LOAD TESTING OF RC STRUCTURES – A CASE OF STUDY

SUMMARY

Load testing may be used as a tool in deciding on either the continued use of an existing structure or the need for its repair. Typically the load test does not provide an indication of the ultimate strength of the structure; rather, the goal is to show a safe margin of satisfactory performance beyond full building code-required service loads.

This research program is meant to develop a set of guidelines to assist engineers to perform a load test. The first phase of this work consisted of the definition of a procedure, divided into several steps, that has to be followed in order to determine: type of load test, type of applied load (distributed or concentrated), magnitude and eventual position of the proof load, and position of the sensors. This preparatory work is necessary in order to correctly design the load test and, consequently, in order to decide the proper kind of instrumentation to use at the site. The second phase consisted of performing a load test, observing the suggestions defined in phase one, of a one way slab located at the University Centre West, a building that was scheduled for demolition, at the University of Missouri-Rolla campus.

Figure 1 - Tested slab

BACKGROUND

To apply test loads to a structure in a systematic fashion for purposes of strength evaluation, two formalized load test protocols are available. The first one is defined in the current ACI 437 Code and it is known as the 24-hour load test, since it is based on a 24-hour duration of static and uniform loading. The second one is known as the diagnostic cyclic load (DCL) test and it is based on cyclic loading of the structure with increasing load magnitudes applied to strategic locations. The objective of this work is to provide the engineer considering to perform a load test according to the methods proposed in ACI 437, with a procedure for determining strip or patch loads (loads resulting from a point load distributed over a small area of rectangular shape) that applied to the member/structure will generate internal forces (i.e., shear or bending moment) at critical locations equal to those resulting from the uniformly distributed load determined in Chapter 3 in ACI 437. The relation between the equivalent test load (w_s) and the uniformly distributed load (w) is described by the following equation:

$$w_s = k_1 \times k_2 \times w = k \times w \qquad \text{Eq. 1}$$

The coefficient $k = k_1 \times k_2$ is obviously greater than 1.0, and takes into account the dimensions of the patch load with respect to the dimensions of the whole slab. The coefficient k_1 depends on the degree of fixity of the slab restraints at the main beam locations, while the coefficient k_2 is a function of the transversal stiffness of the slab.

OBJECTIVE

Determine a protocol in order to run a DCL test on an existing structure, in which it is possible to evaluate the response in real time and, therefore, to consequently adjust the applied test load.

ANALYTICAL DERIVATION OF *K*$_1$ *AND K*$_2$

The phase one of this work aimed to find a protocol to help the engineer to evaluate in real time the equivalent patch load to apply during the load test. As shown in Eq. 1, it results in the calibration of the coefficients k_1 and k_2.

Applying the Betti's theorem to the two systems (see Figure 2) consisting of a uniformly distributed load w over the whole area of the slab (system 1) and a uniformly distributed load w_s that is limited to the transversal width b (system 2),

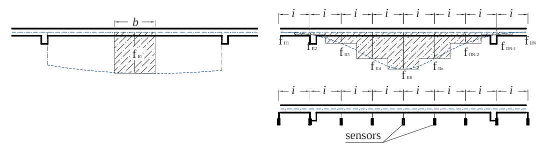

Figure 2 – k_2 derivation

the value of k_2 can be obtained as:

$$k_2 = \frac{\left[i \times \left(\mathrm{f}_0 + \sum_{n=1}^{N} \mathrm{f}_{\mathrm{II}n} \right) \right]}{\mathrm{f}_0 \times b} \qquad \text{Eq.2}$$

The coefficient k_1 is derived setting the equivalency of the maximum moments between the two systems showed in Figure 3:

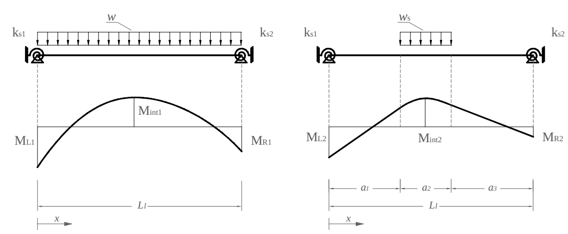

Figure 3 - k_1 derivation

k_{s1} and k_{s2} represent the rotational stiffness of those elements that are at the ends of the tested span. Before performing the load test, their values are unknown, and they need to be determined experimentally by means of the deflected shape of a preliminary load cycle. During the test cycles, their values are calibrated using the deflected shape measured in the previous cycle.

TEST SETUP AND SITE PREPARATION

The second phase of the work consisted of the application of the analytically developed method to a real structure. A one way slab (see Figure 1) was considered a suitable structural element. The load test was designed in such a way that the load was applied by means of a hydraulic jack reacting against the roof slab. Figure 4 shows the used framed system:

Figure 4 - Test Setup

Because of the selected set up it was necessary to isolate a part of the slab, by means of saw cutting, in order to limit the required reaction at the roof slab. The applied load was measured through a load cell, while the deflections were recorded by means of Linear Variable Displacement Transducers (LVDTs) whose location was carefully selected (see Figure 5) in accordance to the protocol developed in phase one.

