Evaluation Method of Development Degree Based on Feature of an Intensity Dissolution Layer

Hegang Tang¹, Yukang Liu²*, Yinding He² and Xianfa Cao³

¹ Guilin Investigation & Research Institute, Guilin, Guangxi 541002, China
² Guangxi Key Laboratory of New Energy and Building Energy Saving, Guilin, Guangxi 541004, China
Email:522350218@qq.com

Abstract. It is common to cause errors in the selection of building foundation in karst terrain. The root reason is that the practical difficulty of karst treatment in foundation cannot be reasonably reflected by the existing evaluation of karst degree. Taking New Terminal of Nanning Wuxu International Airport as an engineering case, this article analyzes the limitation of the existing evaluation indices of karst degree, demonstrates the advanced rationality of intensity dissolution layer’s thickness as the evaluation index of karst degree, and proposes the recommended standard of the evaluation of karst degree. Results show that the intensity dissolution layer, divided by dissolution ratio distribution curve with depth in foundations, comprehensively considers the main depth range of dissolution degree of rock surface and the developing of cavern dissolution, and its distribution characteristics can reflect the most complex depth range of karst foundation. As the evaluation index of karst degree, it is reasonable. Its recommended values are suggested as follows, When the thickness of an intensity dissolution layer is less than 3.0 m, more than or equal to 3.0 m and less than 6.0 m and more than or equal to 6.0 m, the karst degree can be determined as weak development degree, medium development degree and strong development degree.

1. Introduction

Rock surface fluctuation and cavern development are the main reasons for the complexity of karst foundation [1-3]. It is the basic subject of foundation lectotype and design to reasonably predict the complexity of karst foundation [4-6].

Currently, Karst degree [7-9] is the main way for evaluating and predicting complexity of karst foundation. The practice of karst engineering shows that karst degree has a significant influence on the complexity of the karst foundation, but the conclusion of karst degree obtained by the existing methods cannot well reflect the actual complexity of karst foundation [10, 11], which led to frequent engineering accidents due to improper lectotype of karst building foundations. The evaluation theory of karst degree still needs to be further improved.

Taking Terminal of Nanning Wuxu International Airport as an engineering case, this article discusses the limitation of the existing evaluation indices of karst degree, proposes the evaluation method of karst degree with feature of an intensity dissolution layer as the index, and demonstrates its advancement and rationality.
2. The Engineering Situation

Nanning Wuxu International Airport covers an area of 300 mu and is a regional trunk airport that determined by the national civil airport layout. The new terminal building, with a total construction area of 183800 square meters, is designed with an elevation of 123.5 m and divided into five functional areas: Central Hall area I, South horizontal corridor area II, North horizontal Corridor Area III, South vertical Corridor Area IV and North vertical corridor Area V, as shown in the figure 1.

![Figure 1. Terminal plane partition plan.](image)

The site is located in the southeast wing of Tan-He anticline in Suwei fold fault area. In addition to a NE40° strike fault developed about 5km to the northwest of the site, no active fault structure zone passes through the site, and the regional geological structure is relatively stable; The superstratum is composed of Quaternary eluvium silty clay, clay mixed breccia, red clay and lower Carboniferous limestone with occurrence of 150°/15° and stable lithology.

The site is in a dissolved peneplain geomorphic unit, and its surface elevation during the investigation period is 118.73 ~ 123.66 m, with a relative elevation difference of about 4.93 m. In this site, karst forms such as concealed karst funnel, falling-water cave, karst cave and karst fissure are very developed, the rock surface is discontinuous and fluctuates violently, and the conditions of karst foundation are complex.

