Analysis of Seismic Damage Characteristics and Rescue Strategies of Buildings in Tibet Earthquake

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Abstract. On January 7,2025,Dingri County in Tibet's Shigatse City was rocked by a 6.8-magnitude earthquake.The quake struck with a focal depth of 10 kilometers,in an area where the average altitude reaches 4,300 meters within a 5-kilometer radius of the epicenter.Drawing from detailed field investigations,this analysis delves into the earthquake's impact on buildings and the effectiveness of emergency response measures.It highlights the stark contrast between traditional earth-wood structures,which suffered severe damage and were the main contributors to casualties,and modern reinforced concrete frames that showed remarkable resilience.The paper puts forward specific rescue strategies,like leveraging multi-source remote sensing,bolstering aviation rescue capabilities,and refining rescue force distribution,to guide future earthquake responses in similar high-altitude,frigid environments.

Keywords: Tibet earthquake; building damage; seismic performance; emergency rescue; plateau earthquake

1 Introduction

On January 7,2025,at 09,05,a 6.8-magnitude earthquake with a focal depth of 10 kilometers struck Dingri County,Tibet,at coordinates 28.5°N,87.45°E.The disaster claimed 126 lives,injured 188,destroyed numerous homes,and caused severe economic losses [1].The quake's maximum intensity reached 9 degrees,impacting around 411 square kilometers and mainly affecting five townships in Dingri County [2].

The earthquake's epicenter was situated 36 km from Dingri County,164 km from Shigatse's heart,and 379 km from Lhasa.Within a 100 km radius of the epicenter,about 190,000 people reside,with numbers dropping to 50,000 and 10,000 within 50 km and 20 km,respectively.The area within 50 km of the epicenter has an average population density of roughly 6 people per square kilometer.The average elevation near the epicenter is around 4,327 meters,rising above 4,500 meters in the seismic zone.Nestled on

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the southern Tibet Plateau,at the Himalayas' northern foothills,the region is marked by rolling mountains and valleys [3].

Since 1970,eight quakes of magnitude 6.0 or greater have hit within 200 km of the epicenter,including two above magnitude 7.0.The deadliest,the April 2015 Gorkha earthquake (M7.5),occurred 154 km away near Kathmandu.Its aftermath crossed the Himalayas,killing one,injuring four,and costing Tibet 758 million yuan [4-5].

Dingri County lies within the Lajugangriya Belt,part of the northern Himalayan tectonic zone marked by intense neotectonic activity.Since the 21st century,the plateau has seen significant uplift,characterized by north-south fault zones and river incision.Influenced by this tectonic environment,Dingri County has undergone staged uplift,evident in faults,folds,and magmatic activity.

2 Analysis of Building Damage Characteristics

2.1 Seismic Damage Characteristics of Different Types of Buildings

Damage severity exhibited a “stepped” pattern across structural types: formally designed frame or masonry buildings (public, county residential, rural schoolhouse) remained essentially intact with only non-structural damage, whereas owner-built adobe-timber mixed dwellings—lacking any seismic provision and built with highly variable materials—were the only category to suffer mass collapse under the same intensity and accounted for the vast majority of fatalities (As shown in Table 1).

(1) Public buildings

Buildings constructed after 2000, built to code with reinforced concrete frames,mostly stayed intact structurally.However,the finishing suffered, partition walls cracked,ceiling tiles fell,and fixtures shifted.Most damage was superficial,but in some cases,it was more severe. As shown in Figure 1, the school is stayed intact structurally.

Fig. 1. Public buildings picture

(2) Residential buildings

The county's residential building,a professionally designed brick-and-concrete structure,remains largely intact.The two-story reinforced concrete frame structure also stands strong,with only minor cracks in filling walls and some parapet damage (As shown in Figure 2).

Fig. 2. Residential buildings picture

(3) Rural buildings

Survey data from eight settlements reveal clear trends.Post-2008 frame structures had infill failure rates near 80% but structural damage under 5%.1990s brick buildings saw 60% wall deformation,with two partial collapses.Proper column-beam connections saved frames,weak mortar caused wall failures (As shown in Figure 3).

Fig. 3. Rural buildings picture

(4) Self-built housing for farmers and herdsmen

Traditional pastoral homes are built with local materials,featuring adobe walls and wooden pillars.These two-story buildings rest on rough stone foundations.The ground floor,with its thick stone or adobe walls,is mainly used for storage,acting as a raised platform for the upper level.Daily activities occur upstairs,where partitioned spaces are common.Large rooms contain multiple wooden pillars supporting beams,sometimes reinforced with steel,creating a partial wooden framework.Purlins densely support the beams and are anchored to the adobe walls opposite,forming a mixed load-bearing system that combines traditional and modern elements (As shown in Figure 4).

