CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

UTC
R130

Validation and Calibration of Testing Equipment for In-Situ Load Tests

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UTC R130		

4. Title and Subtitle	5. Report Date
Validation and Calibration of Testing Equipment for In-Situ Load Tests	December 2005
	6. Performing Organization Code
7. Author/s	8. Performing Organization Report No.
Nestore Galati and Antonio Nanni	00001340
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Center for Infrastructure Engineering Studies/UTC program University of Missouri - Rolla 223 Engineering Research Lab Rolla, MO 65409	11. Contract or Grant No. DTRS98-G-0021
12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Research and Special Programs Administration 400 7th Street, SW Washington, DC 20590-0001	Final
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A Field data-acquisition system capable to acquire measurands of interest in a load testing was acquired as part of a previous research equipment project. This project intends to validate and calibrate such equipment by conducting an in-situ load test. The calibration of the equipment will be conducted in a laboratory environment first and its validation in the field will follow. The structure chosen for such validation is the structural floor of the speed ramp in a parking garage, Buffalo, NY. The aim of the load test is to assess the structural performance of a typical cantilever portion of the floor system. Such validation will ensure that the in-house built data acquisition system is capable to perform as planned during the test and therefore to guarantee the safety of a load test.

17. Key Words	18. Distribution Statement
Displacement, Forces, Fiber Optics, Bridge Monitoring	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. Of Pages	22. Price
unclassified	unclassified		

Form DOT F 1700.7 (8-72)

IN-SITU LOAD TESTING OF BRIDGE A6102

LEXINGTON, MO

EXECUTIVE SUMMARY

A Field data-acquisition system capable to acquire measurands of interest in a load testing was acquired as part of a previous research equipment project. This project intends to validate and calibrate such equipment by conducting an in-situ load test. The calibration of the equipment was conducted in a laboratory environment first and its validation in the field followed. The structure chosen for such validation was the structural floor of the speed ramp in a parking garage, Buffalo, NY. The aim of the load test was to assess the structural performance of a typical cantilever portion of the floor system. Such validation will ensure that the in-house built data acquisition system is capable to perform as planned during the test and therefore to guarantee the safety of a load test.

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1 INTRODUCTION

This report describes the diagnostic load test performed on the structural floor of the Speed Ramp 5 to 6 highlighted in Figure 1-1, at the Augspurger Ramp Parking Garage, Buffalo, NY. The aim of the load test is to assess the structural performance of a typical cantilever portion of the floor system highlighted in Figure 1-2. This in-situ load test was used to validate and calibrate a field data-acquisition system capable to acquire measurands of interest in a load testing, which was acquired as part of a previous research equipment project.