3. The Data Processing

This study collected all the data of the engineering geological investigation of detailed and constructed phases. Because each functional zone of the terminal has a large construction area, each zone is divided into 2-4 sub areas, which are divided into 14 sub areas, as shown in figure 1. There are two main conditions to be considered in the sub area division: The first is to ensure that there are no less than 12 boreholes in detailed and constructed investigation in each sub area, so as to meet the solution accuracy requirements of the feature of an intensity dissolution layer, and see table 1 and table 2 for the exploration and drilling conditions of each subarea.

| Partition | Number of bores pcs | Number of bores discovered hole pcs | Hole footage m | Rock footage m | Hole bore percentage % | Linear karst rate % |
|-----------|---------------------|-------------------------------------|----------------|----------------|-------------------------|-------------------|
| I-1       | 32                  | 10                                  | 35.4           | 437            | 31.3                    | 8.1               |
| I-2       | 46                  | 21                                  | 59.1           | 562            | 45.7                    | 10.5              |
| I-3       | 46                  | 6                                   | 10.3           | 605            | 13                      | 1.7               |
| I-4       | 32                  | 11                                  | 31.3           | 409            | 34.4                    | 7.66              |
| II-1      | 22                  | 5                                   | 8.4            | 257            | 22.7                    | 3.27              |
| II-2      | 22                  | 0                                   | 0              | 357            | 0                       | 0                 |
| II-3      | 16                  | 4                                   | 6.76           | 221            | 25                      | 3.06              |
| III-1     | 16                  | 6                                   | 3.5            | 191            | 37.5                    | 1.83              |
| III-2     | 17                  | 4                                   | 10.6           | 223            | 23.5                    | 4.76              |
| III-3     | 24                  | 14                                  | 29.5           | 293            | 58.3                    | 10.1              |
| IV-1      | 19                  | 6                                   | 17.6           | 234            | 31.6                    | 7.52              |
| IV-2      | 16                  | 7                                   | 16.3           | 221            | 43.8                    | 7.37              |
| V-1       | 35                  | 31                                  | 121            | 644            | 88.6                    | 18.9              |
| V-2       | 19                  | 33                                  | 21.2           | 222            | 57.6                    | 9.54              |
Table 2. Summary of construction investigation of subdivision.

| Partition | Number of bores pcs | Number of bores discovered hole pcs | Hole footage m | Rock footage m | Hole bore percentage % | Linear karst rate % |
|-----------|---------------------|-------------------------------------|----------------|----------------|------------------------|-------------------|
| I-1       | 193                 | 91                                  | 324            | 2154           | 47.2                   | 15.1              |
| I-2       | 236                 | 85                                  | 199            | 2349           | 36                     | 8.46              |
| I-3       | 267                 | 94                                  | 231            | 3484           | 35.2                   | 6.64              |
| I-4       | 181                 | 53                                  | 193            | 2672           | 29.3                   | 7.23              |
| II-1      | 99                  | 75                                  | 230            | 1629           | 75.8                   | 14.1              |
| II-2      | 72                  | 58                                  | 53.7           | 1094           | 80.6                   | 4.91              |
| II-3      | 61                  | 38                                  | 56.6           | 831            | 62.3                   | 6.8               |
| III-1     | 61                  | 35                                  | 30.3           | 961            | 57.4                   | 3.15              |
| III-2     | 76                  | 34                                  | 33.1           | 1121           | 44.7                   | 2.95              |
| III-3     | 99                  | 59                                  | 138            | 1476           | 59.6                   | 9.37              |
| IV-1      | 131                 | 62                                  | 241            | 1543           | 47.3                   | 15.7              |
| IV-2      | 121                 | 70                                  | 209            | 1396           | 57.9                   | 15                |
| V-1       | 138                 | 107                                 | 414            | 2506           | 77.5                   | 16.5              |
| V-2       | 116                 | 79                                  | 313            | 1490           | 68.1                   | 21                |

The second is to minimize the length-width ratio of the subarea and make the space span of the evaluation subarea smaller so as to achieve the purpose of karst foundation evaluation in small area.

