*Challenges, Opportunities and Solutions in Structural Engineering and Construction – Ghafoori (ed.)*


# Load testing a historic monument

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ABSTRACT: On June 22, 2006, a 230 kg (500 lb) granite fragment fell from the observation deck at the Perry's Victory and International Peace Memorial. The circa 1915 memorial is located on South Bass Island, Ohio. As part of an emergency inspection, the underside of the reinforced concrete Upper Plaza level was surveyed. Extensive and severe freeze thaw deterioration was noted throughout. A load test was conducted to establish whether or not a severely deteriorated portion of the Upper Plaza can safely and reliably support the code prescribed loads with an appropriate factor of safety. At the conclusion of the test, one of the beams did not meet the acceptance criteria. Therefore, after long term repairs to the memorial are completed and public access to the plaza restored, it was recommended that the live load rating be reduced, that the Upper Plaza be shored or reinforced, or that the Upper Plaza be demolished and rebuilt.

## 1 INTRODUCTION

### 1.1 *The battle*

On September 10, 1813, Commodore Oliver Hazard Perry defeated and captured six vessels of Great Britain's Royal Navy at the Battle of Lake Erie. At the conclusion of the battle, Perry penned the now famous words to General William Henry Harrison: "Dear General: We have met the enemy and they are ours." His success enabled Harrison to transport his army to Canada, defeating the British at the Battle of the Thames River. Many consider this victory to be the turning point of the War of 1812.

### 1.2 *The memorial*

As the centennial of the war approached in the early 1900s, it was decided that a memorial would be built to honor Commodore Perry and the men who fought with him, as well as the century of peace between the United States and Canada that followed the war. A design competition was held, and the architects chosen were Joseph Freedlander and Alexander Seymour, Jr. The Perry's Victory and International Peace Memorial is located on an isthmus on South Bass Island in Lake Erie, adjacent to the city of Put-in-Bay, Ohio. The memorial was designed to appear as a Roman Doric column, considered the tallest in the world of its type (Fig. 1). The memorial stands 107 m (352 ft) above Lake Erie, with an observation deck at a height of 97 m (317 ft).

The diameter at its base is 14 m (45 ft). The exterior of the memorial is pink granite from Milford, Massachusetts with a cast in place unreinforced concrete core lined with hard-fired face brick on the interior (Fig. 2). The pink granite was chosen because from a distance it appears brighter than white. Coursing consists of seventy-eight rows of granite, with thirty blocks per course. An elevator runs through the interior of the memorial column, bringing visitors up to the observation deck level.

Figure 1. Perry's Victory and International Peace Memorial.

Surrounding the memorial column is a raised Upper Plaza paved with granite and brick pavers. The Upper Plaza is raised above the natural grade level on a

Figure 2. Memorial under construction (photo courtesy of National Park Service).

concrete structure, consisting of cast in place reinforced concrete columns supporting reinforced concrete beams and integral slab.

Construction of the memorial began in 1912 and was completed in 1915. The memorial was declared a national monument on July 4, 1936, by President Franklin D. Roosevelt and is currently administered by the National Park Service. The NPS maintains an extensive archive at the site, including drawings, specifications, and photographs documenting the original construction and subsequent repair campaigns. Prior to the involvement of the author's firm, the most recent extensive repairs had been completed in the early 1980s. The 1980s work included installation of a waterproofing membrane to protect the Upper Plaza structure from water infiltration. Prior to this work, the concrete structure was unprotected.

## 2 THE INCIDENT

On June 22, 2006, a 230 kg (500 lb) granite fragment fell from the observation deck at the top of the memorial and crashed into the Upper Plaza. An emergency investigation was conducted on the memorial in order to stabilize the area of the failure and inspect the remaining exposed areas of the observation deck. As part of a comprehensive follow-up investigation of the current condition of the memorial, the underside of the reinforced concrete Upper Plaza was surveyed. Extensive and severe freeze-thaw deterioration was noted throughout.

## 3 INVESTIGATION OF THE UPPER PLAZA

### 3.1 *Field survey*

A visual survey and sounding were performed at the Upper Plaza to evaluate the current condition of the reinforced concrete structure. Three cores were removed for examination for freeze-thaw deterioration. One of these cores was tested for compressive strength. Notable conditions observed included concrete deterioration in the form of cracked, spalled, and delaminated concrete. Some areas of concrete sounded "dead" or hollow when tapped with a hammer, indicating delaminations, freeze-thaw deterioration, or other defects. In areas of spalled concrete, corroded reinforcing steel was observed. Areas of previously installed patches were noted. Sound testing of the previous repairs indicated that some areas may be delaminated and/or debonded. Evidence of water leakage through the deck structure in the form of water staining and efflorescence was observed on the underside of the structural slab (Fig. 3).

