

THE MAIN FACTORS AND MECHANISM EFFECTING ON THE EARTHQUAKE RESISTANCE STABILITY OF GROTTOS RELICS AND COUNTERMEASURES

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SUMMARY

The Buddhist art of grottoes is an important part of splendid culture in the long history of China, which is also highly valuable tourism resources. The grottoes and relics have been suffering the erosion of wind, sand, raining water, burning of sunshine, agency of earthquakes and effect of human activity that they come to the state of many types of disease. Furthermore, many grottoes are situated in the areas subject to high seismicity and high intensity, so it is necessary and pressing to enhance countermeasures of earthquake resistance and disaster reduction for grottoes relics preservation, which is of course important for the human civilization to be kept. In connection with characteristics and disease features of grottoes, the internal actions and external environment conditions causing earthquake resistance stability of grottoes, such as weather and climate features, seismicity, hydrology features, environmental engineering geology, structure of grottoes and the particularity of cultural relics and human factors, are analyzed in detail.,the causing mechanism is expounded, and the controlling countermeasures are proposed. It can be served as basis for the scientific conservation and restoration of grotto relics.

INTRODUCTION

The grotto art of Buddhism is an important part of the splendid culture in the long history of China, which is also highly valuable tourism resources. The grotto-cutting was derived from India, started at Han Dynasty, prospered at North wei, Sui and Tang Dynasty, and lasted till Ming, Qing time. There are many famous grottoes in China land, such as Dunhuang Mogao grotto, Datong Yungang grotto, Luoyang Longmen grotto, Tianshui Maiji grotto, Kzer , Dazu stone inscription, Anxi Yulin grotto, Yunjing Binglin Temple grotto and Guangyuan Huangze Temple relief sculptures . It is estimated that the number of grottoes and relief sculptures is more than 250,of which 35 is included in the list of state relics key preservation and more than one hundred in the list of province-level relics preservation, and some have been listed in the world cultural heritage. Grotto construction and sculpture art, like the stars scattered in the state, forms a particular culture group of China.

The grottoes were mainly taken as the ritual sites for Buddhism in the past. Because of the difference between geological condition and climate condition in different place, two method of carving and molding (and painting) were used for the grottoes. During long strain of history, the grottoes have been suffering the erosion of wind, sand, raining water, burning of sunshine, agency of earthquake and effect of human activity that they come to the state of many types of dangers: geological potential disaster ,in that rock mass of slope isn't stable, dangerous stone of precipice is too lot, the cliff of cavern have been crazed, the top of cavern have collapsed and dropped, the weak intercalation has siltized etc geological disease; the disease which caused by rainwater, river water, ground water and other source; the weathering disease of grotto's rock mass and lapidarian

sculpture; the damage of painted sculpture, statue and mural; the harm of sand blown by wind[Jinshi Fan,1993];As the abundant and costly culture heritage, we have duty to preserve the grottoes. Developing the work of preserving the grotto relics, is not only a great task connected with further developing and promoting

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Chinese •all kinds of man-made disaster, including tourism's social effects of pollution, environmental pollution, engineering vibration and other redeposited disaster caused by human being's social and economic activity.splendid culture, but also can bring obvious good profit for Chinese economy. Herence, this article will expound the primary factor effecting on the grotto earthquake resistance and stability, analyze and research the causing mechanism and the comprehensive controlling countermeasures, in aim of promoting the perservance scientifically ,comprehensively and feasibly.

THE PRIMARY FACTOR EFFECTING ON GROTTA EARTHQUAKE RESISTANCE AND THE MECHANISM

Geography climate and meteorological factors

The west-north area and west-south area, in which the grotto relics relatively concentrate, have obvious difference in natural geography and climate. most of the grottos in west-north area are situated at middle of the desert, where is of typical continental droughty climate characteristics, such as the extreme droughty climate, the low level of water, the great difference of humidity and temperature, High frequency of wind saved. The special climate is the main reason that keeps the grotto relics from destroying during a long time. But as the great difference of temperature during a day in this area, and the wide range of humidity in the hole, which has been along with varying of season and intensity of sun's ray, the mural's layer and paint layer and painted sculpture, suffered by alternate hot and cool, drought and wetness for thousands or hundreds year, have been serious full of cracts and faded. on the other side, the desert disease. On the one hand, the top of hole is too thin, which caused by that right affect protective condition and environment of mural. dry and cold climate conditions, objectively resulting in wetting and drying—freeze and thaw disease of the grotto's rock mass, cause the relaxation of the construction of the grotto's rock mass, as well as disintegration and destruction.

