ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0071

Review on the Experimental Research of Model Similar Material Proportioning

Qingxiang Wu

School of Civil Engineering, Henan Polytechnic University, Jiaozuo 454000, Henan, China

Abstract

Similar materials are the basis of physical model tests. The research on similar materials is helpful to promote the development of various geological environment model tests. This paper summarizes the research results of similar materials at home and abroad; The determination principles of main physical and mechanical indexes in the manufacturing process of similar materials are expounded: the performance parameters of similar materials should be coordinated according to the research purpose of model test; The adjustment method of similar material control index is described: the sensitivity analysis of similar material control index is carried out to determine its main influencing factors, and on this basis, multiple regression analysis is carried out.

Keywords

Similar Materials; Control Index; Sensitivity Analysis; Multiple Regression Analysis.

1. Introduction

Since entering the 21st century, China's underground engineering construction has ushered in rapid development. In terms of transportation, by the end of 2020, 16798 railway tunnels have been put into operation in China, with a total length of about 19630km. With the promotion of Western Railway Construction, there will be more and more large buried deep and super long railway tunnels [1]; In terms of energy, according to incomplete statistics, 60% of China's proven coal resources are buried at a depth greater than 800m, and at present, more than 50 coal mines with a mining depth of more than kilometers have reached. The construction of various deep buried underground projects has gradually increased, and the scale, quantity and complexity of rock mass projects have increased significantly. At present, the analysis and calculation of surrounding rock stability of underground engineering basically adopts the traditional continuum mechanics methods, such as elastic mechanics or elastic-plastic mechanics. However, in the actual engineering, the constitutive relations of surrounding rock mass are different in different positions and even in different periods. In quite a few cases, the stress redistribution of surrounding rock after excavation shows nonlinear mechanical effect. At this time, The stability analysis of traditional elastic mechanics or elastic-plastic mechanics is very different from the actual engineering. In view of this situation, the previous engineering experience is often applied in the current design and construction, but the empirical analogy method also has great limitations and can only be used in small and medium-sized projects with simple structure. In short, the basic characteristics of underground engineering construction are "complex and changeable geological conditions, many influencing factors and great construction difficulty".

Similar model test is an effective method to solve complex problems in underground engineering based on similar theory and connecting the process and results of model test with actual engineering through a certain proportion relationship [2-5]. Similar materials are the material basis for constructing similar models, and their material selection and preparation directly affect the success

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0071

or failure of model test. Therefore, it is of great significance to carry out the research on the proportion test of similar materials.

2. Research Status at Home and Abroad

With regard to the selection and preparation of similar materials, many scholars at home and abroad have carried out a series of research work and achieved rich results. In the 1960s, Fumagalli et al. [6] pioneered the engineering geomechanical model test technology and developed rock similar materials with gypsum as binder and lead oxide powder and bentonite as filler, but these materials are expensive and toxic. Glushinkhin et al. [7] former Soviet scientists developed a series of similar materials for model tests for different purposes, including cement mortar, gypsum cement mixed mortar, epoxy resin mortar, etc. The research on related technologies of similar materials in China began in the 1980s. In order to meet the material selection requirements of similar model materials with high density, low elastic modulus and low strength, Boli Han et al. [8] prepared a new geo mechanical model material (MIB) by using aggregates with low elastic modulus and high capacity weight and weakly cemented adhesives. Ma Fangping et al. [9] formulated NIOS model material, which has various mechanics; Zhang Qiangyong et al. [10] developed a new type of geotechnical similar material with iron ore powder, barite powder, quartz sand, gypsum and rosin as raw materials, which can meet the requirements of most rock mass similar materials; Wang Huimin [11] used the mixture of cement, gypsum and sand as similar materials to simulate three typical soft rocks: mudstone, siltstone and fine sandstone; Shi Xiaomeng et al. [12] carried out physical and mechanical tests on similar materials with cement and gypsum as cementing agents and quartz sand and barite powder as aggregates; Yao Jian et al. [13] summarized the characteristics of weathered mudstone stratum, such as more clay minerals, strong water permeability, weak water permeability, expansion with water, easy softening and easy disintegration. River sand, clay powder, gypsum and quicklime were selected as materials to prepare similar materials of weathered mudstone meeting similar conditions; Liu Yongli et al. [14] took diatomite, red clay, river sand, gypsum, cement and marl powder as the main materials to carry out the proportion experiment of similar materials of marl; Liu Yishuai et al. [15] selected yellow sand, quartz sand and barite powder as aggregates and gypsum as cementitious materials to make samples of similar materials of mudstone.

