INSIGHT™

ISSUE NO. 9

A technical newsletter by Raths, Raths & Johnson, Inc. for the construction industry.

"Insight: to see into and understand; an item of knowledge gained by this power."

In this issue of *RRJ Insight*, we discuss problem solving techniques employed to assist a contractor in completing the construction of a new parking garage at the Miami International Airport. Cracking was found in post-tensioned beams. RRJ's investigation revealed this to be a symptom of radically displaced tendons. Using innovative investigative techniques, RRJ was able to locate the as-built tendon profile, in some cases over 20 inches higher at mid-span than designed. Detailed structural analysis and load testing proved only 13 out of 551 beams required repair in order to meet code.

INSIDE

Miami International Airport Parking Garage 7. Routine quality control procedures found significant potential problems. The General Contractor choose to identify and solve the problems thereby avoiding a litigious battle.

Tech Tip

Focus on Static Load Tests of Concrete Structures

Static load tests are generally performed when doubt arises concerning the safety or performance of a structure. Tests can have several objectives. In a new structure, they can be used to evaluate the impact of material, construction, or design deficiencies, that cannot otherwise be readily understood using conventional structural analysis techniques. Certain structures, such as bridges or parking garages, may prematurely deteriorate over time when subjected to harsh, corrosive environments. **Load tests can be used to determine the safe, load-carrying capacity of these deteriorated, weakened structures.** In other instances, Owners may wish to place higher loading demands on a structure than was intended by the original design (i.e., a change in the floor use from offices to storage or filing space). Tests may be performed to determine whether the structure has excess capacity beyond that provided in the original design. Finally, load tests can be performed to demonstrate to the general public the satisfactory performance of a structure with known deficiencies, even though the deficiency may be well understood, and easily evaluated by the engineer.

Most load tests are performed to evaluate the strength, or safety, of structural components such as slabs, joists, beams, or girders. **Components are subjected to code-prescribed test loads that are much larger than actual loads the structure will encounter in its lifetime.** Safety is demonstrated if the tested component can support the test overload without evidence of failure or excessive deflection. It may be equally desirable to evaluate how components of certain structures, such as parking garages or bridges, will perform under the routine, day-to-day repetitive service loads. These service load tests may provide the Owner with information that may be useful in planning maintenance strategies, including expected deflections, extent of cracking, and performance under cyclical loading.

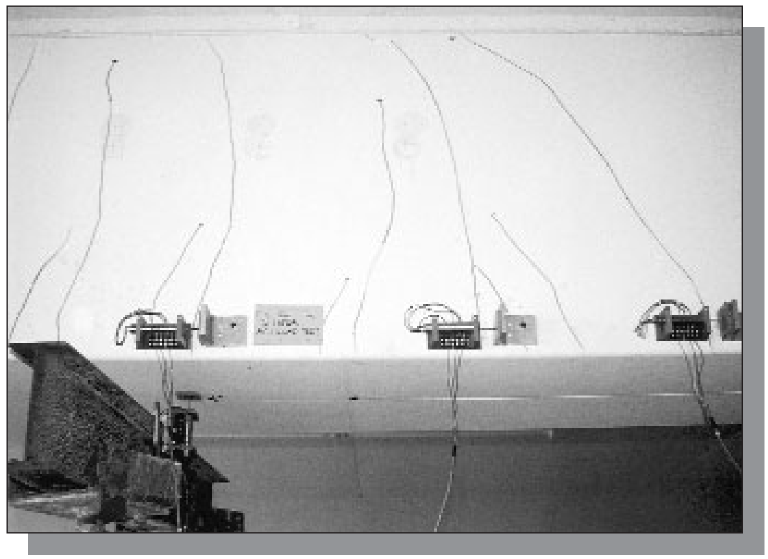

Figure 2 - Mid-span of post-tensioned beam with cracking outlined. LVDT's are in place to monitor crack widths during load test.