The surface of most rock-cut buildings in northwest region is generally covered by sand hill and the sand source is abundant. At the same time, the weather in this region is windy and its strength is large, it occurs abruptly and blows sand far away, this provides external conditions for disasters by wind. On the hand, the strong deflation or abrasion by sand flow makes the top of cave body thin, this threats the preservation conditions and environment for mural paintings. on the other hand, the strong cumulative sand not only blocks trestles and cave gate, pollutes the cave region environment and obstructs tourists to visit, but also the strong wear to mural paintings and statue will happen if sand and dust enter rock-cut buildings[Yucheng Shi,1996]. The typical examples include Mogao cave and Shikong cave, Ningxia.

The southeast region also exist many rock-cut buildings and statues, the weather belongs to the combination of moderate zone and subtropical belt with high moisture and low evaporating. there are a series of strong weathering process' including oxidation, ablation action , hydrolytic action, hydration, biochemical action and so on. The carved stone and rock mass in Shichuan Dazu sculpture ,Huangze statue etc. is suffering severe efflorescence disaster. At the same time, the strong sunlight in summer in this region make the stone surface fracture. The long time spit and vapour in Shichuan often deposits on surface of rock mass, this have some corrosive action on carved stone and lithoglyph.

Earthquake Activities

The various geological disasters on rock-cut buildings include the heavy collapse of rock mass, dense fissure, assorted cliffs and so on. Besides the excessive dig and unreasonable structure, the local region geology and new tectonic movement is a important factor. Many rock-cut buildings locate in the area with complicated geological structure and frequent earthquake. Many historical earthquakes shock rock-cut buildings(such as Dunhuang Mogao rock-cut buildings, Tianshui Maijishan rock-cut buildings etc.). According to "China Earthquake Intensity Zoning Figure(1990)" issued by State Seismological Bureau, more than 60 percent of the major rock-cut buildings announced by State Council locate in the zones whose basic earthquake intensity is seven or above. It is found that the earthquake and geology background where the rock-cut buildings locate is not optimistic. Now it is in the active period of earthquake, we should pay attention to the coming earthquake effect on rock-cut buildings.

Hydrographic Characteristics Factors

Hydrographic factors (mainly including rain, atmospheric water, underground water etc.) is an important reason why lead to many kinds of disasters for rock-cut buildings. The main harmfulness' are: 1degradation accelerates the collapse of rock mass. 2the harmful seepage action of underground water and surface water increase the inside moistness of the cave and accelerate the weathering disintegration of the rock mass of rock-cut buildings, statues and carved stone, also destroy and soften the mural paintings ,and accelerate the mural paintings to be chalked.3the rising water level of river and its continuous corrosion and downcutting lead to destabilization of side slope.4the slow erosion action on carved stone.

Environment Engineering Geology Factors

Lithologic Character

Lithologic character is the innate material base causing many disasters to rock-cut buildings. According to the characters, the rock-cut buildings are classified as sand type, pudding stone type, limestone type, mudstone type, griotte type and mixture type of sand and mud etc. Because of the different material ingredients and structures, the ways, properties and extent causing disaster to rock-cut buildings are different. Decency is the most popular and severe problem, the decency extent is closely related with the rock's physicochemical property, rock mass' structure and the natural environment rock-cut buildings is locating.

Rock Mass Structure

The development extent, slant, combination shape and the space relationship to steep wall of the geological discontinuous surface existing in different rock mass's are an important factor causing disaster to rock-cut buildings. The major harmfulness' are: 1it destroys the completeness of rock mass, degrades the strength of rock mass, leads to the rapture of palisades, produces cliff, accelerates the formation of collapse and spalling of cave top, directly affects the stability of side slope; 2it provides the channel for water permeation and saline matter transportation, produces severe permeable disaster; 3the cross cutting which the fissuring crack imposes on rock mass create the conditions for weathering capacity, accelerates the weathering damage on rock mass; 4the bottom layer of mural painting produces fracture and collapse with the fracture of rock mass.

landform and Topographical Features

Special landform and topographical conditions is not only an important reason why produces various bad geological phenomena , also brings the negative effect on the coming earthquake stability of rock-cut buildings. As most rock-cut buildings locate cliffs of mountain valleys, the height on cliff ,the scale of mountain where rock-cut buildings exist and its relative landform difference with surrounding environment, the slope degree of the rock mass where the upper part of rock-cut buildings locate and microtopography characters etc. are very important for the safety and protection of rock-cut buildings.

