

Survey of the development of reinforced earth retaining wall in China

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ABSTRACT: The paper at first reviews the four stages of development (from 1975 to 1990) of Chinese reinforced earth wall, and then narrates the achievements in this field in briefly, including the internal stability, building materials as well as construction technology. In China, more than 300 reinforced earth structure bodies which have particular national features have been founded and some good beneficial results in economy and society have been acquired.

1 INTRODUCTION

All those compounds which are made from adding a certain number of tensile materials into soil body are named Reinforced Earth. The materials can change soil mechanical property, improve soil shear strength, and bring material mechanical property into full play.

Reinforced earth engineering has been widely applied in civil engineering. Besides retaining structure, it is applied stabilization of slope, treatment of subgrade disease, strengthening of soft ground and steep slope embankment, control of land slide and protection of bank, etc. Approximately 10,000 reinforced earth engineering constructions have fully shown its greater vitality. This paper only referred to reinforced earth retaining wall.

2 SURVEY OF THE DEVELOPMENT

It has been very early since Chinese senior generation of engineers used the method of adding reinforcements into soil body. For example, straw or paper added to earth wall, strip-compacted dam used to strengthen fill slope highway embankment on loess bridge in the northwest of China, sand-bag strengthening bank and ground stabilization with branch or brush mattress in the marshy area. All of those are the primitive application of reinforced earth structure. However, it was a pity that those were not summed up and improved in that time.

Research on reinforced earth retaining wall in China may be divided into following several stages:

The first stage: investigation, preparation and start for research (1975--1982). The 4th Survey and Design Institute, Ministry of Railways started to research in 1975. Investigating and collecting information, then digesting them were carried out during this stage. The first reinforced earth retaining wall was completed in Tianba coal mine, Yunnan province in 1979. That of railway was consequently completed in the pivot of Huailian of China in 1980. In order to make function and mechanism of the structure be clearly realized, prototype exams were conducted in a number of testing walls, which are in Chonghua of Guangdong, Lingchuan of Shanxi, Daye of Hubei, Linghai of Zhejiang, etc., and a set of construction technology has been initially found out. Because the shortage of steel, reinforced concrete, polypropylene strip, bamboo, compound copper waste steel strip and others tried to be used for test according to special conditions of every area. Therefore, foreign tradition of only using steel as reinforcement material in early period was done away with, and Chinese new style was taken on.

The second stage: research on trial and initial spreading (1982--1985). After many test sites were built and examined, the researcher realized that the structure really has a lot of superiorities. So as to exchange experience, extend its influence and make colleagues understand it, "The First National Academic Discussion on Reinforced Earth Engineering" was held in Wuhan city in 1982. At that time, "Information service of Chinese Reinforced Earth Engineering" was set up, which was registered under 4th Survey and Design Institute, Ministry of Railways (The number of member units enrolled in the new

service was developed from 27 units at the beginning till 91 ones, and 21 issues of imperiodical brief reports were published). Then assessment meeting, expedition, on-the-spot meeting special subject exchanging meeting and studying class were held in Taiyuan, Xian, Shengyang, Hangzhou, Shangrao, Emel, Yanan, Nuoyang one after another. At the same time, more practice engineering were carried out. Connected with construction of sites, prototype exams to several different high walls and a series of model tests for function and mechanism of the structure were conducted. Then the research results about basic parameters, acting mechanism and the others related to reinforced earth were obtained step by step. A set of construction technology which are suitable for Chinese condition have been searched and perfected. In the field of construction material, a certain number experiments about physics mechanical properties were made on, and the reinforcement materials suitable for Chinese condition had been basically determined. All above were good preparations for " The Second National Academic Discussion on Reinforced Earth Engineering ".