Once a load test is judged necessary, all interested parties should agree on the objective of the proposed test, on the party responsible for implementing the test, and on the acceptance criteria that all parties will abide by. Tests should be conducted under the supervision of a professional structural engineer, designated by all parties as the Test Engineer-in-Charge. The Test Engineer is responsible for preparing a test procedure, performing an analysis to predict the tested component's behavior, overseeing the test implementation, ensuring safety during the test, and preparing a report of the test findings. A comprehensive test procedure should be prepared and submitted to all interested parties prior to the test. For concrete structures, Chapter 20 of the American Concrete Institute (ACI) - *Building Code Requirements for Reinforced Concrete*, and ACI Committee 437 - *Strength Evaluation of Existing Concrete Buildings*, provide excellent guidelines for developing test procedures. Specific items that should be included in a procedure are:

- Test objective and the components to be tested.
- The test load (usually defined in the building code for strength tests).
- The method of applying test load (i.e. hydraulic jacks, ponded water, or stacked material of known weight). The load devices should be easy to apply and readily removable.
- The number of intermediate increments for applying the test load (at least four), and the method of measuring the structural response (deflection and crack width) at each increment.
- Safety criteria, including requirements for catch shoring installed beneath the tested component. The shoring must be designed to prevent damage to the remaining structure should the tested component fail.
- The structural response that is predicted by structural analyses, which can be used to gage the actual response during the test.
- The acceptance criteria (usually prescribed by the building code).

- David B. Tigue, S.E., P.E.

Laboratory News

Full Scale Load Test Proves Structure Sound

On a recent project at the Miami Airport, (see "Project Profile" article) RRJ conducted both strength and service load tests of post-tensioned garage beams with radically displaced tendons. Previous to the tests, RRJ analytically determined that the beams were in compliance with the building code. The tests were performed to demonstrate to the Owner and public that the beams were acceptable.

> These tests demonstrated that service load deflections and changes in crack width were small. Cracks completely closed to pretest widths after each cycled test load was removed, and cracks did not propagate under the cyclical loading.

As shown in Figure 3, the test load was applied using a series of hydraulic jacks coupled together using manifolds to produce an equivalent uniform load along the beam length. Jacks were controlled by a hydraulic pump with metering valves and calibrated gages. Jack reaction forces were resisted by the self-weight of two constructed floors above the test beam. Catch shoring was installed below the tested member to prevent damage to the remaining structure in case the test member failed. Beam deflections and changes in crack width were monitored at selected locations using Linear Variable Differential Transducers (LVDT's). See Figure 2. Loads were applied in seven increments. At each load increment, beam deflections and changes in crack width were recorded and compared to analytically-predicted values.

Service load tests were conducted on seven post-tensioned garage beams to evaluate their performance and maintenance requirements when subjected to several cycles of routine vehicular loading. These tests demonstrated that service load deflections and changes in crack width were small. Cracks completely closed to pretest widths after each cycled test load was removed, and cracks did not propagate under the cyclical loading. Strength tests were also conducted on eight post-tensioned beams in accordance with building code procedures. The tested beams behaved as predicted by RRJ's structural analyses. The test results gave the Owner, Contractor, and Designer confidence that the constructed post-tensioned garage beams would perform predictably and acceptably.

For more information regarding load testing of structures, refer to the American Society for Testing of Materials (ASTM) STP 702 - *Full-Scale Load Tests of Structures.*

- David B. Tigue, P.E., S.E.
- Douglas J. Berry
- Otto C. Guedelhoefer, S.E.

Figure 3 - Load test consisting of hydraulic jacks coupled together with manifolds to apply an equivalent uniform load across the beam.

RRJ's Evaluation Demonstrates Code-Compliance of Beams With Radically Displaced Tendons