The boundary elevation and thickness of Intensity dissolution layer are solved according to the method introduced in the literature [5], and the specific solution process is as follows:

First of all, the elevation of drilling into the rock, the elevation of the end hole, and the elevation of the top and bottom of all caverns are extracted from the engineering geological investigation of each subarea and dispersed with the thickness of 0.5 m in the depth direction. Then, we need to count the cavern dissolution thickness and the rock surface dissolution thickness in different elevation ranges, and sum them as the total dissolution thickness. The ratio of the total dissolution thickness to the total thickness of the rock layers within the elevation range is the measured value of dissolution rate. The fitting relation equation can be obtained by fitting the measured dissolution ratio curve according to Equation (1). The concepts of the cavern dissolution thickness, the rock surface dissolution thickness and the dissolution ratio mentioned in this paper are detailed in the literature [5].

\[ r = ae^{b(100-H)} \]  

(1)

According to literature [6], the top and bottom boundary elevation of intensity dissolution layer can be obtained by substituting the top boundary dissolution ratio (taking 75%) and the bottom boundary dissolution ratio (taking 25%) of intensity dissolution layer into the fitting relation equation, and the difference between these two elevations is the intensity dissolution layer's thickness. Detailed survey data and construction survey data of each division were processed, and the processing results were shown in figure 2 and table 3. The hole-bore percentage curve in figure 2 belongs to the cumulative curve above a certain elevation.
Figure 2. The depth distribution curve of rate of hole in bore & dissolution ratio at subareas.
Table 3. Table of boundary parameter of intensity dissolution zone in each subarea.

| Partition | Detailed investigation |  | Construction Investigation |
|-----------|------------------------|------------------|----------------------------|
|           | $H_{cr}$ | $H_{cr}$ | $\Delta h_{cr}$ | $H_{cr}$ | $H_{cr}$ | $\Delta h_{cr}$ |
| I-1       | 109.5   | 104    | 5.5        | 109.1   | 104.3   | 4.8       |
| I-2       | 109.3   | 105    | 4.4        | 108.5   | 105     | 3.6       |
| I-3       | 109.5   | 105.6  | 3.9        | 109.4   | 104.9   | 4.5       |
| I-4       | 109.2   | 105.1  | 4.1        | 109.4   | 105.4   | 4        |
| II-1      | 107.8   | 102.8  | 5          | 109.3   | 100.6   | 8.7       |
| II-2      | 114.1   | 109.9  | 4.2        | 114.8   | 109.6   | 5.2       |
| II-3      | 110.9   | 106.8  | 4.2        | 109.9   | 105.7   | 4.2       |
| III-1     | 109.4   | 107.1  | 2.3        | 110.2   | 107.1   | 3.1       |
| III-2     | 109.4   | 105.8  | 3.5        | 109     | 105.7   | 3.3       |
| III-3     | 108.4   | 104.1  | 4.4        | 108.6   | 103.7   | 4.9       |
| IV-1      | 110.8   | 104.8  | 6          | 110.5   | 104.7   | 5.8       |
| IV-2      | 109.7   | 104.3  | 5.4        | 110.4   | 104.5   | 5.8       |
| V-1       | 114.7   | 103.8  | 10.9       | 112     | 103.4   | 8.6       |
| V-2       | 109.1   | 105    | 4.1        | 109.2   | 102.3   | 6.9       |

4. Results Discussion

4.1. Discussion on the Limitations of the Existing Main Evaluation Indexes of the Karst Development Degree

At present, the evaluation indexes of karst development degree mainly include the hole-bore percentage, the linear karst rate, the height difference of bedrock fluctuation, the surface and underground karst phenomenon, and the individual size of karst cave. Regarding the microscopic karst phenomenon of the construction site, the investigation of underground karst mainly depends on drilling, but has actually been converted to rely on line karst rate and hole-bore percentage due to the fact that there are few rock strata exposed to the surface; The macroscopic karst phenomena on the surface are mainly used to distinguish karst landforms, and their engineering pertinence is poor, so karst phenomena are not used as the main evaluation index in engineering practice. Evaluation of individual karst cave morphology and scale is usually used as the evaluation factor of difficulty of foundation treatment in karst cave development position, and generally not directly used as the evaluation index of the overall karst development degree of the site. The overall karst development degree of the site currently mainly adopts the linear karst rate, the hole-bore percentage, and the height difference of rock surface fluctuation.

