lessons learned

Restoration of Harvard University Stadium

By Wayne R. Lawson, P.E.

Harvard Stadium was originally constructed over a five (5) month period in 1903 at a cost of $310,000. In 1910 the colonnade level columns, wall, and roof were added. During the renovation in 1929, steel bleachers were installed at the northeast end making the stadium into an oval configuration and thereby increasing the seating capacity to 57,000. However, in 1952, the bleachers were removed, reverting the stadium back to its original horseshoe shape with a total seating capacity of 37,000. Finally in 1982, at a cost of $8 million, the last renovation was made including precast concrete seating, making the stadium into what we see today.

The physical condition of the stadium in 2004 varies widely, since elements of the 1903 construction are essentially in the same condition as when the stadium was completed. Elements in this condition are concrete walls, columns and slabs which have been largely protected from the elements for over 100 years. At the other end of the spectrum are structural and some largely architectural elements which have been severely eroded and compromised by the environment through the years. Some of the problems were caused by a lack of understanding of structural function and the use of materials of construction, materials which were available in 1903 but were unlike their better counterparts available today.

A structure of this sort with a large expanse of concrete has the potential to undergo thermal expansion and contraction of up to five (5) inches each side of the mass center. It appears as though the builders, constrained by limited concrete transport ability and few construction joint isolation materials, devised an approach which was perhaps the first use of segmental construction in the area. This resulted in a great number of slip joints not always aligned through the structure. Without the corrosion resistant and deformable and low friction materials available today, these joints lost much of their usefulness early in the life of the stadium.

Expansion joints which have "welded" due to corrosion and those which have resisted anticipated movement are examples.

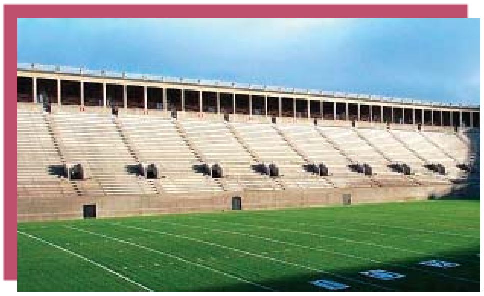
In 2003, CBI Consulting, Inc. was engaged by Harvard University to investigate methods and procedures to be used for maintenance repair of Harvard Stadium. This investigation had several purposes:

a. Correct some of the more serious areas of concrete spalling and deterioration while replicating the natural color tone of the adjacent concrete surfaces.
b. Investigate concrete cracking and methods of repair.
c. Evaluate through load testing the capacity of a typical in-situ concrete transfer beam.

Despite signs of deterioration and evidence of supplemental framing, CBI recognized that the stadium had been successfully utilized for over 100 years without signs of overstress or failure. It was this historical performance that lead CBI to advise the owner that undertaking a field load test was an expenditure that, if successful, would derive significant cost saving to the overall stadium restoration project. Further, section 1709.1 of the sixth edition of the Massachusetts State Building Code permits in-site load tests *"whenever there is a reasonable doubt as to the stability or load bearing capability of a completed building, structure or portion thereof for the expected loads, an engineering assessment shall be required. The engineering assessment shall involve either a structural analysis or an in-situ load test, or both."*

The Massachusetts State Building Code requires that the load test be conducted in accordance with the applicable reference standard, which in this case is the American Concrete Institute (ACI).

Prior to initiation of the load tests, CBI completed a preload test investigation to determine the existing site conditions. This investigation included removal of in-situ concrete cores for compression testing and petrographic analysis. Additionally, a program of concrete excavation and pachometer survey was completed to identify reinforcing steel locations and conditions. The interior concrete transfer beam at Seating Section 26 was selected for load testing based on the visual appearance of the beam (extensive cracks, and extreme efflorescence on the concrete surface), petrographic confirmation of ASR and unknown variables, which resulted in installation of two structural support members during the 1982 repairs.



A number of top surface loading methods were reviewed including mass concrete blocks and water, however these required disruption of the stadium activities. By working with a rigging contractor, an underside loading method was devised, utilizing a crane counterweight load frame that was supported by six (6) 25-ton hydraulic jacks and suspended from the subject beam through a steel cable and harness.

The existing precast seating was disconnected from the beam and temporarily supported with additional shoring, provided to allow four inch settlement of the beam in the event that a catastrophic failure occurred during the load test.

The loading for the test was calculated in accordance with ACI Chapter 20. In order to develop the appropriate test load for the subject beam, CBI first investigated the original 1903 framing conditions. The 1903 framing configuration required that the beam support a total test load of 190 kips, to satisfy

ACI 20.3.2. However, with the addition of supplemental beams and columns in 1982, the total test load requirement for the subject beam is reduced to 90 kips.

Engineering calculations indicated that the beam could support a total dead + live load of 214 kips when considering only the shear strength of the concrete. Further, the beam has a total dead + live capacity of 282 kips when only flexure is considered.

On the basis of this information, CBI concluded that the initial test load should be 90 kips to satisfy the current "as-built" conditions. In the event that this loading was successfully supported by the beam, the test load would be raised to the 1903 framing conditions (190 kips) and if permissible ultimately to the shear capacity of the beam concrete (214 kips).

Dial gauges were installed at each end and midspan to measure deflections during the load test. During the test, the load was applied in four increments: 90 kips, 160 kips, 190 kips and 214 kips. Initially, the entire test load was supported by the six (6) hydraulic jacks. At each test load increment, the jacks were lowered to enable a transfer of the appropriate load to the beam. Deflection measurements were taken by CBI at midspan and adjacent to the supporting columns after each load increment. The deflections were then measured after the final load had been in place for a twenty-four hour period. The test load was subsequently removed after completion of the twenty–four hour load period, and the structure recovered more than ninety percent of the maximum deflection.

The load test results successfully demonstrated that the existing beams could safely support the required dead and live loads. These results eliminated the need for installation of permanent supplemental framing, allowing more expenditures for other necessary stadium repairs and improvements. However, in order to maintain the ASR deteriorated beams it is essential that future moisture ingress be prevented while permitting the moisture within to move outward.

During the investigation, CBI coordinated the installation of sample topical applications of lithium to existing concrete elements in attempts to arrest the deterioration due to ASR. With high material costs and impregnation variations, it was concluded that this was not an effective solution. Therefore, the proposed program of stadium repairs includes coating the beams with a water barrier system and installation of top surface cap flashings. Additionally, the open joints in the stadium seating are to be sealed.

The restoration of Harvard Stadium illustrates the challenges that face the engineer. The completion of a successful project requires an ability to evaluate and solve specific and often unique conditions throughout the design and the construction process. These issues require engineering/technical knowledge and experience, with a clear understanding of the owner's financial limitations.▪

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