Evaluating Current Conditions of Miami Marine Stadium

Despite years of neglect, it appears that the structure can be repaired

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Built in 1963, Miami Marine Stadium is a modernist landmark on the Miami, FL, waterfront (Fig. 1). The signature element of architect Hilario Candela's design is the stadium's concrete hyperbolic paraboloid roof—its 66 ft (20 m) cantilever is one of the longest nontruss cantilever roof spans in the world. Another unusual feature of the design is that about one-third of the stadium is built over the water on concrete piers.

During its 28 years of operation from 1964 to 1992, the 6566-seat stadium was a popular venue for powerboat racing, concerts, rallies, and community events. Shortly after Hurricane Andrew passed through south Florida in 1992, the city of Miami closed the venue because of concerns about the safety of the structure after cracks were observed in several portions of the roof shell overhanging the grandstand. In 1993, Simpson Gumpertz & Heger Inc. (SGH) conducted a detailed structural investigation to determine the causes of the observed cracking and to evaluate the structural adequacy of the roof structure. The investigation showed that the overwhelming majority of the cracking in the roof structure wasn't caused by the hurricane but existed prior to the storm.

SGH also conducted a limited condition survey of other major elements of the stadium structure. The survey identified numerous instances of corrosion-related deterioration that were safety concerns and required evaluation and repair before occupying the stadium. Since then, however, only minimal maintenance has been done, and the stadium has remained unused.

In 2009, SGH conducted a new study to define the cost of structural repairs and identify alternatives for protection of the structure to prolong its useful life.

Fig. 1: Current view of the stadium *(photo courtesy of Rick Bravo)*

The stadium is a cast-in-place concrete structure consisting of five primary structural systems (Fig. 2):

- Foundations: concrete piles with pile caps supporting columns, grade beams, and a seawall;
- Ground-level structure: grade beams and structural slabs-on-ground;
- Mezzanine-level structure: slabs and pan joists generally supported by beams and columns but in some cases supported by hangers connected to the grandstand structure;
- Grandstand structure: vomitory and parapet walls, raker beams, tie beams, and columns supporting tread-and-riser seating slabs; and
- Roof structure: eight hyperbolic paraboloid (hypar) shell units joined by a longitudinal post-tensioned diaphragm wall—each hypar shell unit comprises

Fig. 2: Renderings showing the primary structural systems for Miami Marine Stadium *(images courtesy of SGH)*

Fig. 3: Concrete piles below the lower seating area show moderate-to-severe deterioration *(photo courtesy of SGH)*

four hypar shells and is supported by three inclined columns—two at the back and one in the interior.

The stadium, essentially a marine structure, has four exposure conditions:

- Submerged zone: the portions of the piles below the mean low-water level. These zones are constantly submerged, so corrosion is limited by lack of oxygen;
- Tidal zone: the pile regions between the mean low- and high-water levels. Members are exposed to alternate wetting and drying, so oxygen, water, and chlorides promote corrosion;
- Splash zone: the portions of the piles above the mean high-water level, the seawall, and other structural elements below the lower seating. Members are exposed to cycles of wetting and drying, so chloride concentrations develop within the concrete and an abundance of oxygen and water promote severe corrosion; and

Fig. 4: The undersides of the slabs and grade beams are in good condition *(photo courtesy of SGH)*

Fig. 5: Deterioration in mezzanine slab at hanger location *(photo courtesy of SGH)*

- Open zone: the upper and lower seating structure, ground and mezzanine slabs, ramps, inclined columns, and roof structure. Members are exposed to seawater mist and rain, but conditions are less severe than in the splash zone.

FIELD INVESTIGATION

As part of SGH's team, we visited the site in the fall of 2009. We visually examined the structure for distress and deterioration. We performed ground-penetrating radar testing to measure the concrete cover over reinforcement and extracted more than 20 concrete cores for laboratory testing and petrographic examination. For each of the five major structural systems, the team selected at least one area as representative of the typical condition and one as representative of the worst condition. We surveyed these areas in detail, including sounding for delaminations, measuring cover, and extracting samples. We accessed piles on the water and at the seawalls using a boat and the undersides of the grandstands using a hydraulic lift.

CONDITION OF THE STADIUM STRUCTURE

As might be expected, the portions of the structure located in the splash zone exhibited significant deterioration. Although we were able to examine only those portions of the piles above the waterline, several piles below the lower seating area show moderate to severe deterioration (Fig. 3). The seawall also shows areas of severe deterioration; concrete cores revealed deeper deterioration than was apparent from sounding.

Some columns, beams, and slabs below the lower grandstand show severe deterioration. The top sides of the ground-level slabs show minor deterioration. At two openings, we were able to observe that the underside of the slabs and grade beams are in good condition (Fig. 4); however, the mezzanine slab has localized areas of severe deterioration primarily caused by embedded steel hangers supporting the slab (Fig. 5).

The seating areas, vomitory and parapet walls, raker beams supporting the seating structure, and inclined columns supporting the roof structure (Fig. 6) show moderate deterioration with localized spalls or delaminations. Several parapets around the inclined front columns show severe deterioration, and the beams next to the uppermost seating row show severe localized deterioration.

The roof shows diagonal cracks from 0.013 to 0.040 in. (0.330 to 1.016 mm) wide throughout the front cantilever portion. The severity and extent of corrosion of the reinforcement, however, were less than might be expected because of the use of galvanized reinforcement in the roof. Some post-tensioning anchorage zones of the roof diaphragm are spalled or delaminated.