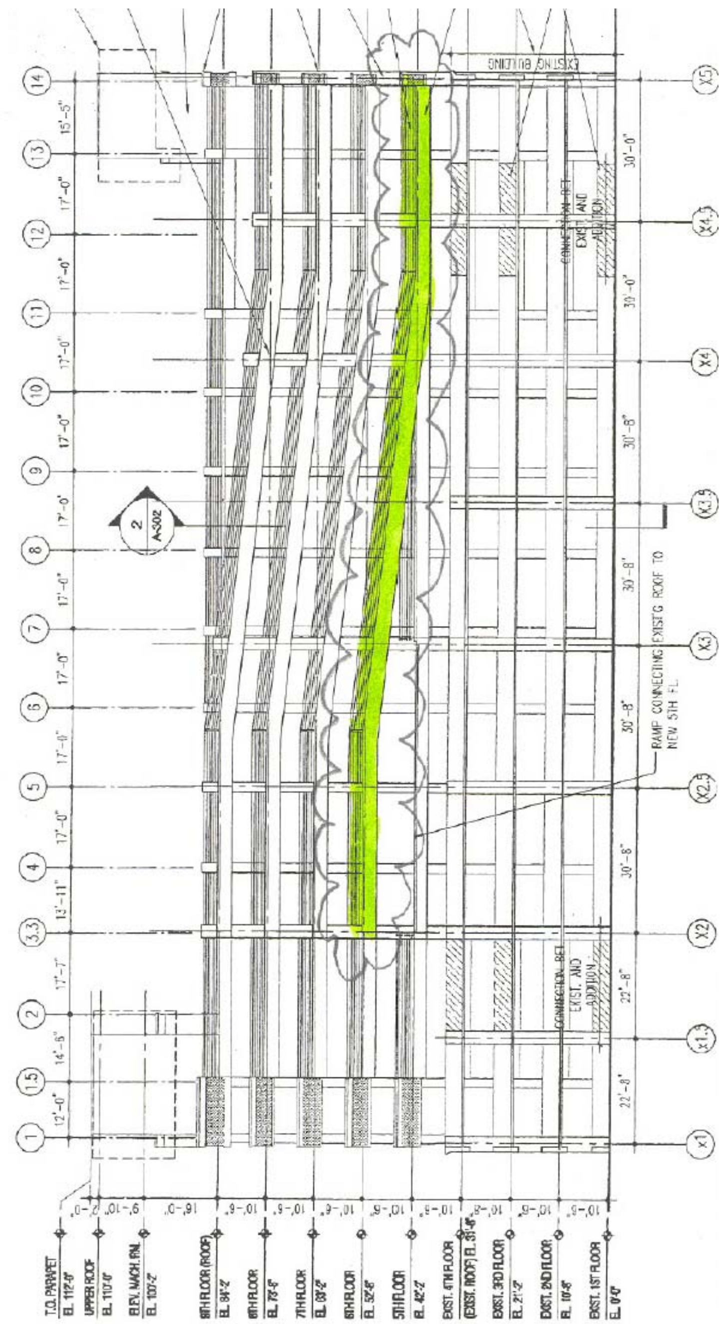


Figure 1-1 - North Elevation of the Augspurger Speed Ramp, Highlighted Ramp 5-6

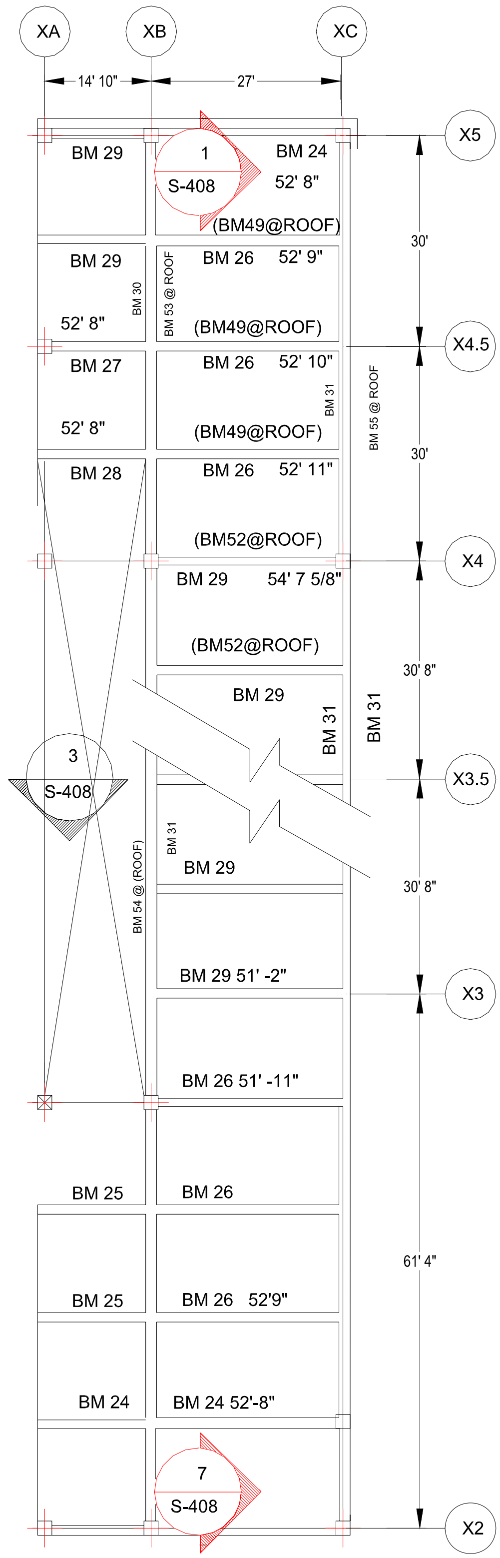
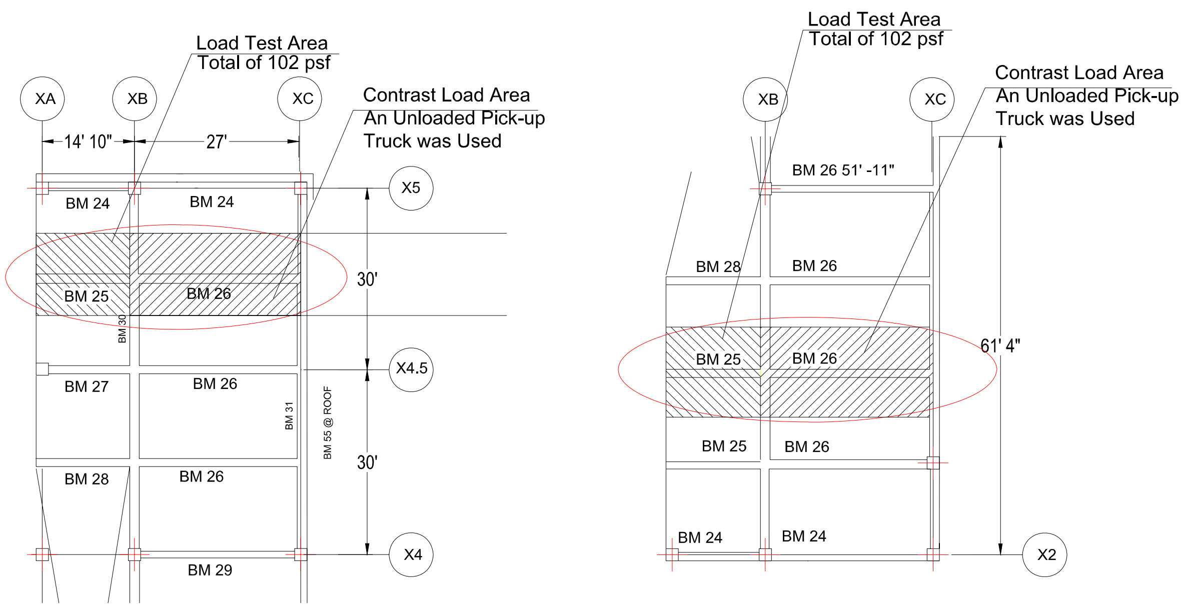


Figure 1-2 Plan View of the Augspurger Speed Ramp with the Highlighted Portions Under Investigation

The diagnostic load testing procedure involves applying concentrated loads to the structural floor components at pre-determined locations. The response of the structural member in the vicinity of the applied loads is monitored and used to evaluate that portion of the member.

The floor under investigation is a cast in place post-tensioned (PT) floor system with a continuous slab supported by joists running in the East-West direction (the ones under investigation are highlighted with a red ellipse) and supported at one end, along alignment XC, and at two thirds, along alignment XB, by beams in the North-South direction (see Figure 1-3). The questioned structural parts of the floor system constitute the flat portion of the "speed ramp", of which a small area, highlighted in Figure 1-3, is cantilevered over a joist spanning between the alignments XA and XB. The speed ramp runs in the Eeast-West direction and is supported by two "knee" beams spanning the entire length of the ramp, from alignment X5 and X2 as reported in Figure 1-2, stiffened at intervals by PT joists running perpendicular to it and supported by RC columns.



a) Test 1 a) Test 2

Figure 1-3 Plan View Detail of the Two Cantilever Portion Under Investigation

Load test evaluation was commissioned in order to investigate whether the cantilevered portions, at the two ends of the speed ramp, were experiencing unexpected permanent deflections, as it was found out during construction.