Fig. 4. Self-built housing Pictures

Table 1. Damage extent and main manifestations by building type.

Building category	Structural type	Seismic design	Damage extent description
Public buildings	RC frame	Code-designed	Light–moderate cracking of infill walls, local ceiling fall
County residences	Masonry / frame	Code-designed	Basically intact; fine cracks in infill, minor paraplet damage
Rural public bldgs	Frame + masonry + steel	Code-designed	Heavy infill damage, some moderate masonry damage, slight structural
Farmer self-built	Farmer self-built	Adobe wall-timber post mixed	None

2.2 Spatial Distribution Characteristics of Building Collapse Damage

Within 5 km of the epicenter,seven villages and two townships (including a town) within 20 km suffered severe residential damage.Fatalities clustered significantly, 123 victims were in Changsuo,Cuoguo,Quluo,Qudang,and Xiege Towns near Dingri's epicenter,with only three in Lazi County.Changsuo Township,in the 9-degree seismic zone,had 94 deaths—75.2% of the total.This high toll stemmed from buildings' poor earthquake resistance and active fault activity in the region,marked by large vertical displacements that exceeded those in the southern 219 Highway area,compounding the disaster's impact. The statistics of earthquake casualties is shown in Table 2.

Table 2. Statistics of earthquake casualties.

villages and towns	Intensity Zone	death toll	Percentage of total deaths
Changshuo Township	Jiudu District	94	75.2%
Cuoguo Township	Jiudu District	14	11.1%
Qilu Township	Octave	13	10.3%
Other regions	7 or less	5	3.4%
amount to	-	126	100%

2.3 Historical Seismic Analysis

This earthquake, with 126 fatalities, plots far above the historical magnitude-casualty trend line for similar events. Beneath the region's low population density lies an extreme concentration of unstabilized adobe dwellings; once the intensity reached IX, this "zero-seismic-capacity" building stock triggered a cascade of collapse-entrapment that made the event Tibet's deadliest since the 1950 Medog M 8.6 quake. The historical seismic is shown in Table 3.

Table 3. Historical seismic.

Time	Location	Magnitude	Deaths
1961.08.17	Dangxiong Tibet	7.0	54
1975.01.19	Zhada Tibet	6.8	47
1993.03.20	Angren Tibet	6.6	2
2008.10.06	Dangxiong Tibet	6.6	10
2025.01.07	Dingri Tibet	6.8	126

2.4 Relationship Between Building Collapse Damage and Casualties

In Dingri County (as shown in Figure 5 and Figure 6), 56% (70) of earthquake fatalities were female,while males made up 43.1% (53).The 24-60 age group had the highest proportion of deaths at 33.3%,followed by the 0-7 age group at 30.9%.The 8-14 and 15-23 age groups accounted for 17.1% and 6.5%,respectively.

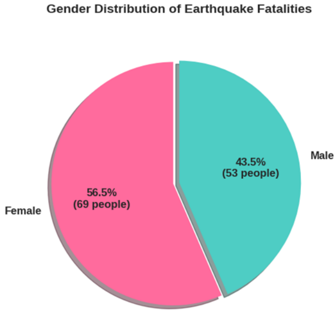

Fig. 5. Gender Distribution of Earthquake Fatalities

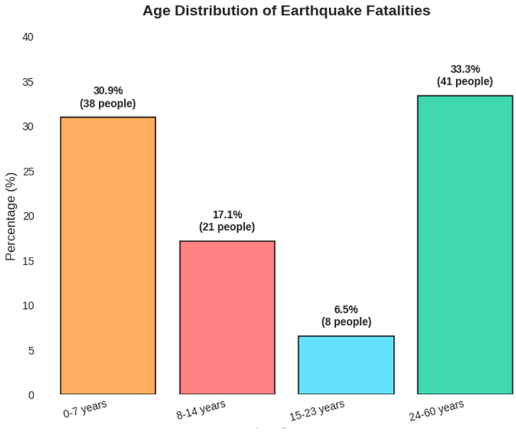

Fig. 6. Age Distribution of Earthquake Fatalities

The main causes of building collapse and casualties include:

(1)The local buildings,mostly adobe houses,exhibit poor seismic performance.Their loose structures and weak earthquake resistance make them prone to collapse during tremors.

(2)The earthquake struck at 09,05,when most residents were indoors,some asleep,leaving them little time to seek safety from the impending danger.

(3)Lifestyle factors: Local residents like to sleep against the wall, and the collapse of earth and wood houses leads to space compression and people being buried.

The earthquake struck in winter,with temperatures plummeting to minus 18℃.Buried individuals,especially the injured,faced rapid energy loss and reduced bodily tolerance in the harsh cold.