To sum up, similar materials in the model are composed of cementitious materials and aggregates. Cementitious materials can be roughly divided into three categories [16]: Organic cementitious materials, such as epoxy resin, rosin, gasoline, etc; Inorganic cementitious materials, such as cement, gypsum, etc; Composite cementitious material refers to the mixture of two or more cementitious materials, which can make up for the deficiency of single cementitious material. The aggregate is generally composed of two or more materials with large differences in bulk density and particle size, which are used to adjust the bulk density and gradation of similar materials. The commonly used aggregates of similar materials include river sand, quartz sand, iron concentrate powder, barite powder, clay powder, etc.

3. Determination of Main Physical and Mechanical Indexes of Similar Materials

There are many factors affecting the physical and mechanical properties of rock mass, and it is difficult for similar materials to have similar parameter indexes. Therefore, in the proportioning test, the parameter indexes of materials will be emphasized according to the research content. Yang Junping [17] in the preparation test of similar materials for class IV weakly expansive surrounding rock, in order to develop similar materials with expansibility, the free expansion rate and dry saturated water absorption are the main control indexes of similar materials. In the experimental study of similar materials of outburst coal, Yin Guangzhi, Gao Kui, Lin Haifei and Wang Hanpeng et al. [18-21] believed that mechanical strength, adsorption desorption characteristics and permeability were the main physical and mechanical indexes of similar materials, and conducted in-depth research on them.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0071

Chu Zhaofei et al. [22] in the research and development of rheological similar materials of soft rock, in order to make the similar materials of soft rock have rheological properties, took the parameters in the viscoelasto–plastic model as the rheological similar control parameters between the similar materials of soft rock and the original rock, and carried out the preparation of similar materials. In order to carry out the physical model test related to rock burst, Jia Baoxin et al. [23] selected the white sandstone of yuezhishan tunnel in Emei section of Chengdu Kunming Railway as the simulation object to prepare the white sandstone similar material, and took the elastic property index, brittleness index and residual elastic energy index as the white sandstone similarity control index to carry out the preparation of similar materials. Li Zheng et al. [24] carried out the Proportioning Test with the permeability coefficient of similar materials as the core in the development of similar materials for seepage model test of rock tunnel.

The performance of similar materials should be similar to that of raw materials, but it is very difficult to make the parameters of similar materials exactly the same as that of raw materials. Therefore, it is necessary to coordinate the performance parameters of similar materials according to the research purpose of model test.

4. Adjustment Method of Physical and Mechanical Indexes of Similar Materials

There are many factors affecting the physical and mechanical properties of similar materials, such as the content of each component of similar materials, the forming pressure of similar materials, the curing time of similar materials and so on. In the preparation process of similar materials, it is necessary to constantly adjust the size of each control index to meet the similarity relationship. At this time, it is necessary to determine the main influencing factors of each control index of similar materials, so it is necessary to analyze the sensitivity of the control index. Yang Xu, Wang Peng, Wang Junxiang, Liu Pan, Liu Liangliang, Xia Yu et al. [25-30] analyzed the sensitivity of control indexes of similar materials in the proportioning test. It is found that cementitious materials have a great impact on material properties, and the strength of similar materials increases with the increase of cementitious material content; Aggregate has a significant effect on the bulk density and compactness of similar materials. With the increase of the proportion of large bulk density aggregate, the bulk density of similar materials increases, and with the decrease of aggregate particle size, the compactness of similar materials increases; The forming pressure has a significant effect on the strength and compactness of similar materials. The greater the forming pressure is, the denser the similar materials are and the higher the strength is; The curing time has a great impact on the strength of similar materials. The longer the curing time, the more sufficient the reaction between cementitious materials and raw materials, and the greater the strength of similar materials. However, generally, increasing or reducing the curing time is not regarded as a way to adjust the mechanical indexes of similar materials. The curing time of similar materials is insufficient, and the mechanical indexes fluctuate greatly.