The height difference of rock surface fluctuation is generally determined by the maximum elevation difference of adjacent borehole rock surface. The limitations of this index are very obvious, mainly in: Even in undeveloped karst sites, there may still be a large height difference in the buried depth of local rock surface, such as locally developed deeper karren, dissolution trough, and dissolution funnel. More typical is: if the borehole happens to fall in the dissolution fissure, then the height difference between this hole and the adjacent hole or other holes in the site can be more than 10m, so it is obviously unreasonable to identify this site as an intensity dissolution site.

There are obvious defects in the definitions of hole-bore percentage and line karst rate, which are mainly reflected in the uncertainty of the calculation depth of these two indicators. According to figure 2, the cumulative curve of hole-bore percentage at different elevations increases with the increase of depth within a certain depth range, which indicates that the investigation depth has a significant impact on the statistics of hole-bore percentage. Under normal circumstances, the deeper the drilling depth, the greater the probability of finding karst caves, and the greater hole-bore percentage; however, the greater the drilling depth, the smaller the hole footage exposed by the unit drilling footage. The
drilling depths of different sites and different projects are not consistent, so these two indicators cannot be uniformly compared between different sites. Even at different survey stages of the same site, the calculation results of these two indicators may be very obvious differences. As shown in tables 1 and 2, in the absolute error data of hole-bore percentage in the two survey stages, except for the smaller values of I-3 and III-3 (the difference is 5.1% and 1.27% respectively), the values of the remaining 12 divisions are greater than 10%, the average value is as high as 26.45%, and the maximum is the value of zone II-2, which reaches 80.56%. Although the absolute error of the linear karst rate at different survey stages is small, the maximum error is also more than 10% (zone II-1 and zone V-2). The relative error is very large, except for I-2(24.2%), I-3 (5.94%), III-3(7.47%), and V-1 (14.1%), the relative errors of the remaining 10 zones are all over 60%, and the maximum relative error is in zone II-1, which is as high as 332.1%.

In addition, in the engineering geological investigation of detailed and constructed phases, the occurrence of the above-mentioned significant difference between hole-bore percentage and line karst rate is by no means an isolated case, but a common phenomenon in engineering practice. Therefore, this difference should not be regarded as a normal error, and its numerical characteristics are more like the of a random experiment, that is, hole-bore percentage and linear karst rate obtained from different survey depths and different borehole spacings are uncertain.

The current mismatch between the evaluation results of the karst development degree and the actual engineering treatment difficulty of the karst foundation is precisely caused by the above-mentioned uncertainty evaluation indicators.

4.2. Rationality of Intensity Dissolution Layer as the Evaluation Basis of Foundation Complexity

In the process of solving the parameters of intensity dissolution layer, the boundary erosion is introduced, which in fact gives a depth control standard for dividing the intensity dissolution layer, thereby eliminating the influence of drilling depth on the parameters of the intensity dissolution layer, which makes the intensity dissolution layer of different sites comparable, which is very conducive to the summary of engineering experience.

Rock surface fluctuation and cavern development are two main phenomena that complicate karst foundation, but the traditional evaluation of karst foundation mainly focuses on the evaluation of cavern, which is obviously biased. In this paper, the key basis for dividing the intensity dissolution layer is the dissolution ratio curve in foundations, which not only considers the development of caverns, but also considers the dissolution of rock surface. Therefore, taking the intensity dissolution layer as the evaluation index of karst foundation complexity is more in line with the actual situation of the project.