Comparisons with 1993 condition survey

When compared with the conditions found in 1993, deterioration doesn't appear to have increased alarmingly. For instance, the cracking on the roof (Fig. 7), deterioration of one of the post-tensioning anchorage zones (Fig. 8), and spalling of columns (Fig. 9) don't appear to have increased significantly. We did observe a tie beam over the water with large spalled areas that weren't observed in 1993 (Fig. 10). It should be noted that since these observations were limited to the elements or areas that we were able to identify in photographs or notes from 1993, we can't generalize the observed deterioration rate for the balance of the structural elements in the stadium.

Fig. 6: Deteriorated inclined column *(photo courtesy of SGH)*

Fig. 7: Cracking on bottom side of roof: (a) 1993; and (b) 2009 *(photos courtesy of SGH)*

LABORATORY WORK

Chloride content

We tested the acid-soluble chloride content of the concrete. The highest chloride contents were obtained in the tidal and splash zones of the piles. The next highest concentrations were obtained in the seawall (splash zone). The lowest concentrations were in the roof. Appreciable chloride concentrations can be found beyond the cover depths.

Table 1 compares the chloride concentrations in cores taken from the roof in 1993 and 2009. As would be expected, in general the chloride concentrations have increased and the chlorides have penetrated to greater depths since 1993.

TABLE 1:
Comparison of chloride concentrations in 1993 and 2009

Sample	Location	Depth from surface, in.	Chlorides, % by mass of concrete	
			1993	2009
Roof No. 1	Top	0.25	0.022	0.079
	Middle	1.5	0.010	0.035
	Bottom	3.0	0.052	0.040
Roof No. 2	Top	0.25	0.022	0.043
	Middle	1.5	0.013	0.031
	Bottom	3.0	0.043	0.060

Note: 1 in. = 25.4 mm

Petrographic examination

We examined seven cores from various locations at magnifications of 6 to 50X. Thin sections from two of these cores were examined at magnifications of 25 to 200X. The quality of the concrete appears to be fair to good, with well-graded and uniformly distributed aggregates and a moderate-to-good paste-to-aggregate bond. Overall, the estimated water-cementitious material ratio (*w/cm*) for the seven cores appears to range from 0.40 to 0.54.

The near-surface concrete exhibits variable carbonation depths among the seven core samples, consistent with variations in *w/cm* and differences in exposure conditions. Overall, there is remarkably little carbonation for a 45-year-old structure.

Fig. 8: Deterioration of post-tensioning anchorage zone of the diaphragm end: (a) 1993; and (b) 2009 *(photos courtesy of SGH)*

Fig. 9: Column showing increased spalling: (a) 1993; and (b) 2009 *(photos courtesy of SGH)*

DISCUSSION

The stadium has been exposed to a tropical climate and marine environment for 45 years. The present deterioration appears to be the result of the warm, moist climate and the high chloride contents in the concrete, not carbonation or low-quality concrete. The varying levels of chlorides at different depths within individual concrete cores and the higher levels of chlorides in the areas of the stadium with more severe exposure to saltwater or salt spray indicate that chlorides weren't incorporated in the original concrete mixture.

The concrete elements show degrees of deterioration ranging from moderate to severe, with the most severe deterioration in the tidal and splash zones. The structural elements in the open zone show moderate deterioration, and the deterioration doesn't appear to have increased dramatically since 1993. Because these observations are limited to areas we were able to identify in 1993 photographs or notes, we can't generalize the deterioration rate for the entire stadium.

The vast majority of the cores show high chloride contents, and these appear to have increased significantly since 1993 (Table 1). The depths at which appreciable chloride concentrations can be found are often greater than the cover depths. Comparing the concrete covers (measured and specified) with the chloride contents at various depths from the surface suggests that corrosion will continue even after repairs unless additional measures are taken. Whereas the roof slab is thin and its reinforcement generally has small cover, the galvanized reinforcement in the roof structure has helped to limit the severity and extent of corrosion as compared with other structural elements.

The piles on the land side of the stadium and the portions of the seaside piles below the mudline aren't exposed to view and their condition is unknown. Although portions of the structure that are continually underwater should have limited corrosion rates due to lack of oxygen, further assessment of the piles would be prudent.

The required remedial work to rehabilitate the stadium's concrete structure will generally fall into two categories: 1) concrete repairs, which are necessary to repair or

Fig: 10: Beams over water showing growth of spalls and new spalls: (a) 1993; and (b) 2009 *(photos courtesy of SGH)*

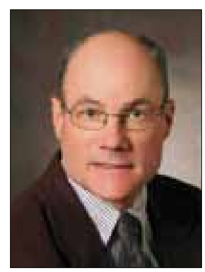
replace the existing damaged concrete elements to ensure that the structure is safe and serviceable; and 2) corrosion mitigation measures, which are necessary to slow the future rate of deterioration and maximize the useful life of the rehabilitated structure.

AFTER FURTHER ASSESSMENT

Further assessment of the piles is planned to better understand the potential economic implications of having a newly renovated superstructure founded on 45-year-old piles. Pending review of the piles, SGH has concluded that the repair and rehabilitation of Miami Marine Stadium for safe public use is technically feasible and practical.

The overall cost to repair and protect the concrete structure alone (excluding architectural improvements such as new railings, improved accessibility, and new concession booths) would range from $5.5 to $8.5 million, depending on the type of corrosion mitigation measures. These potentially include the use of penetrating corrosion inhibitors, waterproofing coatings, cathodic protection, and chloride extraction. All of these repairs and preventive measures can be achieved in a way that preserves and maintains the significant architectural and historic character of this modernist icon.

Selected for reader interest by the editors.



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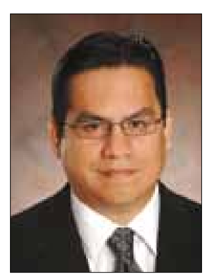

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