by certain conditions, glacial lake can suddenly burst, form a catastrophic flood and cause extraordinarily serious natural calamities. The burst can be divided into two types. One is the sudden drainage of lake water caused by rapid expansion of in-glacier channels under high temperature in summer. The other is the glacial lake bursting because of the suddenly sliding ice destroying moraine blocking lake in front of glaciers. The degree of the damage is determined by the scale of glacial lake, water quantity and the type of burst. Recently, we have found that the flood of glacial lake burst carried moraine and other deposits, which formed the flood damage in lower reaches, on the north slope of the Tianshan Mountains. There is also a similar report about the south slope of the mountains (Gong, 1989).

3.5 Thawing Sinking

The lower bound of permafrost is from 3000 to 3200 meters (Zou *et al*., 1982). The frozen soil and ground ice have certain bearing capacity in the freezing state. The bearing capacity of ice including some soil is 1.4 kg/cm^2, when the temperature is from 0 ℃ to - 2 ℃. But the seasonally thawing stratum of the upper permafrost is influenced greatly by outer conditions. When the temperature goes up in summer, or buildings and roads are built on frozen strata; the seasonally thawing stratum will absorb heat and thaw gradually from the top to the bottom, which makes the thickness of the stratum enlarge. This course is accelerated by the thawing snow water's slowing soaking. As a result of the prevention by the lower permafrost, the water is detained and can't soak down at certain depth, and is difficult to be drained. The soil is watery, just like mud, and loses the bearing capacity completely and causes sinking, collapsing and frost heaving. Hence the engineering installation is damaged seriously. Thawing sinking mostly happens in the section where the upper bound of frozen soil contains large quantities of ice, especially there is thick ground ice.

Owing to the different slope directions, the frozen soil in mountains and its thawing sinking are obviously insymmetry. The difference of the lower bounds between the north slope and the south slope is 400 meters, that of the average annual soil temperature is above 2 ℃, and that of heights of the frozen soil is 80 meters (Zhou *et al*., 1982). Contrasting with the north slope, the south slope of the Tianshan Mountains receives more radiation. Therefore, the seasonal thawing stratum of frozen soil is thicker and the quantity of sinking is greater on the south slope. Simultaneously, in every spring, the temperature of the south slope rises quickly, while declined slowly in every autumn. It makes the thickness of the seasonally thawing stratum thicker, the existing time longer and the damaging period also longer on south slope.

4 SNOW DRIFT AVALANCHE ZONE (UPPER ZONE)

4.1 Snow Drift

In summer, snow drift often occurs in the area above the upper bound of forest. In winter, it is formed in middle mountain, which should belong to snowmelt water freezing zone. The snow flow is drifted by strong wind, the big snowdrifts are produced in leeward area because of the weaker wind and largely snow deposit. The snowdrift covers up buildings and grasslands, blocks up the roads and causes a lot of livestock to be frozen. The people can not live and work commonly. The thickness of the snowdrift usually reaches 2.5 meters; locally reaches 5 or 10 meters, and its length can reach several tens or hundreds meters. Every October to May of the next year, when the snowdrift is serious, it is difficult to sweep the snow even with the sweeping machine. When the road was blocked by snowdrift, the vehicle couldn't pass the road. The men in vehicles are frostbitten or die in the low temperature. In March 1997, in Yili area, the thickness of the snowdrift reached 5 to 10 meters, it covered up the houses of the herdsmen in mountains. The livestock were frozen to die. It was difficult to find out the concrete spots of the herdsman's houses for rescuers.