The 3rd stage... continuously studying and applying step by step. (after 1986). In April, 1986, " The Second National Academic Discussion on Reinforced Earth Engineering was held in Kunming city, Yunnan province. There were 34 valuable research papers which are concerned with the theory of design, scientific test, construction materials, construction technology and so on in this discussion. " The Design Principles of Reinforced Earth Retaining Wall of Railway had been submitted by the research group of reinforced earth retaining wall, 4th Survey and Design Institute, Ministry Railways. The principles had been widely solicited opinions of colleagues and main contents of them been adopted by " Specifications for Design of Supporting structure of Railways Foundation. The specification had been carried on since August, 1990. On the other hand, Highway departments have also drawn up " Specifications for Design and construction of Reinforced Earth Retaining Wall of Highway ". After it spent many years on the application and practising of these specifications, "The 3rd National Academic Discussion on Reinforced Earth Engineering " was held in Chongqing city, in October, 1990. more than 50 papers were exchanged, which concerned research results related to structure of reinforced earth retaining wall. They would play a positive role for technical progress of reinforced earth retaining wall and perfecting construction technology as well as popularizing the application.

Reviewed past time, it only took 12 years from the time of building the first test wall

till now. Based on incomplete statistics, there have been close to 400 reinforced earth retaining walls built in China. The area of building wall has been more than 240,000m², which the department of highways is to about 80% of it, near the system of railways is to about 10% of it, and other system such as coal industry, water conservancy and forestry department are all to about 10%. The kind of structure has been spreading over every provinces such as Hainan and Tibet. Its development is so fast that other new type of supporting structures can not compete with it. At present, the highest site completed is old city's bulkhead to the north of Tongchuan city of Shaanxi, which is 35.5m high. One of the most magnificent reinforced earth retaining wall highway is in Bingjiang road along the north bank of Yangtze River of Chongqing city, which is more than 20m high and have been completed more than 1km among more than 5km in the plan. One of the highest reinforced earth retaining wall in railways is 2m, and the longest one is 1.6km inside Siping railway station. At present, the walling faces are all vertical so as to save land. This kind of structure has already been used for supporting of road, bank protection, wharf, abutment, land reclamation, wind-blown sand protection, land slide treatment and so on. such so, it have saved a large numbers of funds for construction.

3 SURVEY OF RESEARCH DEVELOPMENT

3.1 Calculation of the internal stability

1. Research on relative basic theory:

(1) Direct shear tests and triaxial shear tests for enhancing shear strength were respectively conducted after adding reinforcements into soil body.

(2) Friction tests between different reinforcements and different fills were carried out.

(3) Pull-out tests were conducted when reinforcements were respectively inside the model troughs and in the prototype sites.

2. Study on whole reinforced earth structure:

(1) Both more systematic model tests and centrifugal model tests were conducted.

(2) Prototype tests were more wholly conducted for more than 10 sites.

It has been clearly realized how failure forms of reinforced earth retaining wall by model and prototype testing are. Effective datum about the state of forces born by every member, stress distribution in soil, effects of loads and so on have been acquired. Therefore, the kind of structure have been gotten deeply realized and could provide specific

designs with evidences.

3. Based on the researches of both parts mentioned above, some new views and calculation method were brought forward and verified:

(1) Calculation about lateral pressures: After study and analysis of the practical test datum, it is adopted by " Specifications for Supporting Structure of Railways Foundation " that when wall is lower 10m, earth pressures at rest should be used to the upper half of wall, otherwise, shear strength value should be used to the place of lower half of wall. " Specifications for Design and Construction of Reinforced Earth Retaining Wall of Highway " used the calculation method of French Specification. Effects on relative loads were raised that calculating value of stress distribution in soil according to elastic theory should be close to testing value or be simplified as following: both edges of strip load be downward spread by 30° angle, then be multiplied by the coefficient of lateral pressures.

(2) The vertical stress distribution in soil has been always adopted stress-column theory before. Through the practical test, however, considering reinforcements in soil body's people has generally thought that the high wall which is higher than 10m is not corresponding to the theory. There exists in the tendency that more its depth increases, litter its stress changes. As for how to revise it and make it be rational, it is awaiting deeply studying by means of continuously enriching datum.