1.1 Testing Objectives

The purpose of the diagnostic load test is to simulate the effect of design load conditions with hydraulic jacks that are relatively easy to install and control. For the structure under investigation, the design live load is uniformly distributed downward pressure acting over the entire surface of the slab. Since the load from the hydraulic jacks is concentrated, it is only possible to simulate the effects of the design load on a relative small portion of the structural member. In the unlikely event that permanent damage is done to the structure (such as yielding of the steel reinforcement), this damage would be limited to the localized area of loading. This damage would have little or no effect on the performance of the overall system.

The objective, is to test the deflection of the cantilever portion of the structural component of the floor system (joist and slab) using a point load at the end of the cantilever portion (see Figure 1-4). To this end, a total of two diagnostic in-situ load tests were performed on the floor system, one for each cantilever portion at the two ends of the ramp. The two tests are referred as Test 1 and Test 2 respectively, but will be conducted in the exact same way since both areas to be evaluated, present similar geometries.

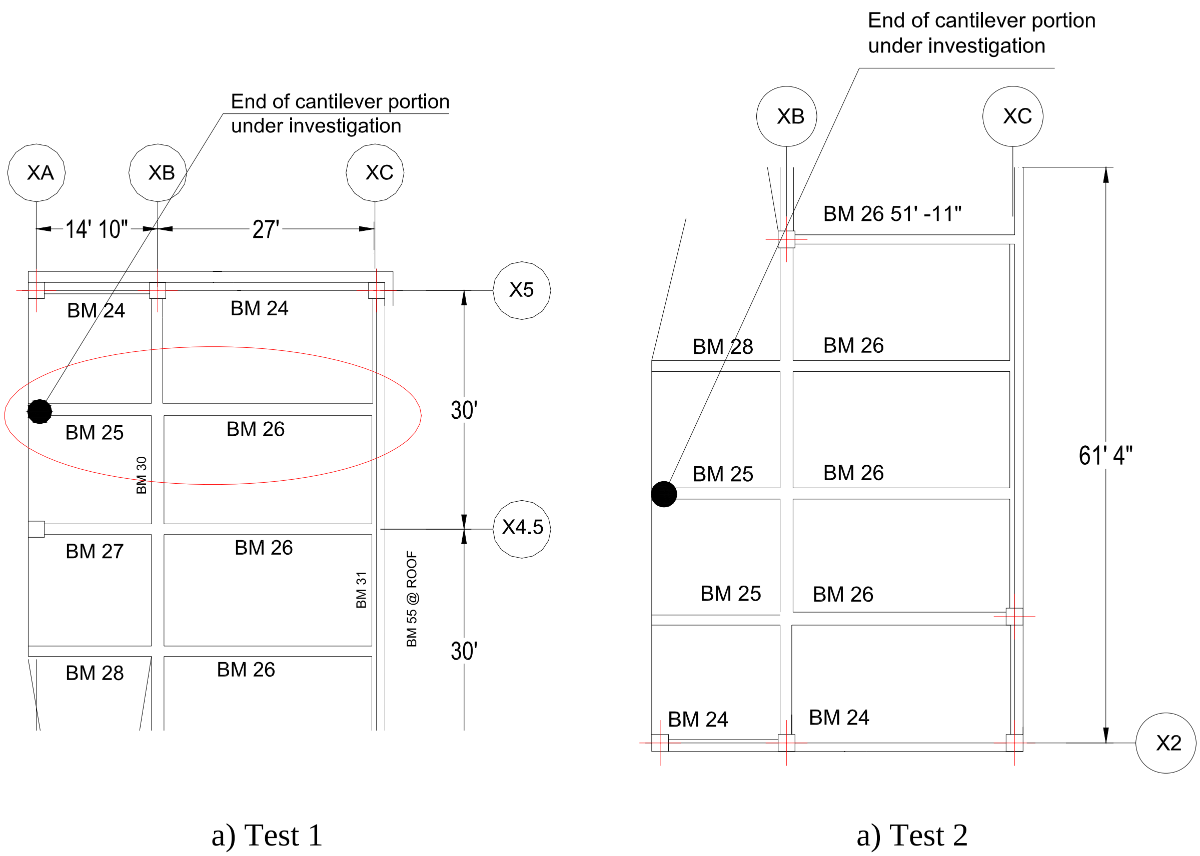


Figure 1-4 Cantilever Portions Under Investigation

Each test will consist in evaluating the performance of a 15 ft width of the beam-slab interaction along the North-South direction, between column lines X5/X4.5 for Test 1 and between column lines X2/X3 for Test 2, as reported in Figure 1-4. Thus, for all load tests, the critical test section is at the end of the cantilever portion in terms of displacement and over the intersection between beam, along alignment XB, and joist perpendicular to it, in terms of negative moment.

1.2 Rationale for the Diagnostic Load Test

The diagnostic load test does not seek to evaluate the safety or the load carrying capacity of the entire structural system. Rather the test is designed to locally verify the performance of a structural member. This is achieved by loading the structural member near its ultimate strength and measuring the response in terms of deformation.

Three acceptance criteria are defined in the Cyclic-Load test procedure and can be easily computed for any structural member by simply checking its behavior under the test load: *Repeatability* and *Permanency* that represent the behavior of the structure during two identical load cycles, *Deviation from Linearity* represents the measure of the nonlinear behavior.

2 PRELIMINARY INVESTIGATIONS

The following summarizes the preliminary assessment of the structure and the sources for the information used in designing the load tests.

2.1 Structural Geometry

The structural geometry including column locations and member sizes were determined from the engineering drawings supplied by Cannon Construction Services, Buffalo, NY.

The structural floor is a one-way PT slab, with a PT joist system, supported on continuous PT concrete beams (beams on alignment XB and XC). The joists considered in this investigation are labeled at both ends of the ramp with BM25, they are 12 in. by 21 in. and they are continuous from alignment XC to XA with a cantilever portion approximately 15 ft long from alignment XB to XA. The floor system consists of PT one-way slab cast monolithically with soffit joists/beams and columns.