According to table 3, the upper boundary elevation error of intensity dissolution layer in the two survey stages is 0.1~2.8 m, with an average of 0.71m; the lower boundary elevation error is 0~2.7 m, with an average of 0.64 m; the thickness error of intensity dissolution layer is 0~3.7 m, with an average of 1.0 m. The number of sites with the boundary elevation error of intensity dissolution layer less than 1.0m accounted for more than 78.6%; the number of sites with the thickness error of intensity dissolution layer less than 1.0 m accounted for 71.4%. This shows that the boundary and thickness of intensity dissolution layer have better numerical stability on the whole. This is because the division of intensity dissolution layer depends on the dissolution ratio curve in foundations, while the deviation of the dissolution rate curve of each partition shown in figure 2 is not large as a whole. The small deviation of the curve has been verified by more than 200 engineering practice sites in southwest karst area. Of course, the numerical stability of the parameters of the intensity dissolution layer is not absolute. For example, in area II - 1, the difference of upper boundary elevation, lower boundary elevation and thickness of intensity dissolution layer in the two survey stages are 1.4 m, 2.3 m and 3.5 m respectively, and similar subregions include V-1 and V-2. Therefore, it is still necessary to verify the division results of intensity dissolution layer through construction Investigation.

The complexity of the karst foundation can be reflected in the thickness of the intensity dissolution layer. The thicker the intensity dissolution layer, the more complex the foundation, and the more
difficult it is for the pile to pass through the ground. From the point of view of the construction process, the average error of depth of pile tip into rock and recommended depth of drilling for construction investigation in the III-1 and III-2 zones is relatively small, and the pile foundation process in these two zones is relatively smooth overall. The pile foundation process in the three zones of II - 1, V - 1 and V - 2 is more difficult, and the pile forming accidents such as borehole inclination, borehole collapse, mud leakage and drilling obstruction are relatively serious. These three zones belong to the most difficult areas in the pile foundation engineering of the whole project. The pile foundation engineering difficulty of other zones is between the above two types of zones. According to the distribution characteristics of intensity dissolution layer in the construction survey stage of each division, the thickness of intensity dissolution layer of III - 1 and III - 2 is 3.1 m and 3.3 m respectively, which belong to the thinnest area of intensity dissolution layer in the site, while the thickness of intensity dissolution layer in II - 1, V - 1 and V - 2 are 8.7 m, 8.6 m and 6.9 m respectively, which belong to the thickest area in the distribution thickness of strong dissolution zone. It can be seen that there is an obvious correlation between the distribution thickness of intensity dissolution layer and the complexity of karst foundation, so it is reasonable to take it as the evaluation index of karst development degree. According to the collected geological data of more than 200 sites, recommended standards of the evaluation of karst degree based on the thickness of intensity dissolution layer ($\Delta hr$) are as follows:

**Table 4. Recommended standards of the evaluation of karst degree.**

| $\Delta hr$/m | <2.0 | 2.0~6.0 | $\geq$6.0 |
|---------------|------|---------|-----------|
| Karst degree  | Weak | Medium  | Strong    |

According to the above recommended standards of table 4, combined with table 3, the evaluation results of the karst degree of Terminal of Nanning Wuxu International Airport are as follows: The thickness of intensity dissolution layer in II - 1, V - 1 and V - 2 are 8.7 m, 8.6 m and 6.9 m respectively, which can be regarded as strong karst development sites; the thickness of intensity dissolution layer in other sites is more than 3.0 m, which can be regarded as medium karst development site. These results are consistent with the results reflected in the site pile foundation construction process.

5. Conclusion

(1) The existing evaluation indexes of karst degree have obvious limitations, which is the fundamental reason that the evaluation results of karst development degree cannot reasonably reflect the actual complexity of the foundation.

(2) The intensity dissolution layer is the fundamental reason that complicates the karst foundation. The intensity dissolution layer of the foundation, which is based on the dissolution ratio distribution curve with depth in foundations, comprehensively considers the main depth range of the rock surface dissolution of the foundation and cavern development, and its distribution characteristics can reflect the most complex depth range of the karst foundation.

(3) Engineering practice shows that there is a unified standard for the division of intensity dissolution layer, the results of the division in different sites are uniformly comparable, and the distribution characteristics of intensity dissolution layer are obviously correlated with the complexity of karst foundation, so it is reasonable to take it as the evaluation index of karst degree.

(4) The evaluation standards for karst degree of building foundation are recommended as follows: When the thickness of the intensity dissolution layer is less than 3.0m, it is judged as weak karst development. When it is no less than 6.0m, it is judged as strong karst development; Other cases are judged to be medium karst development.

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