Safety Monitoring of Engineering Buildings

Yue-Guang HE[1,a,*], Yi-Feng HE[1,b], Sen-Lei SHAO[1,c]

[1]Changsha University of Science and Technology, School of Communication and Transportation Engineering, Changsha 410004, China

[a]hyg@csust.edu.cn, [b]1076959193@qq.com, [c]544012001@qq.com

*Corresponding author

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Abstract. Displacement and deformation of engineering buildings (structures) are objectively inevitable. However, all surface and underground buildings (structures) have certain structural strength to resist surface displacement and deformation. In this paper, monitoring characteristics of high-rise building, slope project, underground rock mass work, dam body, bridge and other engineering projects are analyzed. Safety monitoring is an important measure to assure the safety of engineering buildings (structures). Monitoring of engineering disaster is based on engineering disaster mechanism analysis, monitoring tolerance determination, as well as modern monitoring technical achievements.

Deformation refers to the three-dimensional displacement between point and point on ground surface, in rock mass, engineering buildings (structures) or within buildings (structures). The operation of utilizing monitoring instruments and other special tools and methods to monitor and observe objects under deformation is called deformation monitoring. The aim is to examine whether the monitored buildings (structures) are safe under the influence of external loads. Monitoring results are importance basis for design theory verification and construction quality inspection.

There are several factors leading to deformation of buildings (structures): (1) deformation of ground surface; (2) foundation compaction caused by load of buildings (structures) leads to settlement and deformation of buildings (structures); (3) uneven settlement and deformation caused by changing of geological conditions of foundation; (4) seasonal or periodic temperature change; (5) deformation caused by external forces, such as swing of high-rise building by wind, vibration of bridge because of vehicle moving, influence on slope project caused by blasting operation, etc. [1, 2]

Unexpected, sudden, and disastrous event related with engineering works is often referred to as engineering disaster.

Engineering Buildings Have Certain Ability to Resist Displacement and Deformation

Affected by external forces, it is unavoidable for ground surface and engineering buildings (structures) to take place displacement and deformation. Normally, civil works (geotechnical works and building works) are constructed on or in rock and soil mediums. Displacement and deformation caused by engineering excavation have various forms. Displacement, deformation, even disaster of ground surface caused by underground excavation, urban foundation pit work, and underground tunneling could be seen frequently. Moreover, overusing of underground water may also trigger ground surface displacement and deformation.

All surface and underground buildings (structures) have certain structural strength to resist surface displacement and deformation. If deformation of buildings (structures) does not exceed the maximum limit, there will be no observable damage to such buildings (structures) [3, 4, 5].

Owing to different foundation and structure, the performance of buildings (structures) in resisting ground deformation is different as well. As for this, the severity of consequence caused by building damage is also one of the important factors to identify protection degree. The allowable settlement and deformation quantity of concrete engineering buildings (structures) may be subject to related regulations or experience, but mostly rely on knowledge accumulation.

Engineering excavation will inevitably arouse surface displacement and deformation. However, small amount of settlement and deformation of surface buildings (structures) is allowable, which does not affect the normal usage or lead to damage. According to experiences overseas, the maximum surface inclination bearable to the most sensitive buildings (structures) is 2.5mm/m, and the maximum horizontal tensile strain shall be 1.5mm/m. If surface deformation is within the aforementioned limit, the buildings (structures) may be used safety, without any observable damage.

Monitoring of Engineering Buildings (structures) is a Safety Assurance Measure

Mostly, buildings (structures) are constructed on subgrade with complicated geological structure and uneven rock-soil characteristics. Affected by various forces and natural factors, the service performance and safety status are changing all the time. Abnormity undiscovered timely may lead to serious consequences if left untreated. There are too many severe accidents caused by monitoring carelessness.

The operation of determining the deformation (changing with time) of engineering buildings (structures) and the foundation under loads and external forces is referred to as monitoring. The US Bureau of Reclamation considered that, the necessity of long-term and systematic monitoring on buildings (structures) and the foundation with observation instruments and devices are based on demand of the following four aspects:

(1) Diagnosis demand, including verifying design parameters and improving future designs; assessing and improving the advantages of new construction technologies; diagnosing and reinforcing unsafe signs and risks; ensuring buildings (structures) under sustainable good condition;

(2) Prediction demand: utilizing long-term observation information accumulated to master changing rules, and to effectively predict future status of buildings (structures);

(3) Legal demand: for responsibility and compensation issues related with engineering accidents, such observation information may help to determine the cause and responsibility, which may be used in court judgment.