Earthquake-induced disasters indicate that landform height difference have obvious effect on earthquake disaster, especially when the site locate on the banding nose, towering hill and the steep slope which is not made form rock, the effects are very severe. Many rock-cut buildings were cut on cliff whose height is 20 to 30 meter or even 70 to 80 meter. When they are hit by the coming earthquakes, this special landforms have obvious amplification on the acceleration of the upper rock-cut buildings, this is unfavorable to seismic stability.

The Structural Particularity of Rock-Cut Buildings

As the structures of the massive rock-cut buildings with special function, most rock-cut buildings shape in colony. Many famous rock-cut buildings experienced about 1000-yearred cut, one was cut on another one, the shape is just like a honeycomb. The excessively dense rock-cut buildings make partition wall among the rock-cut buildings and the bottom rock layer become thin, this seriously weakens the rock strength, this is another important reason why causes various geological disasters in side slope. In addition, because of religion and aesthetic standard in that times, the rock-cut building was cut arbitrarily. the different structures correspond different times. Due to the level limit of science and technology, it is impossible for man in that times to design out the reasonable geometry, span, height, the space combination of cave body, construction technology and so on. This certainly brings many incipient faults for the safety of the rock-cut buildings.

Human Social Activities

In history, Chinese caverns are the famous sites of religion activities. Scattering population, inconvenient transportation, add the factor that many caverns are hidden in mountains and forests, which made them affected less by artificial environmental pollution. Even after thousands of years, these caverns keep their original feature. This is a favorable condition for long term preservation of cultural relics. In recent years, however, as tourism develops prosperously, shortsighted activities in economy, cognitive deviation and poor disasters prevention consciousness have changed the natural environment of caverns in many aspects and aggravate the existing damages and, perhaps, induce some new ones.

Damage Due to Tourism

As a common phenomenon of society, economy and culture, tourism has become an important constituent of modern lives. Flourishing of tourism not only stimulates the economic development but also brings some jeopardize. Because of the sharp increase of visitors, on the one hand, the number of different vehicles travelling in the cavern and its auxiliary structures increase greatly and exhaust gas ejected by machines pollutes the environment. On the other hand, flourishing of tourism also drives the development of local service industry, commercial and restaurant industry. As a consequence, residents and floating population nearby increase year by year. Nocuousness, such as sewage, SO₂ and dust also soars, which affect the atmosphere quality of the area heavily.

Moreover, respiring of visitors affects the microclimate inside the cavern dramatically. At the same time, trestle aid on cliff, both upper and lower channels and the thin motherboard of caverns are in distress. It is an incipient threat to the long term preservation and normal function of caverns.

Environment Pollution

Environment pollution includes air pollution and acid rain. With the developing of economy, there rise many factories around the cavern. Most of them lack proper scientific planning and management. The wastes are released into the environment without necessary treatment, which pollute the environment of the cavern seriously. Moreover, the ventilation of factories, use of coal by families as main energy resource and the aggregation of population cause extra heat to enter the air and change microclimate of the area near the cavern. This is a disadvantage to the preservation of caverns.

Serious air pollution will cause the forming of acid rain. When the rock is eroded by acid rain, corrodibility like CO₂ and H₂SO₄, which make the sulphate and carbonate hydrolyze form clay mineral, will reduce the strength of rock body.

Environment Vibration

The environment vibration caused by explosion, machinery, trains, automobiles and other human activities can produce serious effects on historical relics like cavern. Since many mines and plants are located around cavern, vibration value produced by heavy engineering equipment exceeding certain limit can threat the safety of cavern (such as Longmen cavern).

Damage Due to Engineering Activity

Engineering disasters mainly mean the secondary disasters caused by human activities nearby. Mass water exploitation by coal mines and agricultural irrigation around the cavern can obviously decrease the underground water level and probably result in the ground settlement and cause the rapture of the sculpture in the cavern. The excess irrigation for afforestation also lead to the permeation of cavern and aggravate assorted damages.

The Secondary Damage Caused by Improper Preserving Measures

A series of engineering activities and trials for protecting cavern and mending historical relics have been carried out, these can objectively cause some secondary disasters or aggravate it.