2.2 Material Characteristics

The material characteristics were determined from the original design specifications. The specifications indicated a nominal concrete strength of 6000 psi for the concrete joists, slab and beams and minimum yield strength for the steel mild reinforcement of 60 ksi and for the post-tensioned steel bars of 120 ksi.

2.3 Structural Capacity

The positive/negative bending moment capacity and shear capacity of joist BM25 and BM26 as well of the slab and of beams BM30 and BM32 (see Figure 1-2 reference) were obtained from the engineer of record.

Table ***2-1*** provides a summary of the values of moment and shear capacity for the structural members of interest.

2.4 Load Conditions

The loading conditions were derived from information given by the engineer of record. The service dead load results from the self weight of the slab/joist considered over a width of 7.5 ft on each side of the joist as shown in Figure 1-3. Considering the section geometries previously reported and an average density of concrete of 145 lb/ft^3 (ACI 318-02, Section 8.5.1), it was determined that the dead load of the slab/joist system corresponds to a line load of 1.325 k/ft.

Information provided by the engineer indicated that the service live load is 50 psf. The corresponding uniform load to be used for the load testing of the structure according to ACI 437 is $0.85(1.4D + 1.7L) - D = 102$ psf, being D and L the dead and live load respectively.

Table 2-1 – Moment and Shear Capacities of Structural Members

Structural Member	**+M$_n$*** (k-ft)	**-M$_n$**** (k-ft)	**V$_n$**** (k/ft)
Slab	5.68	7.34	7.9
BM25	N/A	349	33.2
BM26	246	349	33.2
BM30	1349	1637	101.1
BM32	727	836	67.4

* at mid-span   ** at supports

3 SUMMARY OF TESTS PERFORMED

Analytical models were implemented in order to determine the magnitude of the concentrated point loads that produce the same positive bending moment of the factored uniformly distributed loads (UDL) at the critical test section.

3.1 Analytical Models

The primary purpose of developing analytical models is to determine the magnitude of the bending moments in the structural components under different service loads and to determine the equivalent test load to produce these moments. Finite elements linear elastic analysis was used in all the cases.

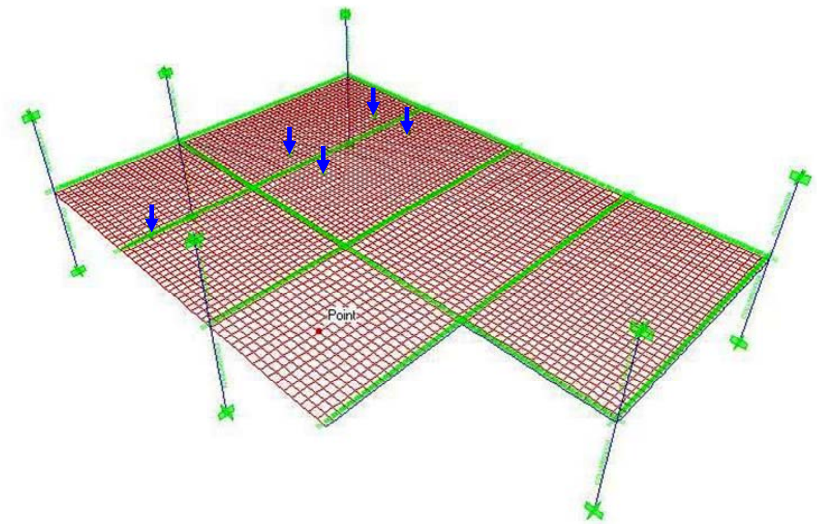
A two-dimensional grid model of the main structural elements, combined with a plate element representing the slab, was used (See Figure 3-1). The grid model consisted of one-dimensional beam elements representing beams and joists. A fine mesh of plate elements was created and added to the top of the grid model. The FEM model was implemented in commercial FEM software: SAP2000.

The value for the point load P_{LL} chosen for the load test was determined in order to produce the same maximum moment on the joist under investigation as the uniform load applied on the portion of structure under investigation. Table 3-1 summarizes the findings in terms of point load P_{LL} determined prior testing using the actual loading configuration for both Test 1 and Test 2. The applied load for test 2 was higher because the loading point was moved closer to the support in order to avoid cutting post-tensioning cables.

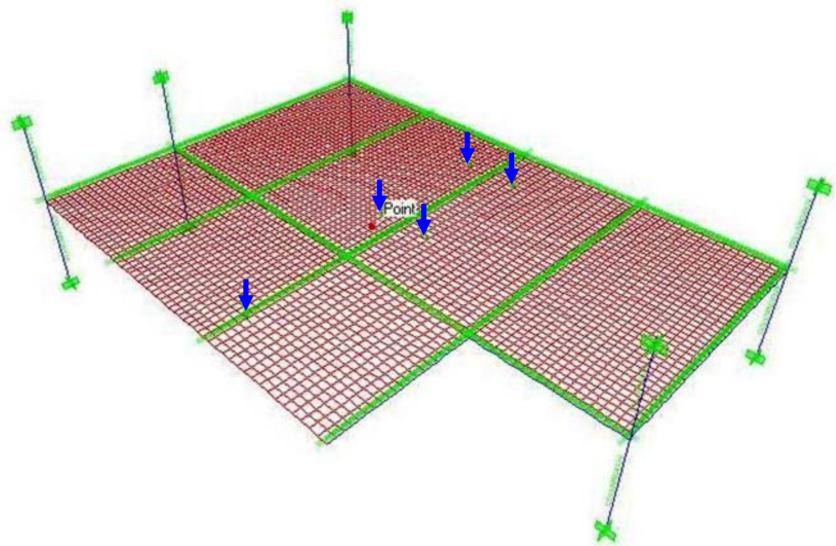
Table 3-1 – Planned Point Load P_{LL} Values

Test	**P_{LL}** [kip]
1	12.1

2	13.8



Load Test 1



Load Test 2

Figure 3-1 – FEM Models for Test 1 and Test 2

4 DESCRIPTION OF THE LOAD TEST

4.1 Testing Apparatus

The testing equipment to be used consists of two 50 ton hydraulic cylinder jacks and a hydraulic pump for applying the load, linearly variable differential transducers (LVDT's) for measuring deflections, and a 50 kip load cell for measuring the applied load (see Figure 4-1).

