

# The Study on Structural Design of Buildings on the Slope

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**ABSTRACT** The current code for structures mainly focuses on the flat ground buildings, neglecting the particularity of the structure on the slope due to the lack of targeted control indicators and guidance. Several problems that require special considerations in design and some reference solutions were proposed from three aspects, including seismic design, foundation design and supporting structure design.

## KEYWORDS

Structural design  
Supporting structure  
Foundation design

## 1. Introduction

In recent years, as people living increase environmental requirements, and adapt to the natural environment, combined with the mountainous terrain of mountain building more and more in suburban mountain and mountain city.

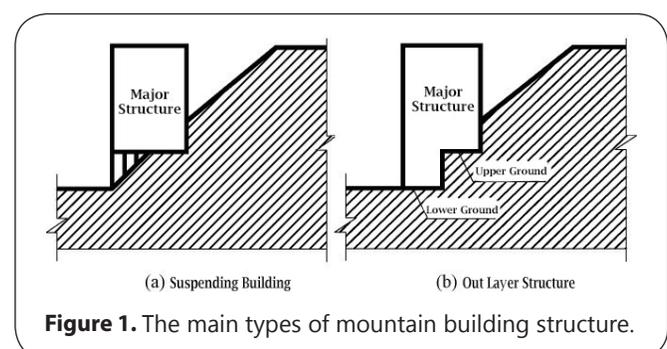
Mountain building structure [1] in the form of mountain building structure, due to mountainous terrain means necessary, on the slopes and cannot be reduced to the same level of structural forms part of the base member is not bound by the same horizontal plane. To adapt the structure and topography of mountain building unique form, while the need to adapt and mountainous terrain, causing its structure is not easy to adjust, while accompanying irregular vertical plane irregularities. This determines the complexity and particularity of mountain seismic design seismic response of structures.

Due to the lack of mountain seismic design of building structures and the special problems of understanding related to the investigation and analysis of earthquake damage, targeted research is still relatively small. There is no system of basic research carried out structural design special problems of mountain areas, the lack of mountain building structure design guidance research, but did not match with the national norm. But with the accumula-

tion of more and more practical engineering needs and engineering experience, research in this area has been some progress. Chongqing Municipality in the forthcoming "Chongqing Residential Building Code" (hereinafter referred to Chongqing Residential specification) for computing aspects of mountain building and construction, etc. have put forward some demands, but its comprehensiveness and specific operability the actual project has yet to be tested. This article intends to propose some design work the problems encountered and part of the solution from the seismic design, foundation design, retaining structures design in three aspects, for similar projects.

## 2. Type Delimitation mountain building structure

According to the structure of the main types of mountain building in Chongqing Residential specifications mentioned are hanging off the foot structure and layer structure (Figure 1). Basic engineering practice this can be classified into two categories or types derived.



## 3. Mountain building seismic design of special problems

Seismic design of building structures through the concept of design, calculation and seismic structural measures to achieve three levels. Conceptual design is the overall struc-

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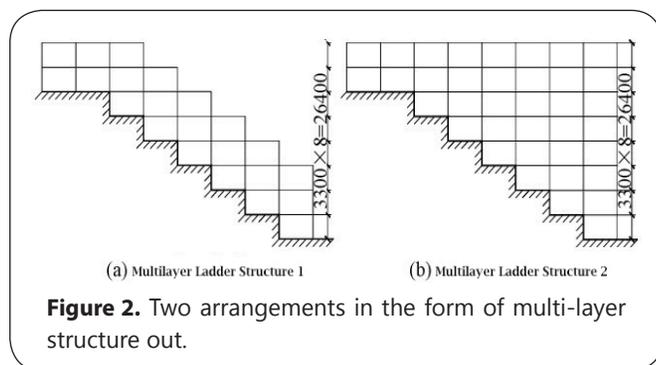
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ture of the overall seismic performance of the control, usually by controlling the structural height and aspect ratio, and the vertical plane of the building structure and other aspects of the rules to achieve. Wherein the plane and vertical rules of concrete structure is achieved by controlling the stiffness ratio, intensity ratio, reversing the effects of other indicators. And when the actual calculation of these indicators, there are two problems: First, how indicators in real terms; the second is whether the adaptation of these indicators mountain building. Currently, the specifications of the control of these indicators are based on more conventional terrain and for consideration of the special nature of mountain building deficiencies. So, based on indicators of control over conventional terrain of the building, to be corrected by the structural characteristics of mountain building it becomes very necessary.