Based on the sensitivity analysis of the control indexes of similar materials, the main influencing factors of each control index can be determined, and the quantitative relationship between each control index and the main influencing factors can be found through multiple regression analysis, so as to improve the efficiency of the Proportioning Test of similar materials.

5. Conclusion

This paper summarizes the research results of similar materials at home and abroad; This paper expounds the determination principles of main physical and mechanical indexes in the manufacturing process of similar materials: it is very difficult to make the parameters of similar materials exactly the same as the raw materials, so it is necessary to coordinate the performance parameters of similar materials according to the research purpose of model test; The adjustment method of the control index of similar materials is described: the sensitivity analysis of the control index of similar materials is

carried out to determine the main influencing factors of each control index, and on this basis, the quantitative relationship between each control index and the main influencing factors is found through multiple regression analysis, so as to improve the efficiency of the Proportioning Test of similar materials.

References

[1] Tian Siming, Wang Wei, Gong Jiangfeng. Development and prospect of railway tunnels in China (including statistical data of railway tunnels in China by the end of 2020)[J]. Tunnel Construction (Chinese and English), 2021, 41(02): 308−325.

[2] Abusharar S W , Han Jie. Two-dimensional deep-seated slope stability analysis of embankments over stone column-improved soft clay[J]. Engineering Geology, 2011, 120(1−4): 103−110.

[3] Huang Feng, Zhu Hehua, Xu Qianwei, et al. The effect of weak interlayer on the failure pattern of rock mass around tunnel−scaled model tests and numerical analysis[J]. Tunnelling and Underground Space Technology Research, 2013, 35(35): 207−218.

[4] Li Huaizhan, Guo Guangli, Zha Jiangfeng. Study on time-varving characteristics of similar material model strength and the regulation measures[J]. Environmental Earth Sciences, 2017, 76(15): 1−11.

[5] Lin Peng, Shi Jie, Zhou Weiyuan, et al. 3D geomechanical model tests on asymmetric reinforcement and overall stability relating to the Jinping I super-high arch dam[J]. International Journal of Rock Mechanics and Mining Sciences, 2018, 102: 28−41.

[6] Fumagalli E. Statical and Geomechanical Models[M]. New York: Springer Verlag. 1973.

[7] Glushikhin F.P., Kutsnetsov G.N., Shklyarsky M.F. et al. Modeling in geo-mechanics[M]. Moscow: Nedra, 1991.

[8] Han Boli, Zhang Wenchang, Yang Cunfen. New geomechanical model material (MIB)[J] Engineering Journal of Wuhan University, 1983(1): 11-17.

[9] Ma Fangpin, Li Zhongkui, Luo Guangfu. NIOS model material and its use in geo-mechanical similarity model test[J]. Joural of Hydroelectric Engineering, 2004, 23 (1): 48−51.

[10] Zhang Qiangyong, Li Shucai, Guo Xiaohong, et al. Research and development of new typed cementitious geotechnical similar material for iron crystal sand and its application[J]. Rock and Soil Mechanics, 2008, 29(8): 2126−2130.

[11] Wang Huimin. Simulation study on similar materials of large diameter drilling in soft rock stratum[D] Nanjing: Central South University, 2009.

[12] Shi Xiaomeng, Liu Baoguo, Xiao Jie. A method for determining the ratio of similar materials with cement and plaster as bonding agents[J]. Rock and Soil Mechanics, 2015, 36(5): 1357−1362.

[13] Yao Jian, Li Yun, Huang Xin, et al. Experimental study on the proportion of similar materials in weathered mudstone stratum[J]. Modern Tunnelling Technology(S2), 2018(add 2): 1069−1079.