3 Analysis of Emergency Rescue Difficulties

3.1 Challenges Posed by High-Altitude and Cold Environment

Five kilometers from the hypocenter,the ground reaches 4,327 meters,with villages higher still at 4,500+.At these altitudes,rescuers battle hypoxia—dizziness,nausea,and impaired judgment.As night falls,the cold intensifies,with 20-degree temperature swings common.Tents ice over,fingers stiffen,and the mountain itself claims more victims.

3.2 Frequent Aftershocks Increase the Risk of Rescue

By 10,00 on January 10,1,653 aftershocks had been logged,including 38 of magnitude 3.0 or greater.Experts caution that the quake zone still faces risks of 5-6 magnitude tremors soon.Frequent aftershocks threaten rescuers and raise the chances of secondary disasters,disrupting relief efforts' continuity and effectiveness.

3.3 High Risk of Secondary Disasters

Following the earthquake,the area—located in the Himalayas' northern foothills with its rugged mountains and valleys—saw landslides,roadbed deformation,and sand liquefaction.These secondary disasters worsened rescue efforts and posed significant risks to the safety of those involved in the relief operations.

3.4 Weak Infrastructure Restricts Rescue Efficiency

The epicenter lies in a remote,cold mountainous region with poor transportation and fragile infrastructure.Lifelines like communication and power are severely damaged and hard to restore.This hinders the rapid deployment of rescue forces and supplies,while impeding information flow,severely limiting relief efficiency.

4 Emergency Rescue Strategy Recommendations

4.1 Expand Data Acquisition Channels and Accurately Assess the Disaster Situation

Leveraging technology to boost emergency response can lessen earthquake impacts.Building collapses,a major concern in post-quake relief,not only show earthquake severity but also are the main reason people are trapped and buried.

We suggest creating an integrated space-air-ground system for assessing buried personnel.By merging multi-source remote sensing and basic data with deep learning,it achieves deep multimodal alignment.This system analyzes building traits and data transmission across spaces,offering smart decision support during crucial post-earthquake rescue efforts.

4.2 Rapidly Improving Aviation Emergency Rescue Capability

Air emergency rescue can quickly complete the following key tasks after an earthquake:

Disaster reconnaissance and info transmission, Swiftly reach the disaster zone by air,conduct thorough surveys using photoelectric gear and synthetic aperture radar,and relay high-def images and data in real time.

(2) Search and rescue and transfer of personnel: hover rescue in complex terrain area to transfer trapped personnel to safe areas.

(3) Material transportation and delivery: Fast transportation of food, medicine, tents and other relief materials, and accurate delivery by air to the disaster areas with inconvenient transportation.

(4) Emergency communication support: Serving as an "airborne base station" to restore public network signals in disaster-stricken areas and ensure uninterrupted communication

(5) Medical rescue and transfer: The injured are quickly transferred to the rear hospital to shorten the time of first aid and improve the efficiency of treatment

During the Dingri earthquake,the Wing Loong-2H drone delivered crucial reconnaissance data to rescuers,underscoring high-tech gear's vital role in plateau earthquake relief.

4.3 Optimizing the Deployment and Support of Rescue Forces

In view of the characteristics of earthquake rescue in plateau, it is suggested that:

(1) Form a professional plateau rescue team: select and train professional rescue personnel adapted to the plateau environment, and equip rescue equipment adapted to the plateau environment.

Establish a tiered rescue system, Allocate rescue forces scientifically based on disaster assessments,prioritizing the hardest-hit areas' urgent needs.

Enhance high-altitude rescue personnel protection, Supply ample oxygen,cold gear,and altitude medication.Implement a rotation system to prevent non-combat casualties from altitude sickness.

(4) Improve the logistics support system: establish a rapid supply channel to ensure the timely supply of food, medicine, fuel and other relief materials.

4.4 Strengthening the Seismic Retrofitting of Traditional Dwellings

This earthquake shows traditional homes cause most casualties.It's advised to assess their seismic performance in plateau areas,create tailored retrofitting plans,and promote simple reinforcement methods to boost resilience.Meanwhile,targeted education campaigns should raise seismic safety awareness,enhancing local earthquake preparedness.

5 Conclusions and Outlook

The Tibet 68-magnitude quake highlights seismic challenges in high-altitude,cold areas,with unique building damage and complex rescues.Traditional earth-wood structures failed,causing high casualties,while modern frames held up.Rescue faced harsh conditions,aftershocks,secondary risks,and poor infrastructure.

Future priorities, Implement a rapid disaster assessment system with remote sensing and AI,boost aviation rescue in high-altitude areas,optimize rescue force deployment,and upgrade traditional housing seismically.These steps will enhance disaster response,minimizing casualties and damage.

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