(4) Research demand: observation information is real reflection of performance of buildings (structures), providing quantitative information for future design, which may be applied to improve construction technology, and is favorable for updating of design concept and understanding of damage mechanism.

Safety Monitoring Has Been Applied with Important Engineering Buildings (structures)

Construction of engineering buildings changes the original status of ground, leading to certain external forces to the subgrade of buildings. This will inevitably cause deformation of subgrade and stratus around.

Monitoring of engineering buildings (structures) is involved with wide fields. For example, the 16th International FIG Conference considered that, if the purpose of monitoring was to keep the deformation within a certain allowable range, so as to ensure the safety of building, the error of monitoring should be less than 1/10~1/20 of the allowed deformation quantity, or 1~2mm. If it was for the purpose of scientific research, the precision should be even higher. Period of deformation monitoring refers to the time interval between two monitoring operations, which should be able to reflect settlement and deformation process of buildings, without omitting the deformation moment. As for this, monitoring period shall be fixed according to deformation quantity within unit interval, as well as the effect of external factors. Deformation monitoring points are comprised by base points and work points.

Monitoring of High-rise Buildings

High-rise buildings have high gravity center, large load, more floors and deep foundation pit. As for this, monitoring points shall be buried at corners, mid-points and turning points of buildings; one work point shall be deployed 10~20m around; settlement joints or junctions between the new building and the original building; internal load bearing walls or columns; vertical and horizontal axis; around main equipment (such as crown block); around dynamic load, and other areas with adverse geological conditions [7].

Owing to subgrade deformation, other external load and internal stress, buildings and the foundation may as well take place deformation. For foundation, the main monitoring items include even settlement and uneven settlement. In accordance with settlement monitoring information, the absolute settlement and average settlement of foundation may be calculated. On this basis, relative inclination and relative bending (deflection) may be figured out according to uneven settlement. Uneven settlement of foundation may even lead to twisting of buildings. When stress caused by uneven settlement exceeds the tolerance of buildings, fissures may be caused on buildings. To some extent, inclination and fissure of buildings are mainly caused by uneven settlement of foundation. Even settlement may not lead to fracture, fissure or gap of buildings. However, excessive absolute even settlement may as well arouse some troubles.

Slope Project Monitoring

Under the long-term effect of gravity, structural force, seismic force and other external forces, slope rock mass tends to slide downwards, leading to instability (geological disaster) of slope. In water conservancy, energy, mining, and traffic fields, monitoring of slope is designed to assess the stability of slope during construction and operation, so as to give according report; to provide technical basis for prevention and treatment of (possible) landslide; to evaluate existing landslide and reinforced landslide; to provide parameters for displacement analysis and numerical simulation analysis and computation [6, 7].

Slope monitoring is comprised by surface monitoring and underground monitoring. (1) Surface monitoring normally includes macroscopic engineering geological and hydrogeological survey, as well as on-the-spot observation of surface deformation (fissure). (2) The purpose of underground observation is to reveal displacement and stress changes in rock mass of slope. If necessary, geophysical prospecting method may be applied to monitor the occurrence and development of potential sliding surface in rock mass. Underground observation shall be applied together with surface observation, so as to make assessment and prediction of slope rock mass stability more comprehensive and more feasible.

Characteristics of slope monitoring: (1) the complexity of rock-soil mass medium leads to large monitoring range and uneven stress distribution. As a result, it is hard to form unitary model. Monitoring is more than to acquire the data, but also to assess and analyze the data. (2) Plenty of monitoring items, including surface deformation monitoring, underground deformation monitoring, physical parameter (such as stress) monitoring, environment factor (such as underground water), weather, earthquake, etc. The work load is excessively high, leading to complicated process. (3) Long period, normally over 2 years: the whole course from project feasibility research to construction and engineering application requires monitoring personnel and monitoring equipment with good continuity. Data recording and format shall be consistent as well.

Monitoring requirements are normally proposed by the Designer, and the Owner shall employ qualified monitoring institution to prepare monitoring scheme. The monitoring scheme may be implemented upon the approval of the Designer, the Supervisor and the Owner. The scheme shall include monitoring items, monitoring purpose, test methods, deployment of monitoring points, and alarm value of monitoring items, information feedback system, site raw information and records.