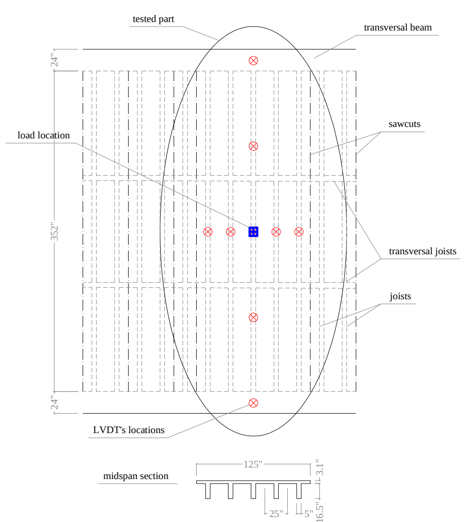

Figure 5 - Instrumentation location

TEST, RESULTS, AND DISCUSSIONS

The distributed test load was calculated according to Chapter 20 of the current ACI 318 Building Code, and assuming a design live load of 100 psf. From a preliminary analysis, the equivalent concentrated test load resulted in about 90 kip, and the load magnitude of the 3 pair of twin cycles was set to 30, 60 and 90 kip. Figure 6 shows the time history of the load test: the twin cycles were divided into 4 or 5 steps.

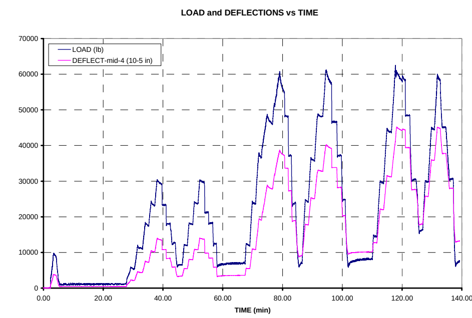

Figure 6 – Load and deflection time history

During the test several parameters were monitored: repeatability, permanency and deviation-from-linearity indexes (see ACI 437), as well as the coefficients k_1 and k_2. It has been noted that the structure was not behaving as expected and during the second pair of cycles all the parameters were indicating a non linear behaviour, therefore the load test was considered failed (the structure wasn't safe for a design live load of 100 psf). For this reason the last two cycle magnitudes were set to 60 kip instead of 90 kip. Figure 7 shows the load-deflection plot (at the central location): it can be noted that starting from the second pair of cycles permanent deflections were caused.

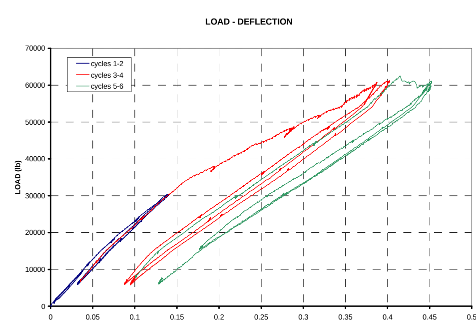

Figure 7 – Load-deflection diagram

Table 1 shows that the acceptance criteria adopted by ACI 437 indicated a unsatisfactory behavior starting from the third cycle.

Table 1 - Performance indexes

Cycles	I_R (≥95%)	I_P (≤10%)	I_{DL} (≤25%)	Performance
I-II	98.93	5.97	0.46	*satisfactory*
III-IV	98.17	17.84	28.16	*n-satisfactory*
IV-VI	99.71	23.20	38.58	*n-satisfactory*

Table 2 shows that the equivalent total test load (obtained from the adjourned coefficients k_1 and k_2) was decreasing during the course of the test: it was due to a reduction in the global stiffness, expressed as actual boundary conditions (k_1) and load sharing effect (k_2).

Table 2 – Equivalent test load

Cycles	k_1	k_2	Equivalent test load (kip)
I-II	0.340	19.86	95
III-IV	0.333	16.94	80
IV-VI	0.333	15.92	75

The slab was loaded to the ultimate capacity since the building was scheduled for demolition. A sudden, as well as unexpected, shear and de-bonding (of the longitudinal bars) failure occurred at 79 kip (see Figure 8).

Figure 8 – Failure

After the test, the failed joist was inspected: it was found that the longitudinal reinforcement was double with respect to the amount indicated in the design drawings.

CONCLUSIONS

The following conclusions can be drawn from the current research using the DCL test:

- Hydraulic jacks allow a structure to be tested more easily than conventional methods, and offer a significant load control that means a safer load test.
- The real time monitoring of both the performance indexes suggested by ACI 437 and the parameters reflecting the general behavior of the structure, provides more information about the condition of the tested structure that can warn the engineer of imminent failure or damage.

FOR FURTHER RESEARCH

A procedure for other structural situations, as well as the relative test information, is needed in order to create a sort of reference load test "manual".

WANT MORE INFORMATION?

Details on this test program and additional data can be found in the final report.

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