THE COMPREHENSIVE MEASURES FOR PRESERVATION

Cavern preservation virtually is to deal with the mutual coordination and unification of the cavern relics and natural environments, cultural environments, administration agency, service utilities, tourists and so on, thus to protect cavern and prolong its natural enduring period. Confronted with the increasingly serious damage due to

natural disasters and human activities, there is the urgent and necessary task of taking action on disasters prevention and mitigation. According to the forming and developing of different damage and the unique feature of relic preservation, corresponding measures should be taken. However, the principle of “having prominence and to be practical and effective, juxtaposing prevention and treatment of damage and dealing with the damage in an integrated way, keeping the originality of relics and making it harmony with the environment.” is applied[Yucheng Shi, 1998].

Giving More Attention to the Research on Damage Prevention and Mitigation

It is necessary to carry out the survey, exploration and evaluation of the geological conditions. At the same time, studies on the seismic stability of rock body and auxiliary construction of the cavern, the effect of human activities on the damage forming and the protection of stone stature, fresco and color sculpture should be continued.

Strengthening the Engineering Measures of Prevention and Attaching More Importance on the Selection of Scheme of Treatment.

Under the pre-condition of doing no harm to the relics, it is important to strengthen the treatment effort and intensify the integrated management of the cavern to nip in the bud of damages of all kinds to the cavern. The decision-making system composed with experts and administration officials should be established. With the system, it is possible to select treatment measures of technically practical and economically reasonable before they are put into practice.

Establish or Perfect a Dynamic Damage Monitor System of Cavern and Environment Monitor System

The monitor on the environment charges is a predetermination of any treatment measure. The dynamic monitor system on geological disasters and environment quality should be established or perfected. On the other hand, a long period monitor system on cliff rapture, small grotto and the strength and displacement of auxiliary constructions is necessary.

Proper Limitation on Human Activities, Strengthen the Environment Management and Broaden the Function of Cavern Management Agency

It is very useful to stipulate a perfect rules, employ a proper policy, pass some laws on the management of cavern and make all these under strict supervision to guarantee their implementation.

Establish the Information System Including the Cavern Archives, Damage Prevention and Environment Monitor Information

This is to design computer information systems which is capable of creating database and sorting, storing, managing, retrieving and transferring data. Information, such as nearby environmental disasters, human economic activities, the excavating of cavern and its artistic value and geometry size, characteristics of surrounding rocks, distribution of ruptures, previous engineering treatment, scientific trial performed, the diagnosing and analyzing of potential damages, the prevention of damages, the repairing of relics and observation data on micro-climate in the cavern should be included.

Increasing the Investment for the Prevention and Mitigation of Damages to the Cavern

Certain amount of funds should be provided for the environment protection related to the cavern preservation and damage prevention and mitigation. The preservation of cavern relics is a public affair. The money and preservation effort from the government are not enough, Investment from all sides should be encouraged. At the same time, cavern relics are valuable tourism resource and cultural treasure, expanding of its economic potential, more international cooperation and exchange on cavern preservation and utility. Propaganda and donation from organizations and individuals should be encouraged to get enough funds.

ENDING

The historic relics are an valuable cultural phenomena, which is an vivid record of the life of our ancestor. There is great importance for the modern society to keep the continuity of our history. But the prevention and mitigation of damage to the cavern relics is a complex systems engineering. On the one hand, not only the

serious danger posed by natural disasters should be take into consideration, but also the involvement of various human activities in the forming of damages to the cavern should also been realized. On the other hand, it should be understood that the prevention of historic relics such as cavern is an extensive social campaign, which needs the participation of government institutes and the public and depends much on the advancement of science and technology. With that common understanding, a optimum environment for the preservation of relics can be created through overall planing of preservation measures. The further work needed for the preservation of cavern relics is to clarify the forming and developing mechanism of all the damages to the cavern theoretically and to find preservation measure of more effective and all-sides.

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REFERENCES

Jinshi Fan(1993) , “Report on the Future Prospects for the Maintenance and Conservation of the Dunhuang Mogao Grottoes”, *Proceedings of Dunhuang Research*, pp4-12.

Yucheng Shi(1996),“Effect of Future Earthquake on the Dunhuang Mogao Grottoes And Their Subsidiary Buildings”,*Northwestern Seismological Journal*,Vol.18,No.3, pp42-47.

Yucheng Shi(1998), “Earthquake Resistance of Grottoes and Preservation of Cultural Relics”, *Journal of Catastrophology*, Vol.13, No.4, pp90-94