### 3.2 *Structural analysis*

The results of a structural analysis indicated that the Upper Plaza structure as originally designed would have adequate capacity to carry the design live load of 4.8 kPa (100 psf). There is no known method of structural analysis to reliably predict the behavior of the deteriorated concrete or determine whether any of the distress observed is a result of current structural inadequacy. However, observations of visible portions of the plaza structure as well as analysis of the concrete cores indicate that freeze-thaw deterioration of the concrete is extensive and severe. The distress is highly variable and the extent is difficult to quantify.

Because the Upper Plaza could be easily shored at the basement level, it was possible to perform load testing to evaluate the behavior of the structure by monitoring deflections, and to determine whether it has sufficient strength and reliability in its current, partially deteriorated condition.

Figure 3. Extensive and severe freeze-thaw damage to underside of Upper Plaza.

## 4 LOAD TEST OF THE UPPER PLAZA

### 4.1 *Load medium*

Once the decision to conduct the load test of the Upper Plaza was made, various methods for application of the test load were reviewed. Using dead weights or large test frames was ruled out since transportation to the island is limited to ferry boat or small airplane. With water plentiful from nearby Lake Erie, the use of a water tank or swimming pool was determined to be the best alternative.

### 4.2 *Shoring*

Prior to conducting the load test, steel frame shoring was installed under the structure with sufficient capacity to safely support the test loads and weight of the plaza in the event of a structural failure. The shoring was positioned approximately 50 mm (2 in) below the structure to allow for anticipated deflections, while also providing support should excessive deflections occur.

### 4.3 *Crack mapping*

The structure beneath the test area was inspected and sounded with a hammer for spalls, delaminations, cracks or other signs of distress. The distress conditions observed were recorded on an inspection data sheet. Significant existing cracks were marked and initial crack widths recorded directly on the structure. Changes in crack length and width were monitored and recorded during application of the test load.

### 4.4 *Instrumentation*

Deflections of the beams and slab areas were monitored using cable extension transducers (CET) installed at twenty locations. Figure 4 is a plan view showing the locations of each installed instrument. Each CET has a measurement range of at least 50 mm (2 in) with a resolution of 0.025 mm (0.001 in). The CETs were wired into a panel board, which was interfaced to a data acquisition system.

### 4.5 *Test criteria*

The load test was performed in accordance with the strength evaluation procedures prescribed in Chapter 20 of the American Concrete Institute Building Code Requirements for Structural Concrete (ACI 318-05). The design live load for this structure is 4.8 kPa (100 psf). As specified in Section 20.3.2 of ACI 318, the total test load (including dead load already in place) shall not be less than 0.85 (1.4D + 1.7L), where D is the dead load or self-weight and L is the design live load. The dead load was calculated based on measurements of the as-built dimensions of the beams, girders and slab in the test area. The required superimposed test load was determined to be 8.5 kPa (178.4 psf).

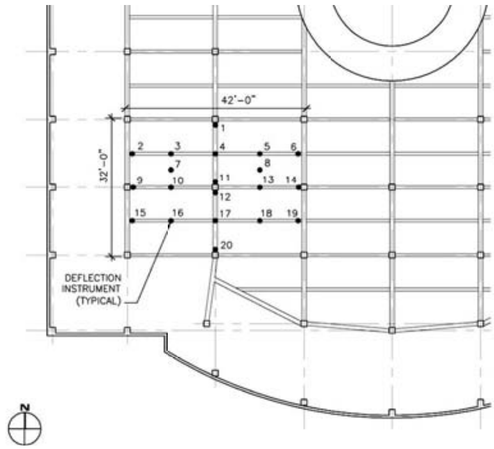


Figure 4. Plan view of deflection instrument locations.

Figure 5. View of load test in progress looking down from the observation deck (note repairs to observation deck facade).

### 4.6 *Load application*

Three 5 m (16 ft) by 10 m (32 ft) by 1 m (40 in) deep lightweight swimming pools were installed adjacent to one another in the designated test area (Fig. 5). The 8.5 kPa (178.4 psf) test load was achieved with a water depth of 876 mm (34.5 in) of water over the entire test area. A large pump was used to bring lake water into the center pool. Two smaller pumps were used to pump the water out of the center pool and into each adjacent pool.

### 4.7 *Test procedure*

At the onset of the test, an initial loading of ten percent of total test load was applied in order to assure that the structure was behaving as predicted and the loading mechanism and instrumentation were functioning as designed. Once it was determined that the structure was behaving as expected, the remainder of the test load was applied in four equal increments. It took approximately five hours to achieve the maximum load. At each load stage, the flow of water was stopped while readings were recorded on the deflection instruments and a crack survey of the test area was conducted. Once the total test load was achieved, it was kept in place for a period of 24 hours. During this hold period, deflection readings were taken periodically. After the test load had been in place for 24 hours, the water was drained from the pools in the reverse order of load stages. Deflection measurements were obtained after each load decrement and 24 hours after the test load was completely removed.