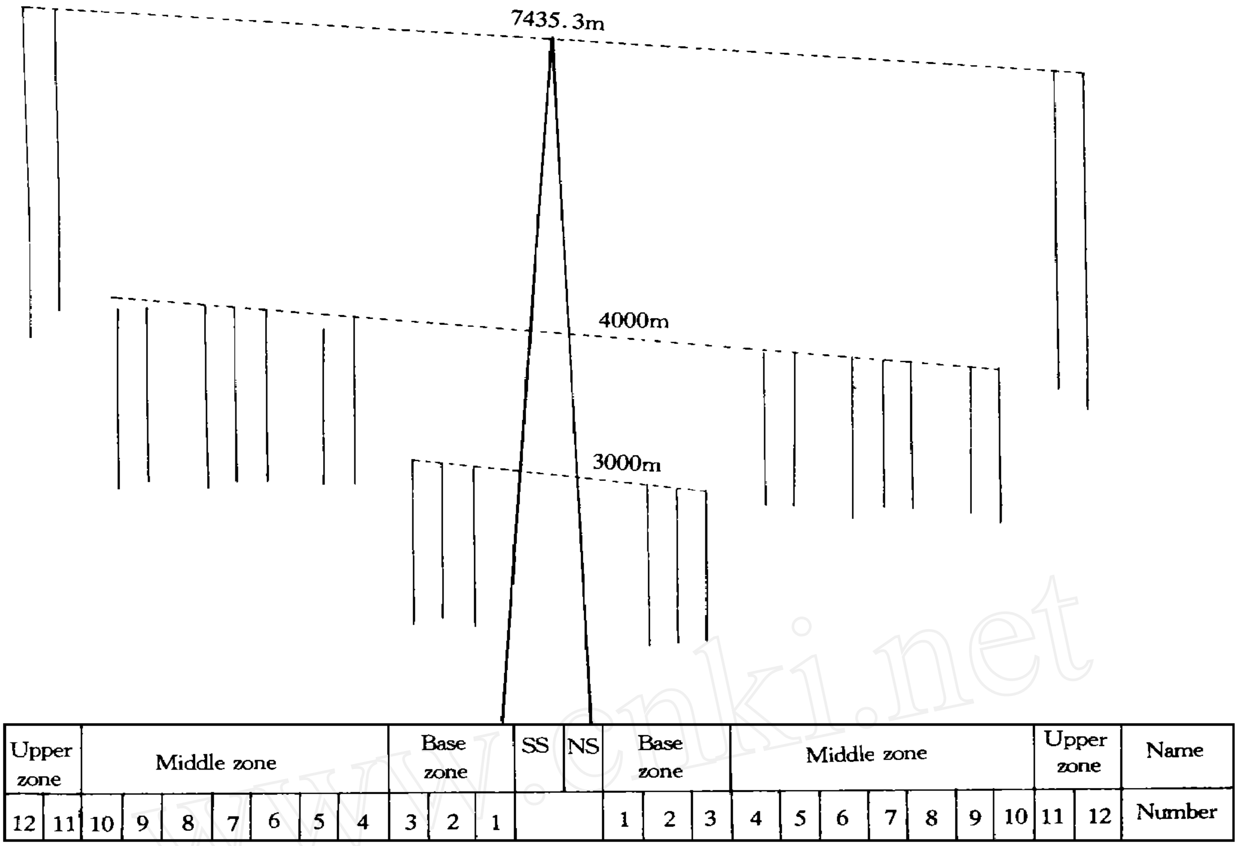
4.2 Avalanche

The stable limiting depth of snow on slope remains certainly. If the thickness of the snow exceeds the limiting depth, the intensity of the snow declines. The nature of the snow changes, so the accumulated snow moves rapidly from the upper to the low along the slope and forms avalanche usually. In the stable period of snow accumulation the depth of the snow on slope increases and reaches to the limit gradually with the snow falling continuously. During the course, the continuously strong snow falling caused by suddenly changing weather can cause the depth of the snow growing rapidly and exceeding the limit. The stable limiting depth of the snow has closely relation with the snow kind, slope and plant. In December of 1966, 278 avalanches engendered in a 27-km section of the middle part of Tianshan highway. About 44 000 m^3 of snow was accumulated on the road, the thickest snow reached 8 meters. The river course was covered by avalanche, thus forming a temporary lake, and the trees, 55 cm in diameter, were pulled up and thrown to the lower reaches (Hu *et al.*, 1987). According the differences of the height and climate, the avalanche in the Tianshan Mountains can be divided into two zones (Hu *et al.*, 1987). One is high mountain avalanche in summer, the other is middle mountain avalanche in winter, they belong to snowmelt water freezing zone.

5 CONCLUSION

Summing up what mentioned above, the vertical zone spectrum of natural disasters caused by climatic factors in the Tianshan Mountains is shown in Fig. 3. It presents a regular replacement with the changes of the height of mountains, which has closely relation with the vertical changes of temperature, precipitation, etc. Slope direction of mountains makes the height of the natural disaster zone different. On the south slope, with small precipitation and high temperature, every zone is generally 200 to 400 meters higher than that on the north slope. While in frequency of disasters occurrence caused by rain, on the two slopes, the quantitative difference is several orders. For example, on the south slope, a destruction of rainstorm or a debris flow occurs every several or more than ten years; while on the north slope, it occurs several times in a year on different scales.

The higher the mountain is, the more integrated the vertical zone spectrum of natural disasters is. For example, the highest peak of the Wutai Mountain, Shanxi Province, is only 3058 meters. Contrasting with the Tianshan Mountains, it doesn't have snow drift and avalanche zone in its vertical zone spectrum.



1. Water destruction by torrential rain, 2. Collapse, 3. Debris flow by torrential rain, 4. Destruction by thawing snow water, 5. Icing damage, 6. Glacial debris flow, 7. Glacial lake burst, 8. Thawing sinking, 9. Middle-mountain avalanche in winter, 10. Middle-mountain snowdrift in winter, 11. High-mountain snow drift in summer, 12. High-mountain avalanche in summer. SS: south slope, NS: north slope.

Fig. 3 The vertical zone spectrum of natural disasters in the Tianshan Mountains

The temperature declines from low latitude to high latitude, which indispensably makes the height of natural disasters distribution be controlled by temperature decline. For instance, the lower bound of thawing sinking is about 4100 meters in the Kunlun Mountains, it declines to 3100 meters in the Tianshan Mountains, and it is only 2500 meters in the Alty Mountains. Simultaneously, from humid area in east part to arid area in west part, the distribution height of some natural disasters also ranges from low to high. For example, the lower bound of thawing sinking is 1900 meters in the Changbai Mountains, 2500 meters in the Wutai Mountains and 3100 meters in the Tianshan Mountains. Generally speaking, due to the regional diversity of temperature and precipitation, the vertical zone spectrums of natural disasters in mountains are different in different latitude and longitude zones.

In addition, there is something to be emphasized. Influenced by such factors as the shape of mountains, the location of rivers, the slope direction and the gradient and so on, the bounds of different zones in zone spectrum are not identical. They influence each other and present obvious translation or crisscross. We must establish local vertical zone spectrum of natural disasters in mountains according to the actual local situation and make full use of it in avoiding and mitigating the hazards.

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