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Structural Monitoring and Control During Support System Replacement of a Historical Gate

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***Abstract*—**Middle-gate is located in Hasankeyf, Batman dating back to 1800 BC and is one of the important historical structures in Turkey. The ancient structure has suffered major structural cracks due to aging as well as lateral pressure of a cracked rock which is predicted to be about 100 tons. The existing support system was found to be inadequate to support the load especially after a recent rock fall in the close vicinity. Concerns were increased since the existing support system that is integral with a damaged and cracked gate wall needed to be replaced by a new support system. The replacement process must be carefully monitored by crackmeters and control mechanisms should be integrated to prevent cracks to expand while the same crack width needs to be maintained after the operation. The control system and actions taken during the intervention are explained in this paper.

***Keywords*—**structural control, crack width, replacement, support

I. Introduction

MIDDLE-GATE is located in Hasankeyf, Batman dating back to 1800 BC [1] and is one of the important historical structures in Turkey. The gate is located on a path leading to the upper city which is protected by steep cliffs on all sides and two other gates. The ancient structure has suffered major structural cracks due to aging as well as lateral pressure of a cracked rock which is predicted to be about 100 tons (Figure 1). The existing support system was found to be inadequate to support the load especially after a recent rock fall in the vicinity. Concerns were increased since a large rock block has fallen within close proximity of the middle gate and an existing support system that is integral with a damaged and cracked gate wall was inadequate (Figure 2) and needed to be replaced by a new support system. The support system replacement was a very risky process since the wall and existing support system were in a balance state, removing the existing system would leave the wall vulnerable to immediate damage. Therefore, the cracks needed to be monitored by crackmeters and a control mechanism must be integrated to prevent cracks to expand. Following the replacement of the support system, the new system should maintain similar level of crack on all important locations. Closing the cracks too much relative to their original states should also be prevented since such an action would generate additional stresses and deformations at other places. The monitoring and control system would ensure post replacement condition to be similar to the original state as well.

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II. Data Acquisition / Monitoring System

A simple and efficient monitoring system was implemented focusing on the major cracks on the middle gate. The most significant crack was located at the entrance wall on the valley side (Figure 2). The diagonal cracks were clear indication of shear loading exceeding the load carrying capacity of the gate wall. Four crackmeters were placed on the visible cracks of the wall, one at the bottom right corner, two crackmeters at the mid-height of the wall, and fourth gage located on the crack at the top of the wall. The crackmeters were placed in horizontal direction measuring the lateral movement of the upper side of the wall relative to the lower side of the wall separated by a series of diagonal cracks. Two additional crackmeters were located at the cracked rock block behind the middle gate observing movement in the vertical and horizontal directions. The datalogger used for monitoring and control was Campbell CR800 [2] with 6 single ended channels. The system can read 5000mV with 1333μV resolution about 3750 resolution lines or close to 212 which corresponds to 12 bit ADC. Although 16, 18, and 24 bit ADC systems are setting the current standards, 3750 divisions on a 100mm measurement system would provide 0.026667mm resolution. The datalogger programming was made such that each measurement is repeated 500 times with 50 Hz integration frequency to improve the resolution up to 0.0003 mm taking advantage of the random noise on the measurement data vibrating around the actual data. The crackmeters used in the study were potentiometric kind having practically infinite resolution. Therefore, the CR800 system with 6 single ended input channels was the optimum solution for the monitoring project of middle gate. An additional temperature and relative humidity sensor was also integrated to the measurement system to compare, correlate, and compensate temperature induced movement components in the measured long term monitoring data. Temperature and Relative Humidity Probe Model CS215 from Campbell was used which uses SDI-12 protocol to communicate with the datalogger. SDI-12 is a digital communication between the sensor and the datalogger, which permits utilizing digital channels leaving space for the analog sensor channels. Since collected temperature and humidity data is digitized at the sensor, the data can be transmitted over long distances. The sensor can read temperature data between -40° to +70°C with ±0.4°C (+5° to +40°C), ±0.9°C (-40° to +70°C) accuracy as well as 0 to 100% RH (-20° to +60°C) with (at 25°C): ±2.0% (10-90% range), ±4.0% (0-100% range) accuracy.