## 5 RESULTS

### 5.1 *Acceptance criteria*

The ACI acceptance criteria require that the structural members tested show no evidence of failure, such as structurally significant cracking or spalling. ACI 318 also requires that the measured maximum deflections satisfy one of the following conditions:

$$\Delta_{\max} \leq \frac{\ell_t^2}{20,000\,h} \quad (1)$$

or

$$\Delta_{r\max} \leq \frac{\Delta_{\max}}{4} \quad (2)$$

where $\Delta_{\max}$ is the measured maximum deflection under the full test load, $\Delta_{r\ \max}$ is the residual deflection, $\ell_t$ is the span length, and $h$ is the overall thickness of the member. The residual deflection $\Delta_{r\ \max}$ is the difference between the initial deflection prior to loading and the final deflection after load removal. If the structure shows no evidence of failure, recovery of deflection after removal of the test load (Equation 2) is used to determine whether the strength of the structure is satisfactory.

### 5.2 *Test results*

All of the elements in the area tested sustained the required test load without evidence of failure. Net deflections were determined by subtracting the average of the deflection at each support from the deflection reading obtained at midspan. The maximum net deflections measured at each location are summarized in Table 1.

#### 5.2.1 *Beams*

Of the six reinforced concrete beams tested, load testing showed that one of the beams did not meet the ACI criteria for both maximum deflection and residual deflection. The center of the beam at CET 13 had a maximum deflection of 5.4 mm (0.212 in), which exceeded the calculated deflection limit of 3.7 mm (0.147 in). In addition, CET 13 had a residual deflection of 1.6 mm (0.063 in), which exceeded 25 percent of the maximum deflection, or 1.3 mm (0.053 in). The beam at CET 13 was not observed to have distress conditions present based on the visual survey.

#### 5.2.2 *Girders*

Of the two reinforced concrete girders tested, CET 4 had a maximum deflection of 2.8 mm (0.110 in), which exceeded the calculated deflection limit of 1.7 mm (0.068 in). However, CET 4 had a residual deflection of 0.7 mm (0.027 in), which did not exceed

Table 1. Summary of load test results.

| CET location | Element | Existing condition | Calculated maximum deflection (mm) | Recorded maximum deflection (mm) | Recorded deflection exceeds calculated | 25% of maximum deflection (mm) | Permanent deflection recorded (mm) | Permanent deflection recorded exceeds limit |
|---|---|---|---|---|---|---|---|---|
| 3 | Beam | Previous patch | 3.7 | 2.8 | | | | |
| 4 | Girder | Hollow sounding | 1.7 | 2.8 | Yes | 0.7 | 0.7 | No |
| 5 | Beam | Previous patch | 3.7 | 3.4 | | | | |
| 7 | Slab | Hollow sounding | 1.9 | 0.4 | | | | |
| 8 | Slab | Hollow sounding | 1.9 | 0.2 | | | | |
| 10 | Beam | Previous patch | 3.7 | 3.6 | | | | |
| 13 | Beam | No observed distress | 3.7 | 5.4 | Yes | 1.3 | 1.6 | Yes |
| 16 | Beam | No observed distress | 3.7 | 1.7 | | | | |
| 17 | Girder | Hollow sounding | 1.7 | 1.5 | | | | |
| 18 | Beam | No observed distress | 3.7 | 2.2 | | | | |

25 percent of the maximum deflection and therefore met the acceptance criteria. The girder at CET 4 was observed to have been "dead" or hollow sounding based on the visual survey.

#### 5.2.3 *Slabs*

Of the two slab areas tested, both met the ACI acceptance criteria. Both were considered "dead" or hollow sounding when surveyed, likely indicating early age freezing and severe freeze-thaw deterioration. Results of the petrographic examination of concrete cores taken from slab areas adjacent to the load test area correlate well with the results of the visual survey and sounding.

## 6 CONCLUSION

Based on the overall findings, the load test results did not correlate well with the findings of the visual survey and sounding of the concrete in some areas. Visual observations, confirmed by the limited laboratory study, showed that extensive freeze-thaw deterioration has occurred. Similar conditions were observed in other areas of the Upper Plaza that were not a part of this load test. The load test results indicate that, in its current condition, the Upper Plaza structure does not meet ACI criteria to safely support the design live load. Therefore, as part of long term repairs to the memorial to restore public access to the Upper Plaza, it was recommended that the live load rating be reduced, that the Upper Plaza be shored or reinforced, or that the Upper Plaza be demolished and rebuilt.

## ACKNOWLEDGEMENT

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