A data acquisition system recorded data at a rate of 1Hz from all devices, displaying real time on a computer screen (see Figure 4-2), the load-vs.-deflection curves of two significant locations.

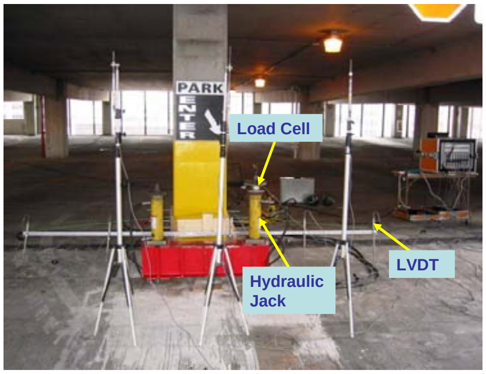


Figure 4-1 – Loading and Measuring Equipment

Figure 4-2 – Data Acquisition System

The list of the instruments used is given in Table 4-1.

Table 4-1 - Instruments to be used

Code	Channel	Instrument	Measurement
LC	3	Load Cell	Applied Load
DJ1	4	±2” LVDT	Deflection (Joist)
DJ2	5	±2” LVDT	Deflection (Joist)
DJ3	6	±1” LVDT	Deflection (Joist)
DJ4	7	±0.5” LVDT	Deflection (Joist)
DJ5	8	±0.5” LVDT	Deflection (Joist)
DS1	9	±2” LVDT	Deflection (Slab)
DS2	10	±2” LVDT	Deflection (Slab)
DS3	11	±2” LVDT	Deflection (Slab)
DS4	12	±2” LVDT	Deflection (Slab)

DS5	13	±1" LVDT	Deflection (Slab)
DS6	14	±1" LVDT	Deflection (Slab)

4.2 Load Test Configurations

Figure 4-3 reports a simplified scheme of the test set-up. Both load-tests were a close-loop test in which the hydraulic jacks pushed simultaneously against a spreader beam transferring the load to the test member (slab/joist) below and reacting against a spreader beam reacting against the floor below the one to be tested. As the hydraulic jacks extend, they pull on the high-strength steel bars which lift the reaction steel beam below the test member. Once the reaction beam comes into contact with the structural floor, the resulting force is a downward force under each hydraulic jack. Wood bearing pads were used between the spreader beams and the structural floor, to protect the concrete from any localized damage.

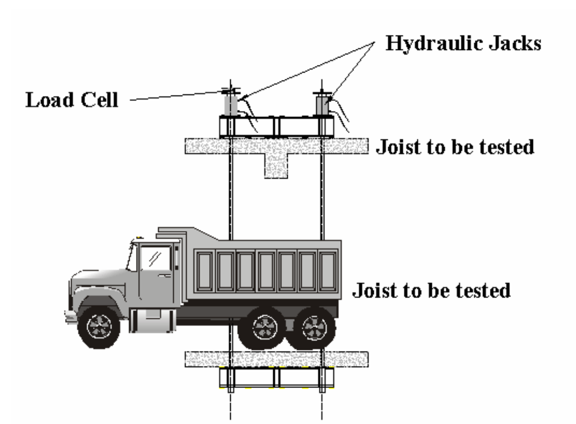


Figure 4-3- Setup of the loading apparatus for Both Load Test

A standard pickup truck was used to contrast the negative moment generated over span B-C and another one was used to contrast the upward force generated by the contrast spreader beam on the floor system below the one tested.

4.3 Deflection Measurement

Deflection measurements were taken in 11 different locations so that the joist, slab and beam connected to the structural member under load, were monitored during the entire load test. Deflection measurements were taken with 0.5", 1" and 2" LVDT's either mounted on a frame connected to the column of the building in front to the one being tested (DJ1, DS1, DS2, DS3 and DS4), or mounted on the same level on telescopic stands and measuring against the floor above. Deflections were acquired by measuring the relative displacement of the concrete member during testing. The LVDTs layout for Load Tests 1 and Test 2 are showed in Figure 4-4 and Figure 4-5, respectively.