(3) The stress distribution in reinforcement is almost identical to foreign practical tests: there is a certain distance between the peak value in reinforcement and wall face board, and the stress at the tail of reinforcement is zero. The state of stress is suitable for practice.

(4) The principle about how to divide the validity area and ineffective area of reinforcement: Based on most of information analyses of practical tests, it is thought that there does not exist in failure plate in stable wall body. Now, on-line of the stress peak value of reinforcement is regarded as the latent failure plate of wall. As the method of $0.3H$ is verified to be basically fitable to practice by most of conditions, it is generally looked upon as evidence of design.

(5) Determination of design pulling force in reinforcement: A few part of units have introduced foreign ready-made calculation formula, e.g. Meyerhof's Method in French Specifications and so on were used. But most parts of units calculated the forces born by every layer of reinforcement according to lateral pressure figures and the distributions of reinforcements then made it be times the coefficient of safety. Such so, the

tensile stress in reinforcement could be determined. At the same time, after the method of foreign calculation was studied and compared, based on the Chinese practical conditions, a part of parameters was regulated and modified, and different expressions were deduced.

(6) Relation between the form of friction force and total pull-out resistance: A unitary coefficient of friction was adopted to calculate before. The concept of interlocking force was brought up after studied. Thereby, the total pulling-out resistance should be equal to the sum of frictional force and interlocking force, and its relationship was dedrivated. It explains that the coefficient of friction is still a constant. Simultaneously, some unit suggested that the cohesion between fill and reinforcement should be respectively considered.

3.2 Construction material

1. Facia panels of wall: At first, based on Chinese condition, every kind of forms of small facia panels made of concrete or reinforced concrete were used. Every block of it is about 1.5KN heavy and the area of it built wall is $0.5m^2$ so as to be convenience to manual construction. At present, cross-form and rectangle-form, and next groove-form and L-form of facia panel are used most popularly. In individual site the concrete shell arcuate facia panel with mat reinforcement was used, and so on. These facia panel are made according to specific condition of construction and featured with every own speciality.

2. Reinforcement: In the early period of start, every variety of reinforcements mentioned above has been used in order to overcome the difficulty of shortage of steel. The reinforcement of reinforced concrete connection in series and polypropylene strip are considered to be suitable for Chinese condition through a lot of practice engineerings. They have been used by most of workers on reinforced earth retaining wall. Polypropylene strip has been widely used in highway engineering, however, the deformation and creep of it are both large, and there is still no conclusion about its service life resulted from the problem of its anti-aging. For this reason, reinforced concrete connection in series are widely used in the open traffic line of railway.

3. Earth fill: It is major material forming wall body. The principle of using local materials has been carried on since start of the research. In this way, it can reduce engineering cost and be convenient for spreading and applying. So, it is necessary to study the measures making the quality and stabilization of structure be ensured and the

method improving soil character. At present, a variety of soil, construction rubbish and fly ash have been all used except slurry, humus and living rubbish.

3.3 Construction technology and other hands

1. Constructed procedure of reinforced earth retaining wall is resembling face boards--filling soil--laying reinforcements, and then from beginning to the end. Those details of construction are different from the design properly in every site.

2. Because reinforced concrete and polypropylene strip used as reinforcements are originated in China, a set of method corresponding to construction has been found out in special design, construction technology, and items of paying attention to construct.

3. Appropriated methods of treatment have been carried out, i.e. compaction, waterproof, drainage and specific construction technology, etc. These methods improving soil characters have been found out and studied, and been detailedly regulated to ensure the stability of structure.

4. Mechanics of interreaction between reinforcement of reinforced concrete or polypropylene strip and soil has been studied. So have been done form of reinforcement, method of connection, details of structure, influence of the state of bearing forces by single reinforcement due to the length of reinforcement. Appropriated views and conclusion were brought out so as to provide forcefull evidence for design.

5. Relatively systematic tests of polypropylene strip's creep and its engineering property were conducted. It has been clearly realized the deformation's speciality and materials' character. Intergrated with the application of reinforced earth retaining wall, it is suggested that the value of deformation control the strength of design.