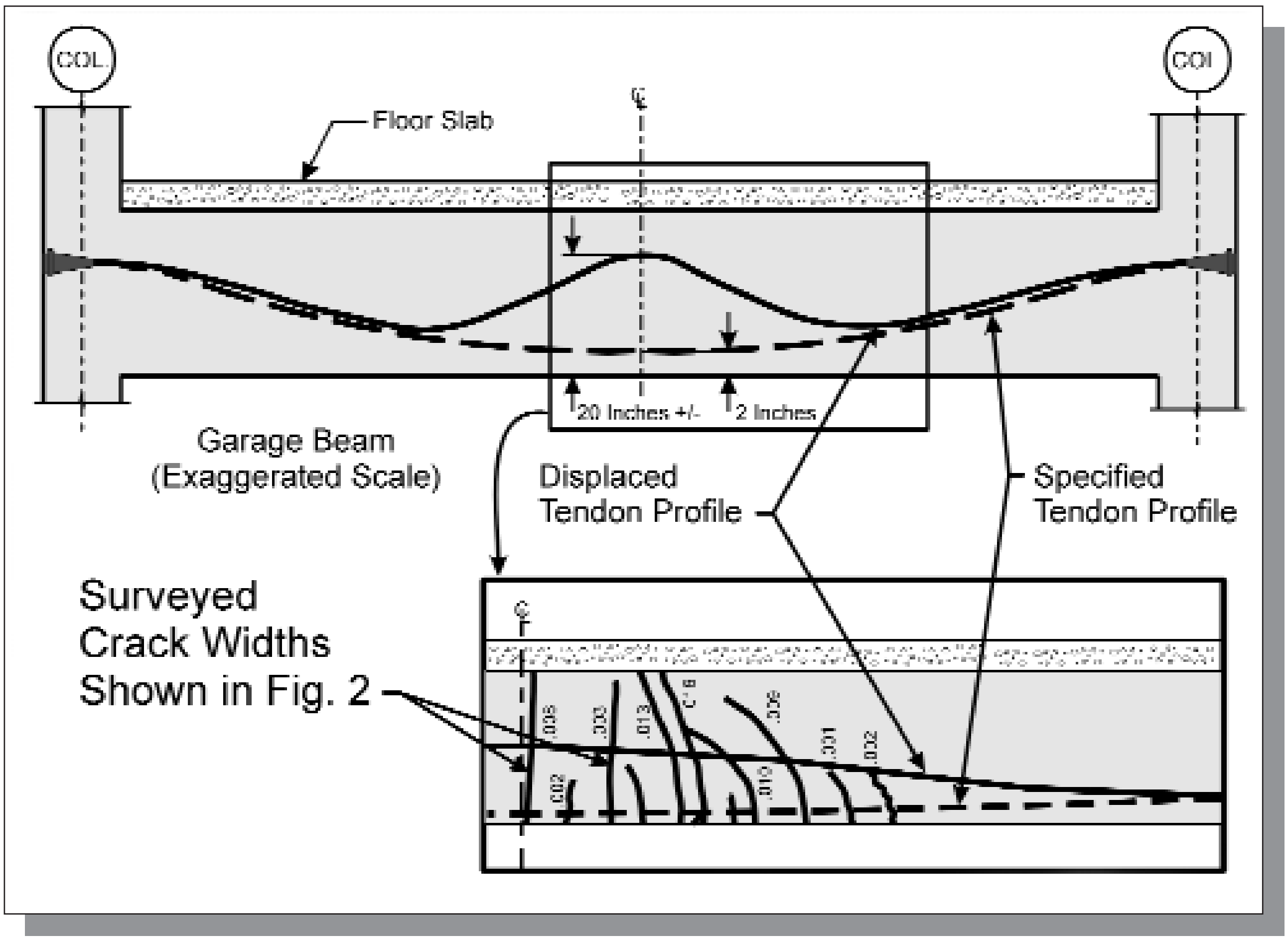

Figure 4 - Typical beam elevation showing displaced tendon profile and surveyed crack widths.

During the quality control inspections at the Miami International Airport Garage 7, certain post-tensioning ducts were discovered to have significantly floated upward near the midspan of the garage. Some ducts were found to be over 20 inches higher than specified. This discovery caused concern not only for structural safety, but also for the impact any repairs would have on the scheduled opening of the garage, which was in high public demand. The Owner initially considered demolition as the only viable means of correcting over one-hundred garage beams. This repair method was not only costly, but also would have seriously postponed the garage opening. RRJ load tests of several beams with displaced ducts confirmed predictions of RRJ structural analyses that all but 13 beams conform with building code requirements for strength and serviceability. Repairs were implemented to the satisfaction of all parties, and the garage was opened in a timely manner.

Project Profile

Miami International Airport – Parking Garage 7

The Ground Transportation Improvement (GTI) project for the Miami International Airport included the construction of a new, seven-level, cast-in-place concrete parking garage. The garage was constructed with conventionally-reinforced concrete floor slabs supported by post-tensioned concrete beams and conventionally-reinforced concrete columns. **During construction, quality control tests and inspections revealed potential problems with the strength of concrete placed in certain structural elements and the placement of certain post-tensioning cables in the floor beams.** RRJ was engaged by the General Contractor to perform a comprehensive investigation to evaluate the concerns.