III. SUPPORT SYSTEM REPLACEMENT PROCESS

The execution work needed to start with careful considerations and contingency plans if the main planned action would fail. However, the monitoring system gave silent alarms before the actual replacement work has started as a subgroup of workers responsible of the cleaning work unwillingly damaged the existing support system. As the SMS alarm automatically sent by the datalogger was received, a warning was given on site and the new support system had to be rapidly completed as the crack was quickly opening (Figure 3). The new system was completed in less than a day by extra shifts and post-tensioning was applied on the new support system by turning bolts at the end of the new anchors. The system was tightened by hand, and the actual load level existed neither in the old nor in the new support system was known. As the crack width monitoring was continued, the crack width that was rapidly opening before the intervention was observed to be quickly recovering. However, the recovery seemed to be progressing far beyond the original crack width (Figure 4). The over tightening in the new anchorage system was evident from the measured data. The crack was monitored to be closed about 0.2mm more than the original crack width. In order to restore the crack to its original width, the anchor's bolt was rotated backwards. Bolt teeth had about 20 rotations in 73mm distance. The bolt had to be untightened about 1/20 rotation to bring back to original width [3]. The leverage to untighten the bolt had 1m radius. The operator was asked to revolve the end of the leverage about 0.32m to achieve 0.2mm release [3]. The measured data indicates the untightening process bringing the crack width back to its original value (Figure 4).

Although monitoring system was mainly intended for the support replacement process, system left functional after the replacement work was completed. Yellow and red alarm zones were defined in the datalogger program to warn users by SMS text messages when the crack width exceeds predefined limits. When the red alarm zone is exceeded, the system would flash a red light and give an audible alarm sound to warn tourists and local people around the gate to evacuate the region since a rapid collapse might be expected. Alternatively, the alarm system would also go off to warn if a vandal action takes place such as cutting the sensor cables or damaging one or more sensors. This would also be helpful to minimize the damage to the monitoring system.

IV. CONCLUSIONS

The monitoring and control system used in the middle gate has proved to be essential since the system has set an alarm as the unexpected movement was detected and relevant precautions were taken.

Furthermore, the crack width was adjusted back to its original state using the control system maintained by the crackmeters.

The installed health monitoring system was intended to be used for the critical support replacement program; however, the performance of the new support system is also monitored for the first full year following the support replacement process. In this way, unexpected critical movement in the cracks can be detected before an unwanted catastrophic collapse of progress of the cracks beyond reparable limits.

Such a control and monitoring system used in the middle gate must be an integral part of restoration studies that involve critical details and applications.

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[2] User manual of Campbell CSI, cited on 24 July 2011, http://www.campbellsci.com/cr800-datalogger
[3] A. Turer, *Hasanakeyf Middlegate (Ortakapi) Field Execution Report.* (in Turkish), Ankara, Turkey, 2011.

Fig. 1 Middle Gate general view, cracked rock & force paths, and crack pattern

Fig. 2 Close view of the middle gate entrance wall on the valley side

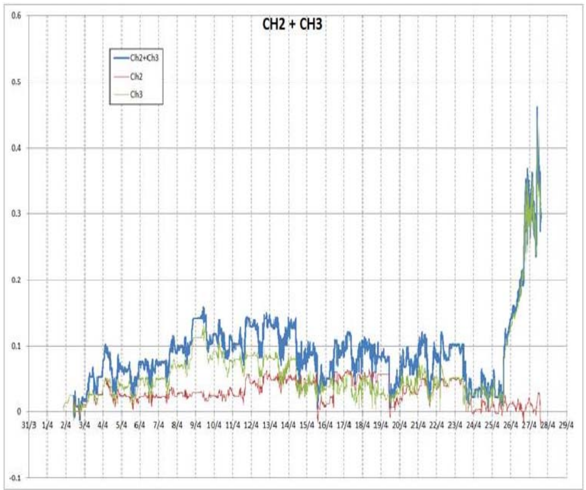

Fig. 3 Monitoring data of the wall crack for about first 25 days

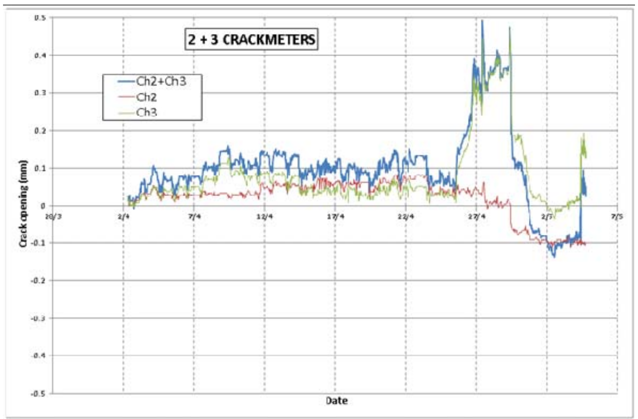

Fig. 4 Crack control by bolt rotation adjustment