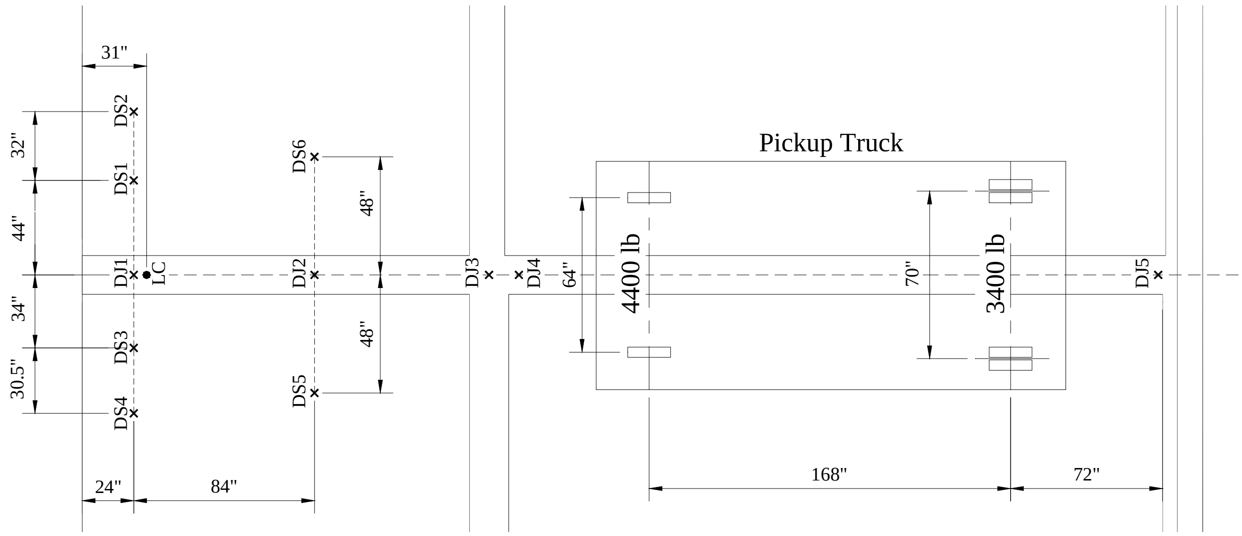


Figure 4-4 – LVDTs Layout for Load Test 1

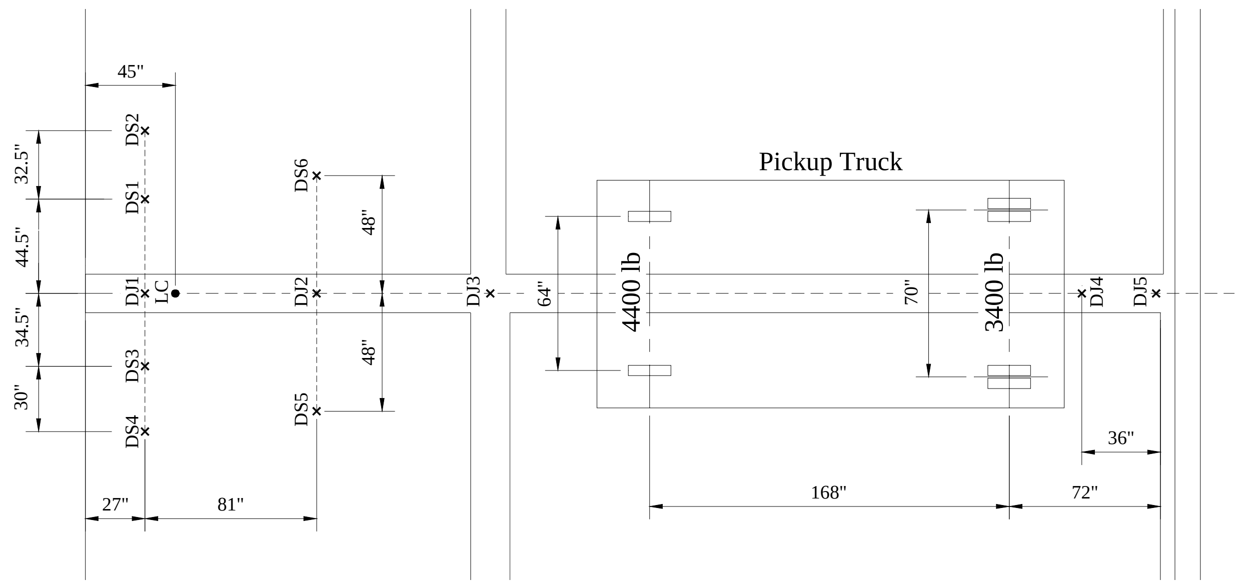


Figure 4-5 – LVDTs Layout for Load Test 2 (Not to Scale)

5 TESTING PROCEDURE

Once all instruments were connected, a preliminary load was applied to seat all test setup components and to eliminate slack in the system. Following the preliminary load, the structural component was loaded in six loading cycles. The peak load for each successive cycle is gradually increased to approach the maximum test load. Each cycle consisted of a minimum of 4 approximately equal load steps followed by at least 2 steps to unload the structure (See Figure 5-1). Each load step was maintained for at least 2 minutes. During this time, deflections of the structure were monitored for stability. The peak load for each successive cycle was gradually increased to approach the maximum test load. Two cycles using the maximum test load were applied to verify repeatability of the measurements.