According to actual safety level, supporting structure, deformation control requirements, characteristics of geological and supporting structure, the below slope project monitoring methods may be adopted: slope stop displacement observation; anchor rod tension and pre-stress loss monitoring. Monitoring scheme may be determined according to design requirement, slope stability, surrounding environment and construction schedule. If there is risk, monitoring shall be enhanced.

Monitoring of Underground Rock Mass Works

Construction and environment monitoring is performed for according information feedback and prediction, so as to optimize construction organizational design, to guide site construction, to ensure the safety and quality of underground rock mass work, and to improve the social, economic and environmental benefit of projects [8,9]. Monitored values may be used to guarantee the safety of preliminary support and secondary lining, as well as to determine the best time for secondary lining construction. As inverse analysis information for design revision, monitored values provide reference for determining proper supporting parameters under various geological conditions. When the convergence deformation of excavation section has reached the optimal value of deformation allowance specified in design, supporting mode of the section shall be considered as most reasonable. As for this, supporting mode for surrounding rock ahead shall be the same as the section. In construction, designed deformation allowance of surrounding rocks in tunnel shall be adjusted according to construction monitoring results, so as to ensure the thickness of secondary lining, and to reduce backfilling amount. When the supporting form is determined, it is still necessary to compare actual geological conditions with predicted conditions, so as to continually correct prediction parameters and to ensure the accuracy of prediction. On the other hand, deformation observation points shall be established to monitor the deformation of surrounding rocks, for the convenience of correcting supporting parameters. Summarization shall be performed repeatedly in the same way. Raw geological information in design, predicted geological information, and actual geological condition shall be compared and analyzed. Monitored values of surrounding rocks under supporting condition shall be comprehensively analyzed, so as to make tunnel supporting parameters perfect match surrounding rock geological conditions and hydrologic conditions, truly realizing "dynamic and information-based" design.

Lining structure of tunnel section in underground works is normally designed according to new Austrian tunneling method, in which, geological and supporting condition, surrounding convergence, vault settlement, and surface settlement are the main items to be measured and monitored. The monitoring frequency and times are determined by the distance between excavation face and measurement section, as well as the excavation depth of underground works. Actual measurement frequency shall be fixed according to the measurement results of previous two measurement operations.

Dam Body Monitoring

Physical parameters of deformation and stress are important quantities in monitoring of service performance of dam body. Deformation is more direct and reliable, so that it is often taken as a primary monitoring quantity domestic and overseas [10, 11]. Dam body planning and design - construction - operation monitoring are indispensable links. Missing of any link may affect the safety operation of dam, making it hard to form feedback channel, or to constitute "closed loop system".

International Dam Conference recorded and analyzed 1100 dam accidents. According to cause and frequency, 30% were resulted by catastrophic flood, low design flood and failure of flood discharge equipment; approximately 27% were caused by complicated geological condition, foundation instability and unexpected structural accident (such as over-optimistic load assumption); 20% were caused by over-high uplift pressure of underground seepage, increment of seepage and dam foundation deformation caused by high seepage gradient; 11% were attributed to dam aging, building material deterioration (such as fissure, corrosion and weathering), as well as low construction quality, which may reduce material strength; 12% were resulted by other special reasons. Among all wrecked dams, earth and rock-fill dam takes up a high proportion. Most of these dams were lack of qualified observation facilities. Drawing support from the above analysis on the cause and frequency of dam accidents, we are to help people realize the importance of safety monitoring for the safe operation of dam and other water conservancy buildings.

Shown by practices, monitoring of dams, water conservancy buildings, and foundations may achieve three objectives: monitoring the safety of buildings in preliminary and subsequently long-term operation; improving design and construction quality via continuous feedback in construction; verifying design and construction via inverse analysis of actual service performance, so as to provide scientific basis for improving and revising design theory.

Conclusion

Settlement and horizontal displacement are indexes indicating displacement of engineering buildings (structures). Deformation indexes include inclination, deflection and horizontal deformation. The purpose of disaster monitoring of engineering buildings (structures) is to prevent disasters, and to take handling measures after disasters. Safety monitoring is an assurance to disaster prevention, reduction, dynamic and information-based construction. Monitoring of engineering disaster is based on analysis and determination of monitoring tolerance of engineering disaster. On the other hand, monitoring of engineering building (structure) deformation should also fully make use of achievements in modern surveying technology.

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