### 3.1. Seismic conceptual design issues

Structural height defining how to determine the starting point, is to take the highest or lowest ground or mean Chongqing Residential norms drawn from the lower side of the outdoor ground starting, this terrain is relatively conventional terms are strict building requirements, many practical projects are also essential Click adoption. But for multi-off layer (hanging feet) structurally, whether it is the same adaptation structure as shown in Figure 2, the height of the two structures are the same.



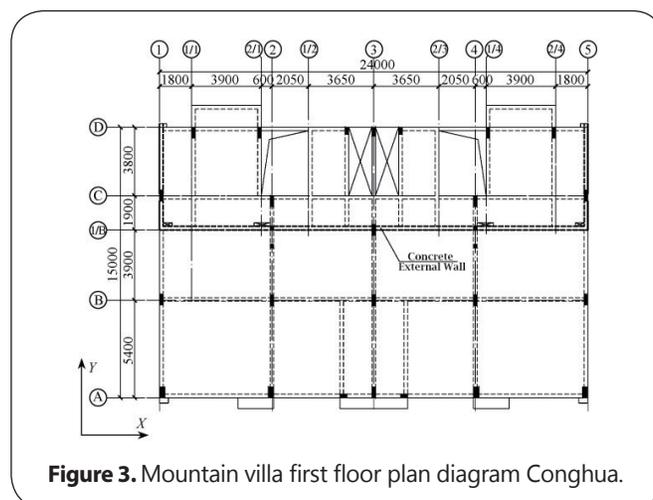
Press the Chongqing Residential specifications starting from the lower side of the outdoor ground to the height of the main roof structure 1 and structure 2 is the same height, have reached 26.4 m, it should be defined as a senior. But for the structure 1, its maximum height main vertical member was 9.9 m, it should be considered by the multilayer structure. It is suggested that the definition of building height limits should be adding additional conditions: not more than the actual height of the main vertical members (including its upper part is Underpinning member height) is appropriate.

Structure embedded solid end how rational selection. Structures for the mountain, the bottom of the constraint is not the same level of its unique characteristics, it should also be embedded solid points at different heights according to the actual selected. But embedded solid end of the fixed point on the inlay solid or solid point lower inlay

according to “Seismic Design of Buildings” (GB 50011-2010) [2] (referred to as the anti-regulation) the provisions described in section 6.1.3: multi-layer and high-rise building with basement, when the basement of stiffness and shear capacity than the upper floor is relatively large, the basement ceiling can be regarded as embedded solid parts yield under earthquake site will take place on the ground floor, while the affect the basement. As can be seen from the provisions of explanation, embedded solid end means end embedded solid strength on the Chongqing residential specification prepared: embedded solid end position when the election on the ground, the lower part of the lateral stiffness of the structure and the corresponding portion of the upper structure ratio  $\geq 2$ .

But only control the stiffness ratio, without control embedded solid end of the following anti-side member layout is reasonable, I believe that the effect of reversing the control structure is still defective. Recommended for displacement ratio calculation, embedded solid end embedded solid still choose the next point, and note the point where embedded displacement ratio solid layer control. The author of a mountain villa from engineering practice to be controlled in this way, as shown in Figure 3 and 4 are planar, cross-sectional view of the villa. Due to the presence of a solid basement under the inlay façade, lower inlay solid layer and the upper layer embedded solid whole layer stiffness ratio of X to 3.25, Y direction is 3.69.

If we consider only the corresponding portion, stiffness ratio should be bigger, full compliance with the requirements of the embedded solid layer as an embedded solid end. At the same time as the embedded solid layer embedded solid end to displacement ratio X is 1.58 (corresponding to maximum story displacement angle is 1/9999, refer to “Technical specification for concrete high-rise building structure” (JGJ3-2010) [3] (referred to as high regulation) in section 3. 4.5 shows that displacement ratio to meet regulatory requirements), Y direction is 1.26. The results show that under the reverse effect due to the embedded solid layer of anti-bias on the structural side members bring obvious. It controls its displacement ratio is reasonable and necessary.