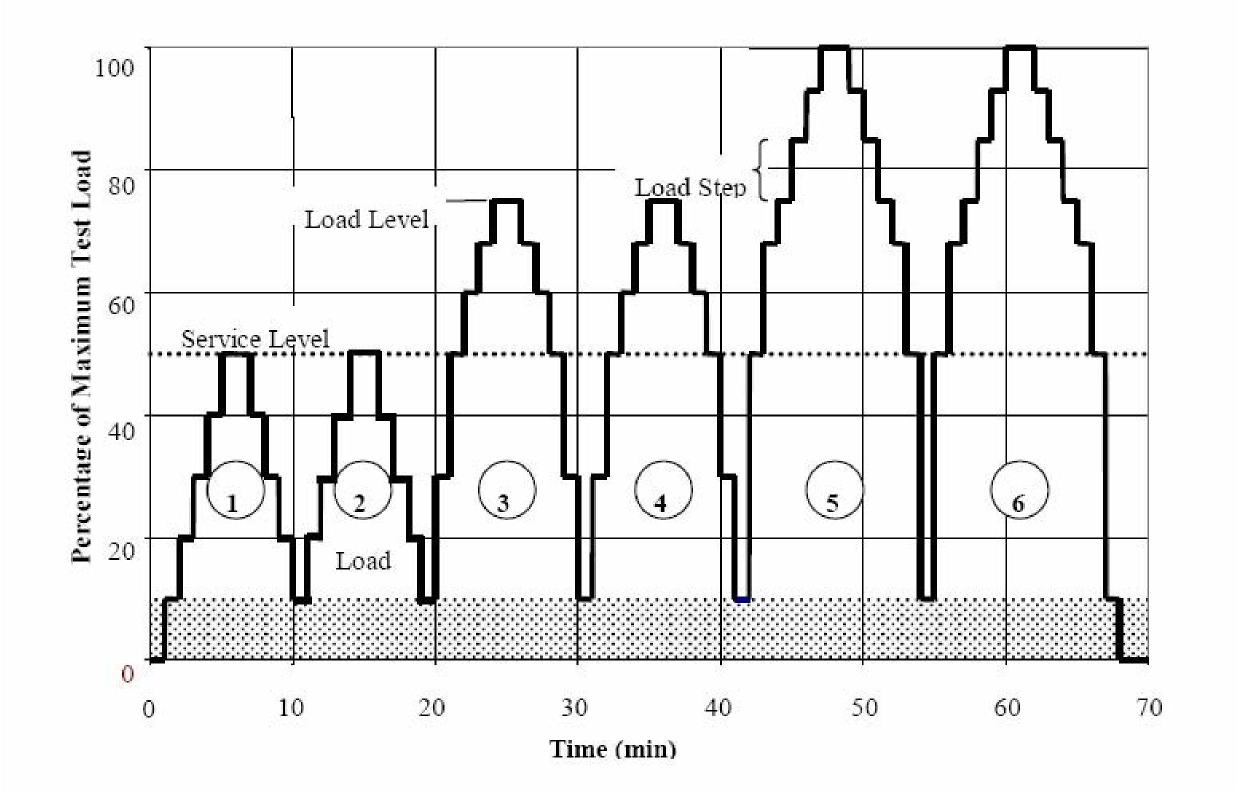


Figure 5-1 - Load steps and cycles for a diagnostic load test

The load cycles for the each load test are listed in Table 5-1 and Table 5-2 for Load Test 1 and Load Test 2, respectively.

Table 5-1 - Anticipated load cycles for Load Test 1 and 2

Cycle	**Step Increment**	**Load Applied by Each Jack*** (lb)	**Total Applied Test Load** (lb)
Pre-Load	0	0	0
	1	585	1170
1 and 2	1	1170	2340
	2	1755	3510
	3	2340	4680
	4	2925	5850
	5	2340	4680
	6	1755	3510
	7	1170	2340
	8	585	1170
3 and 4	1	1170	2340
	2	2340	4680
	3	2925	5850
	4	3510	7020
	5	4386	8772
	6	3510	7020
	7	2925	5850
	8	2340	4680
	9	1170	2340
	10	585	1170
5 and 6	1	1170	2340
	2	3510	7020
	3	4095	8190
	4	4680	9360
	5	5265	10530
	6	6050	12100
	7	5265	10530
	8	4680	9360
	9	4095	8190
	10	3510	7020
	11	1170	2340
	12	585	1170
	13	0	0

*This rapresents the load value measured by the load cell

Table 5-2 - Anticipated load cycles for Load Test 1 and 2

Cycle	**Step Increment**	**Load Applied by Each Jack*** (lb)	**Total Applied Test Load** (lb)
Pre-Load	0	0	0
	1	667	1334
1 and 2	1	1334	2669
	2	2002	4003
	3	2669	5338
	4	3336	6672
	5	2669	5338
	6	2002	4003
	7	1334	2669
	8	667	1334
3 and 4	1	1334	2669
	2	2669	5338
	3	3336	6672
	4	4003	8006
	5	5002	10004
	6	4003	8006
	7	3336	6672
	8	2669	5338
	9	1334	2669
	10	667	1334
5 and 6	1	1334	2669
	2	4003	8006
	3	4670	9341
	4	5338	10675
	5	6005	12009
	6	6900	13800
	7	6005	12009
	8	5338	10675
	9	4670	9341
	10	4003	8006
	11	1334	2669
	12	667	1334
	13	0	0

*This rapresents the load value measured by the load cell

6 TEST RESULTS AND DISCUSSION

6.1 Load Test 1

The joist was loaded to a maximum total load of 12100 lb. At the critical section, this load produced a negative moment (-M) similar to that caused by uniformly distributed load (UDL) of 102 psf. No failure signs were observed at this load level. Relatively small deflections were measured during testing with no signs of cracking. Figure 6-1 shows the measured deflections by LVDT DJ1 during the six cycles. As seen in the figure, the behavior of the joist was elastic with no residual deflection measured when the load was removed. The joist passed the test since repeatability, permanency and deviation from linearity were within the limits prescribed by ACI 437 (See Table 6-1).

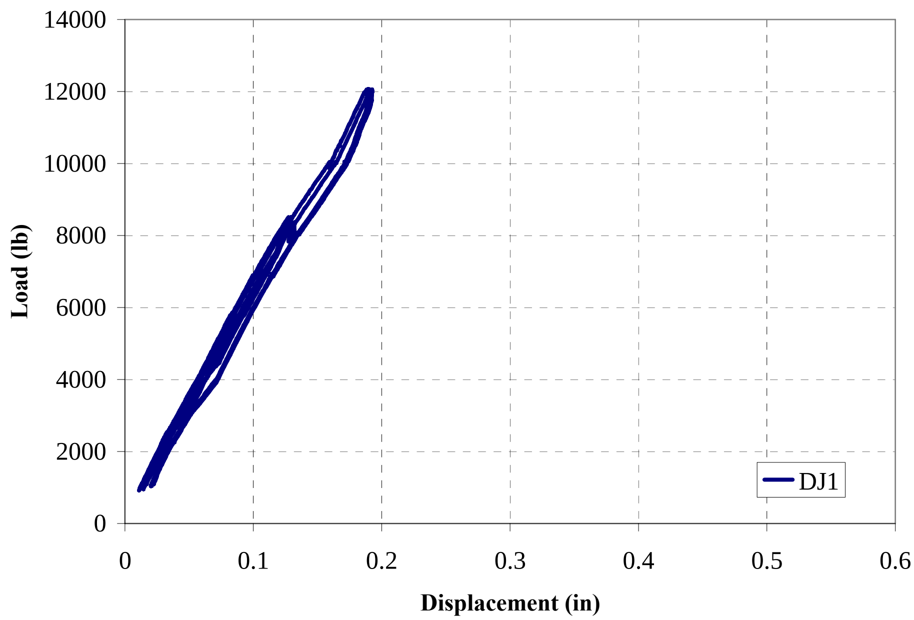


Figure 6-1 – Load Deflection Diagram Corresponding to Test 1

Table 6-1 – Experimental Results of Load Test 1

Cycle	Repeatability (≥ 95%) (%)	Permanency (≤ 10%) (%)	Deviation from Linearity (≤ 25%) (%)	Performance
1 and 2	110.3	0.4	2.1	Satisfactory
3 and 4	101.1	0.8	6.7	Satisfactory
5 and 6	101.3	0.9	11.3	Satisfactory

Load Test 2

The joist was supposed to be loaded to a maximum total load of 13,800 lb. At the critical section, this load produced a negative moment (-M) similar to that caused by uniformly distributed load (UDL) of 102 psf. No cracking signs were observed up to a load level of 12,400 lb. At this load level a flexural crack produced in the slab at the maximum negative moment area which caused the load to decrease to 11,000 lb. At this point the test was considered “not passed” and the structure was gradually unloaded to 1,300lb (i.e., 10% of the planned maximum load). Two more load cycles were applied at a maximum load of 10000 lb. in order to guarantee the safety of the structure al a lower load level (See Table 6-3).