[14] Liu Yongli, Zhou Wenzuo, Guo Bin, et al. Study on marl similar materials in similar simulation test[J]. Chinese Journal of Rock Mechanics and Engineering, 2020, 39(add 1): 2795−2803.

[15] Liu Yishuai, Li Changjin, Li Tingchun, et al. Experimental research on Influencing Factors of mechanical properties of similar mudstone materials[J], Mining Research and Development, 2020, 40(6): 80−84.

[16] Zhu Moran, Xiong YunWei, Dai LinChao, et al. Research status and prospect of similar materials for coal and gas outburst [J]. Safety in Coal Mines, 2019, 50(04): 173-176+180.

[17] Yang Junping, Zhou Lixin, Zhao Weijie. Experimental study on similar materials of grade IV weak expansive surrounding rock based on orthogonal design[J]. Science Technology and Engineering, 2016, 16(35): 294-298+309.

[18] Yin Guangzhi, Wang Dengke, Zhang Dongming, et al. Test analysis of deformation characteristics and compressive strengths of two types of coal specimens containing gas[J]. Chinese Journal of Rock Mechanics and Engineering, 2009, 28(2): 410-417.

[19] Gao Kui, Liu zegong, Liu Jian. Study on permeability comparison tests with two different gas content coal samples[J]. Coal Science and Technology, 2011, 39(08): 57-59.

[20] Lin Haifei, Zhai Yulong, Li Shugang, et al. Research on mechanics and permeability characteristics of similarmaterial of solid-gas coupling based on orthogonal design[J]. Journal of China Coal Society, 2016(3): 672-679.

[21] Wang Hanpeng, Zhang Qinghe, Yuan Liang, et al. Development of a similar material for methane-bearing coal and its application to outburst experiment[J]. Rock and Soil Mechanics, 2015, 36(6): 1676.

[22] Chu Zhaofei, Liu Baoguo, Ren Darui, et al. Development of rheology similar material of soft rock and its application in model test[J]. Rock and Soil Mechanics, 2019, 40(06): 2172-2182.

[23] Jia Baoxin, Yuan Wenya, Ma Chaoyi, et al. Ratio test and characteristic analysis of similar materials in white sand rock[J]. Chinese Journal of Underground Space and Engineering, 2022, 18(02): 503-512.

[24] Li Zheng, He Chuan, Gao Xiang, et al. Development and application of a similar material for rock tunnel seepage model test[J]. Journal of Harbin Institute of Technology, 2017, 49(09): 33-39.

[25] Yang Xu, Su Dingli, Zhou Bin, et al. Experiment study on similarity ratio of similar material for model test on red-bed soft rock[J]. Rock and Soil Mechanics, 2016, 37(08): 2231-2237.

[26] Wang Peng, Shu Cai, Shi Feng, et al. Orthogonal experimental study of similar materials properties of different densities, sand-binder ratios and residual moisture contents[J]. Rock and Soil Mechanics, 2017, 38(S2): 229-235.

[27] Wang Junxiang, Cui ningkun, Lin Yaxian, et al. Preliminary application of Similar materials development and model test of phyllite[J]. Chinese Journal of Underground Space and Engineering, 2021, 17(01): 87-97.

[28] Liu Pan, Ma Rongrong, Teng Zhiqiang. Material parameters sensitivity analysis of rock-like sample with iron crystal sand [J]. Journal of Hebei University of Engineering (Natural Science Edition), 2017, 34(01): 12-16.

[29] Liu Liangliang, Wang Hailong, Liu Jiangbo, et al. Low strength similar materials proportioning test based on orthogonal design[J]. Journal of Liaoning Technical University(Natural Science), 2014, 33(02): 188-192.

[30] Xia Yu, Nie Hongtao, Zhang Zejun. Study on rapid proportioning of similar materials in Geomechanical Model Test Based on multiple regression analysis[J]. Journal of Guangxi University of Science and Technology, 2019, 30(01): 103-109.