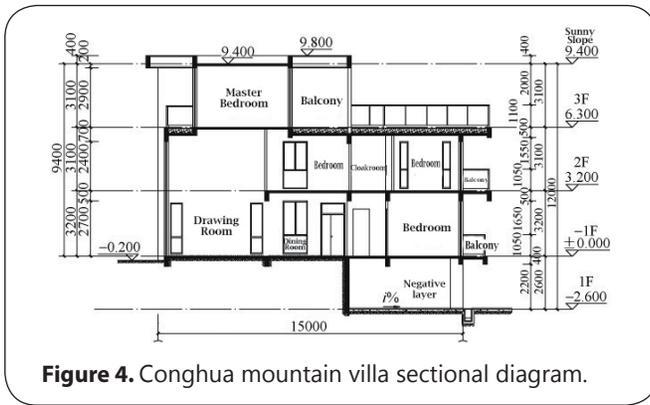


Figure 4. Conghua mountain villa sectional diagram.

The results also reflect the embedded press as embedded solid end to control the displacement of more than a solid layer on the solid layer embedded displacement ratio is relatively large, but among its corresponding maximum drift angles are very small. We recommend anti-regulation and high regulation limits control release containing embedded solid member floor displacement ratio.

(Maximum displacement/minimum displacement) and (maximum displacement/average displacement) curve can be seen from Figure 5, 1.4-1.6 substantially straight section, rather than the inflection point of anti-regulation and high regulation provisions, from a security perspective, there is a certain leeway. We recommend reference to "the implementation of Guangdong Province Case < Technical Specification for Concrete Structures Tall Buildings > (JGJ 3-2002) Supplementary Provisions (DBJ/T 15-46-2005) [4] in height for Class A torsional displacement ratio in the interlayer displacement angle is small enough, relaxed to 1.8.

In addition, as fixed-point embedded in different elevations, its lateral stiffness in the foot hanging on or off the floor level, the lower the presence of lateral stiffness mutation, if just degree difference between the larger, can cause upper and lower member forces mutation, prompting some members ahead of destruction, so mountainous control structures or on their feet hanging off the floor level, the lower stiffness ratio is very important. Chongqing residential high specification with reference to the proposed regulation concerning the conversion layer stiffness ratio

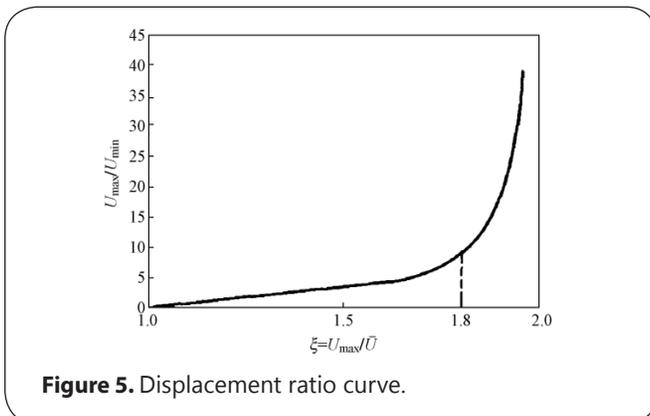


Figure 5. Displacement ratio curve.

under control requirements, the corresponding stiffness control indicators, and this requirement is largely perfected the mountain structures control targets in terms of the rules, but also have Operability.

### 3.2. Earthquake force calculation on the issue

The seismic force analysis and calculation methods, how to simulate real seismic forces mountain building structures? Existing seismic force analysis and calculation method is based on analysis of embedded solid foundation for simultaneous input terminal and each base seismic force carried out. The basis of the actual mountain building structure high and low, the nature of soil may also have a greater difference, conventional seismic force calculation of adaptability for further study.

Mountain building structure due to the integration of environment and terrain, easy to form a one-sided, two sides, three sides of the basement with constraints, such basement mechanical characteristics under seismic influence soil properties constrained by side, their seismic action Further studies response characteristics required. Existing common structural calculation software flexibility and operability of all are needed to be improved.