Table 6-2 - Anticipated load cycles for Load Test 1 and 2

Cycle	**Step Increment**	**Load Applied by Each Jack*** (lb)	**Total Applied Test Load** (lb)
6 and 7	1	1000	2000
	2	2000	4000
	3	3000	6000
	4	4000	8000
	5	5000	10000
	6	4000	8000
	7	3000	6000
	8	2000	4000
	9	1000	2000
	10	667	1334
	11	0	0

*This rapresents the load value measured by the load cell

Figure 6-2 shows the measured deflections by LVDT DJ1 during the seven cycles. As seen in the figure, the behavior of the joist was elastic until reaching 12,400 lb. After the formation of the crack, the joist behaved un-elastically presenting a relevant plastic deformation after unloading. The two additional cycles at a lower load level were considered to be satisfactory since they passed requirements on repeatability, permanency and deviation from linearity prescribed by ACI 437 (See Table 6-3). Only a 2% reduction in the stiffness was recorded while comparing cycles 6-7 with cycles 3-4.

Table 6-3 – Experimental Results of Load Test 2

Cycle	**Repeatability (≥ 95%)** (%)	**Permanency (≤ 10%)** (%)	**Deviation from Linearity (≤ 25%)** (%)	**Performance**
1 and 2	99.2	3.2	0.3	Satisfactory
3 and 4	101.0	1.2	11.7	Satisfactory
5	N/A	18.6	30.56	Not passed
6 and 7	98.4	2.2	N/A	Satisfactory

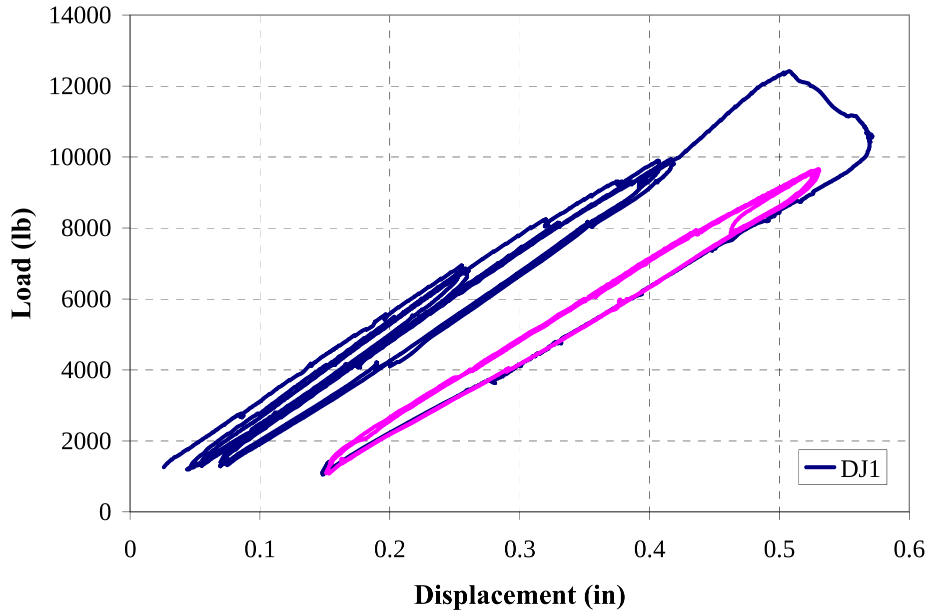


Figure 6-2 – Load Deflection Diagram Corresponding to Test 2

7 CONCLUSIONS

Two diagnostic in-situ load tests were performed on the floor system. In all load tests, the critical test section was over the intersection between beam, along alignment XB, and joist perpendicular to it, in terms of negative moment. The structural members were loaded until the desired moment at critical sections was produced or inelastic behavior (e.g., cracking was observed).

The joists were loaded to a maximum total load of 12,100 lbs and 12,400 lb for Test 1 and Test 2 respectively. Test 1 was considered satisfactory since repeatability, permanency and deviation from linearity were within the limits prescribed by ACI 437. In Test 2 the joist experienced cracking at a load of 12,400 lb and the planned maximum load of 13,800 lb was never applied. Such cracking generated significant residual deflections after the member was unloaded. This test is considered “not passed”.

8 RECOMMENDATIONS

1. Since the two tests, performed on very similar portions of the structure, gave conflicting results in terms of cracking, a more detailed analysis by the engineer of record is suggested.
2. Even though the deck portion subjected to Test 2 experienced cracking, it is considered safe under the existing service loads (a service load of 70 psf corresponds to the two additional cycles performed at 10,000 lb). However, the engineer of record may not have intended for the system to crack at a service load corresponding to 90 psf (12,400 lb). One of the possible reasons for the observed performance could be an unintended loss of prestress. It is suggested that the engineer of record re-compute the effective prestress

force based on the field determined cracking moment. Based on the findings, it could be established if an upgrade action is needed.

3. It is suggested that the area cracked during testing be repaired to prevent fatigue or durability problems over time.

9 REFERENCES

1. ACI 318-02, 2002: “Building Code Requirements for Structural Concrete and Commentary (318R-02),” Published by the American Concrete Institute, Farmington Hills, MI, pp. 443.

2. ACI 437R-03, 2003: “Strength Evaluation of Existing Concrete Buildings,” Published by the American Concrete Institute, Farmington Hills, MI.