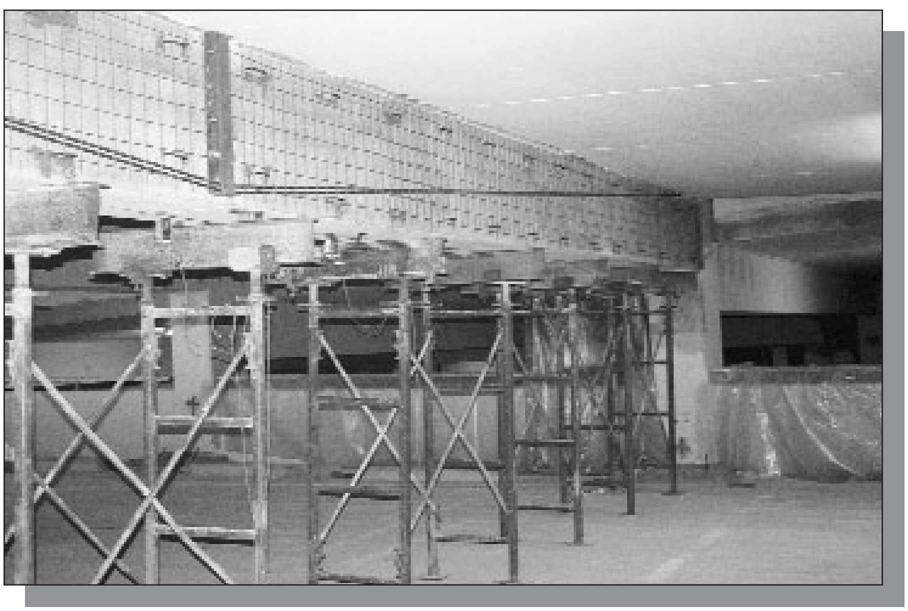

Figure 1 - External post-tensioning repair installed with wire mesh in place prior to gunnite application.

RRJ created a computer data base of cylinder strength test reports for all concrete placed in the garage. From this data base, certain isolated areas of low strength concrete were identified. Petrographic studies of concrete samples taken from these areas revealed that the low strength concrete was caused by high air content. **RRJ subsequently performed structural analyses to evaluate the acceptability of low strength concrete placed in certain post-tensioned beams and columns.** Calculated service load stresses and deflections for the post-tensioned beams were compared to allowable values specified in the building code. Building code requirements for ultimate strength were also evaluated. RRJ concluded from this review that the lower strength concrete placed in certain beam and column elements was acceptable.

During our survey of the project's 551 post-tensioned concrete floor beams, RRJ discovered that a few beams exhibited unusual crack patterns that were not characteristic of the typical restrained volume change beam cracks observed throughout the garage. Further X-ray and destructive inspections revealed that the post-tensioning ducts had been displaced upward over 20 inches near the mid-span of these 36-inch-deep beams.

State-of-the-art, impulse radar techniques were used to identify tendon duct profiles of all post-tensioned beams. Constructed tendon duct profiles were categorized and incorporated into our previously-developed mathematical models of the garage frames. Structural analyses and evaluation of these frames, supported by load tests, identified only thirteen beams with displaced post-tensioning tendon ducts that did not comply with building code strength and/or serviceability requirements. **RRJ designed a conceptual repair to supplement the constructed post-tensioning tendons with external post-tensioning.** This repair was further developed and implemented by the post-tensioning subcontractor. External post-tensioning cables were protected by gunnite applied to each vertical beam face. Refer to Figure 1.

RRJ's analysis proved the lower strength concrete placed in certain beams was acceptable and no repair was needed. The completed post-tensioned beam repairs, including the installation of external post-tension on certain beams constructed with displaced tendon ducts, result in garage beams that comply with the South Florida Building Code and industry standard requirements for strength, serviceability, and durability. All repairs were successfully implemented to the satisfaction of Owner, Engineer, and Contractor. The investigations and analysis proved the garage problems to be much less extensive than originally thought, saving the Contractor the cost of unnecessary and wide spread repairs.

- David B. Tigue, S.E., P.E.
- Douglas J.Berry
- Otto C. Guedelhoefer, S.E.

Professional Services

Design	Investigation	Testing	Client Services
Structural	Leakage	Onsite Testing	Model Building
Restoration	Failure/Collapse	Instrumentation	Dispute Resolution
Renovation	Tolerance Evaluation	Laboratory Testing	Courtroom Exhibits
Architectural	Cladding Performance	Material Properties	Document Reviews
Curtain Wall Redesign	Expert Witness Service	Performance Analysis	Job History Reconstruction
Historical Preservation	Material Evaluations	Full Scale Load Testing	Cause/Fault Determination
Material Failure Redesign	Specification Conformance	Manufactured Products	Litigation Support

RRJ is available to help you with any questions you may have regarding our services or a specific article in our newsletter.
For additional information call:

Ms. Barbara J. Smith, S.E., P.E.
at 1-800-826-6822

Raths, Raths & Johnson, Inc.
835 Midway Drive
Willowbrook, Illinois 60521-5591

Bulk Rate
U.S. Postage
PAID
Irving-Cloud
Publishing Co.