In addition, the mountain building structural internal force analysis conventional computing software under earthquake also need to improve, such as off the layer structure shown in Figure 2 (especially multiple layer structure out) calculation and analysis, which are not adaptable obvious: If PKPM out of the above-mentioned multiple-layer structure of the internal forces analysis shows, which is characterized by seismic shear structure with no distinction between ordinary and still increasing from top to bottom, but actually since the ground layer of the vertical member will be transmitted to the base portion of the seismic action and then spread to the foundation, so the ground floor of seismic shear layer should be reduced only realistic.

### 3.3. Problems of earthquake on structure

Because of the characteristics of mountain building structure itself, the seismic performance should have its own unique characteristics, anti-regulation should be added to a portion of the contents of an analysis of the seismic performance of mountain building structure, according to the force, deformation characteristics, targeted to strengthen the weak parts.

Chongqing Residential specification intends to post on the ground mountain building structures and seismic level hanging feet off the floor-level portion of the increase. Also provides for off-layer structure with the upper layer of the ground floor off the column adjacent to a thickness of not less than 120 mm, ground post and off layer part of strengthening the requirements for pull beam connected.

#### 4. Mountain building structure foundation design special problems

Mountain building structure foundation design has its own unique characteristics: the need to consider the impact based on the terrain, the venue at the same time, due to the impact site, it must consider the feasibility and difficulty of construction.

Under mountain building in most cases building with original terrain, th is time, under normal circumstances, the foundation is better, good stability of the slope itself (if necessary fill, the fill slope stability program subject to checking and processing), but because of the presence of building foundations on the slope it adds additional stress, the impact of this stress on the slope calculation must be analyzed. "Building Foundation Design Code" (GB 50007-2011) [5] (referred to as the foundation specification) in paragraph 3.0.2 points out, built on a slope or slope near buildings and structures, there should be checking their stability. While specific control methods for natural base in 5.4. To sum up the basic principle is: slope stability to meet the requirements of their own, building foundations try not to adversely affect the slope (Foundation specification within the provisions of Article 5. 4.2 range), if you need to calculate the next analysis of stress. **The slope stability.**

According to these principles, under the edge of the slope away from the building generally considered natural-based, while the slope side of the building considered as deep foundations, which bring adverse effects can be avoided slope stability. But generally the edge of the slope terrain, smaller venues, a large deep foundation construction difficult. Conventional pile foundation construction machinery on site requirements are relatively open, difficult to apply. Relatively speaking, the construction of manual hole digging pile (pier) is flexible, adaptable, basic quality is more assured, and with more applications, but due to its large operating risk workers and restricted, and pile too near the slope, because the pile in slope, the lateral earth pressure suffered unequal partial pile and easily create security threats to workers. How to make construction machinery miniaturization and can adapt to changing venues, the construction unit will need to improve existing equipment.

The author in Conghua mountain villa, on the part of filling deep slope adjacent building with a small, steel pipe pile foundation, due to its size and construction equipment, drilling equipment equivalent size, so small footprint and flexibility. Use seamless steel tube (Figure 6) 146 × 10, the pile tip into the weathered granite layer is not less than 3m, pile capacity value of 600 kN.

Two key quality steel pipe piles: one into the rock section must be guaranteed, through communication with the construction unit, the actual construction, the rock section with DTH opening 146 to 168, effectively ensure the quality of the rock section; the second is the upper part of the pile of soil (especially filling) of the pile side grouting

should be guaranteed, the purpose of this grouting pile increase to fill the gap protection layer and between the pile and the soil, providing pile side constraints, to ensure that the pile is not instability. Figure 7 static load test results show that pile of good quality, meet the design requirements.

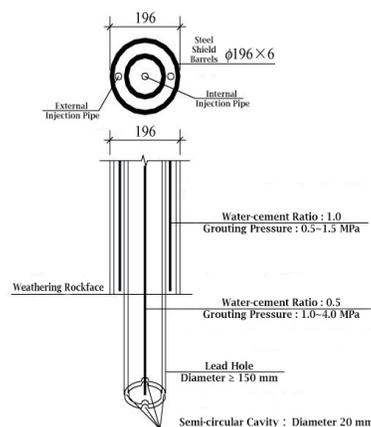


Figure 6. 46 × 10 steel piles.

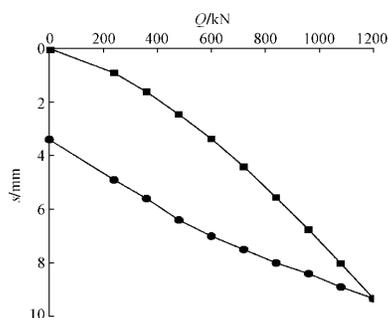


Figure 7. Steel pipe pile Q-s curve.

Small steel pipe pile exist pile capacity is relatively small, the costs pile unit strength more than other type of pile some disadvantages, therefore, should not be widely promoted, but in terms of the multi-storey building would be a good select.

Foundation depth mountain structures, often subject to site constraints, high and low, the use of different lengths of column design time if the building when the aerial, be sure to pay attention to one of the short column strengthened. Short column shear failure-prone, with stiffness due to short columns, seismic action is relatively large, more prone to damage, this should be strengthened in the seismic structure of short column shear failure to prevent it, or add its large base depth, avoid short column.

#### 5. Mountain building structure retaining structures designed special problems

Most mountain building structure need retaining structures, while the relationship between the retaining structure and the building process a lot of thought. Anti-regulation provisions described in section 6. 1.14 of advice: each

side appears basement depth difference is large landfill in the mountains (Singapore) to building retaining structures should be set separately. Anti-gauge intentions very clear, in the case of non-full buried basement, divided by two, respectively concise and independently of the main structure of the model and retaining structure model.

This method is convenient and practical, but not perfect, as aspects affecting the economy and the construction period and so on. Such as the height off the layer structure, off layer is at around 3m, earth pressure is not great, but due consideration temporary soil seepage side, when you need to set a concrete wall, only considered from the perspective of earth pressure, only this concrete walls and floor of the relevant range of suitable thickening and strengthening reinforcement appropriate to meet the requirements. In this case the increased costs relative to the other retaining structures do less, without the additional step. The author of the mountain from the villa is designed in accordance with the previously mentioned two walls one way, pay attention to the existence of this wall will cause stiffness mutation, causing the sudden increase in displacement ratio, thereby increasing the reverse effect structures for earthquake caused bad influence.

However, due to the displacement ratio control structure, but from low-intensity area into smaller uncertainties brought under earthquake. When completed through field visits, wall without cracking phenomenon, waterproof with good results, it is a more successful application.

Single out the segment height relatively large, priority specification recommends that a separate set of retaining structures. It is necessary to set up a separate retaining wall is not, I suggest: a single layer of a large fall off into several smaller layer height, the horizontal distance between meet certain aspect ratio (to be based on the nature of the soil, such as general hard plastic clay layer by 1: 2) In this case, the internal layer can even swap backfill and grading not only provided envelope wall.

Taking into account the reverse effect basement exterior wall brought, uncertainties in the external walls of earth pressure under seismic action may be the current speci-

fication recommends retaining structure and the main points expenditures structure the main reason. Theoretical basement exterior wall of earth pressure analysis on the influence by the earthquake, it will need more scholars to explore.

## 6. Conclusion

With more and more, the unique design of building structures in mountains encountered more and more, but the special nature of mountain seismic building structure is not adequate theoretical research and analysis of existing norms is relatively rare for a mountain building of provisions, theoretical research lags behind the actual project. This article from the actual project encountered problems, this paper proposes partial solutions. But research and theory building on mountain practical engineering aspects of the research needed majority of designers and scholars to do more work in order to prepare as early as possible and to enact mountain building structure design specifications.

## Conflicts of interest

These authors have no conflicts of interest to declare.

## Authors' contributions

These authors contributed equally to this work.

## References

1. Chongqing Residential Building Code draft. (2013). *Chongqing: Chongqing Municipal Construction Commission.*
2. GB 50011-2010 seismic design of buildings. (2010). *Beijing: China Building Industry Press.*
3. JGJ 3-2010 Technical specification for high-rise building of concrete structures. (2011). *Beijing: China Building Industry Press.*
4. DBJ/T 15-46-2005, Guangdong Province, the implementation of "Technical Specification for Concrete Structures Tall Buildings" (JGJ 3-2002) supplementary regulations. (2005). *Guangzhou.*
5. GB 50007-2011 Building Foundation Design Code. (2012). *Beijing: China Building Industry Press.*