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Load Tests of Concrete Structures: Methods, Magnitude, Protocols, and Acceptance Criteria

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Reported by ACI Committee 437

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This report provides the recommendations of Committee 437 regarding selection of test load magnitudes, protocol, and acceptance criteria to be used when performing load testing as a means of evaluating safety and serviceability of concrete structural members and systems. The history of load factors and acceptance criteria as found in the ACI 318 building code is provided along with a review of other load test practice. Recommended revisions to load factors to be used at this time, additions to load testing protocol, and revisions to acceptance criteria used to evaluate the findings of load testing are provided.

Keywords: acceptance criteria; cyclic load test; deflection; deterioration; load test factors; load test protocol; monotonic load test; reinforced concrete; strength evaluation.

CONTENTS

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CHAPTER 1—INTRODUCTION

1.1—Background

Significant revisions were made in Chapter 9 of ACI 318-02 to the load factors to be used for determining required strength. The load factor for dead load was reduced from 1.4 to 1.2, and the load factor for live load was reduced from 1.7 to 1.6; other changes were also made as given in equations for required strength in Chapter 9. The strength-reduction factors (ϕ-factors) were also modified. The ϕ-factor for shear and torsion was reduced from 0.85 to 0.75, while the ϕ-factor for compression-controlled members was reduced from 0.70 to 0.65 unless spiral reinforcement is provided. The ϕ-factor for tension-controlled members (most flexural members) was not reduced, and remains 0.9.

The load factors and load combinations of ACI 318-05 match those of ASCE 7-02 (American Society of Civil Engineers 2002). The changes were made to unify the load factors used to design concrete structures with those generally used to design structures constructed of other materials, such as structural steel. The changes also facilitated the design of concrete structures that included members of materials other than concrete.

Chapter 20 (Strength Evaluation of Existing Structures) of 318-02 and 318-05 was not changed from the previous code with regard to load test procedures. Section 20.3.2 (Load Intensity) of ACI 318-02 was not changed from the 1999 edition; that is, the total test load (including dead load already in place) was still defined to be not less than $0.85(1.4D + 1.7L)$, with live load permitted to be reduced in accordance with the applicable building code.

The reduction in load factors used for computing required strength without a corresponding reduction in the test load intensity resulted in two effects. First, the test load was no longer a fixed percentage of the required strength. Second, the test load was now in the range of 93 to 98% of the required strength for tension-controlled sections rather than 85% of the required strength as was the case in ACI 318-71 through 318-99.

ACI Committee 318 requested that Committee 437 review and report on the load intensity requirements of Chapter 20. In the process, Committee 437 has undertaken a thorough review of the historical background of load testing and developed not only recommendations for revisions to the test load magnitude (TLM), but also to the protocol for load testing and the acceptance criteria used to evaluate the results.

1.2—Introduction

The provisions of Chapter 20 of ACI 318 have remained essentially unchanged for an unprecedented period of time since the publication of ACI 318-71, when the code was changed from working stress design to ultimate strength design. Before the 1971 code, the test load requirements or acceptance criteria were revised with almost every new edition of the code dating back to 1920. Chapter 3 and Appendix B of this report provide a detailed review of the history of the load test requirements and acceptance criteria in ACI 318. They also provide a discussion of other international standards and of significant research and reporting of other organizations on the subject of load testing.

The changes made in the load factors and load combinations of ACI 318-05 require a re-examination of the load test requirements of Chapter 20 of ACI 318-05. This report presents the recommendations of Committee 437 for revisions to the requirements of Chapter 20. Three key areas are addressed: load factors to be used in defining the TLM; the load test protocol; and acceptance criteria.

As will be discussed further in Chapter 4, the purposes of the recommended revisions to the TLM definition are twofold. The first purpose is to define a test load that will demonstrate a consistent safe margin of capacity over code-required service live load levels. Secondly, the definition of the test load primarily in terms of service live load rather than required (ultimate) strength is meant to emphasize the fact that load testing is (typically) a proof loading. In the experience of the committee members, most structures being load tested pass with small deflections. Load testing does not typically provide an indication of the ultimate strength of the structure, and that indication usually is not the goal of load testing.

Since 1920, the acceptance criteria used with load testing have incorporated a limit on measured maximum deflections after a 24-hour holding period of the total test load. The current criteria have not changed since ACI 318-63. Currently, the deflection limit is described by the formula $\Delta_{max} \le l_t^2/20{,}000h$. The theoretical basis for this formula had its origins in the first decades of the 20th century. The committee has researched the origins of the formula and re-evaluated its appropriateness. The committee recommends adopting other more meaningful deflection acceptance criteria.

Chapters 5 and 6 of the report discuss selection of a load test protocol and recommended changes to the acceptance criteria used in strength evaluation and load testing. Committee 437 in its report 437R-03, "Strength Evaluation of Existing Concrete Buildings," has discussed a cyclic load test method that offers advantages in terms of reliability and understanding of structural response to load when compared with the conventional static load test. Chapter 6 presents recommended acceptance criteria for both the 24-hour static test and for the cyclic test. Acceptance criteria for serviceability are also given.

1.3—Limitations

Procedures and recommendations provided in this report are intended for structures and buildings using concretes of normal strengths. The methods are not intended for bridges, structures with unusual design concepts, or other special structures. The methods are not intended to be used for product development testing where load testing is used for quality control or approval of mass-produced members. Testing for resistance to wind and seismic loads is not discussed. AASHTO provisions for load testing of bridge structures are outside the scope of this report. Load testing to determine ultimate strength is also outside the scope of this report.

CHAPTER 2—NOTATION AND TERMINOLOGY

2.1—Notation

The notations reported in this section refer to the symbols used in the numbered chapters.

h = overall thickness of member, in. (mm)
l_t = span of member under load test; units depend on structural member considered (ACI 318)
s = average spacing between cracks, in. (mm)
D = total dead load: $D_w + D_s$; units depend on structural member considered
D_s = superimposed dead load; units depend on structural member considered
D_w = dead load due to self-weight; units depend on structural member considered
F = loads due to weight and pressure of fluids with well-defined densities and controllable maximum heights; units depend on structural member considered
I_{DL} = deviation from linearity index, dimensionless
I_P = permanency index, dimensionless
I_R = repeatability index, dimensionless
L = live loads produced by use and occupancy of the building not including construction, environmental loads, and superimposed dead loads; units depend on structural member considered
L_r = roof live loads produced during maintenance by workers, equipment, and materials or during life of structure by moveable objects such as planters and people; units depend on structural member considered
P = applied load during load test (Fig. 6.1 and 6.2)
P_i = load of point i in load-deflection envelope for computation of I_{DL} acceptance criterion (Fig. 6.2)
P_{min} = minimum load to be maintained during load test (typically 10% of total test load)
P_{ref} = reference load for computation of I_{DL} acceptance criterion (Fig. 6.2)
R = rain load, or related internal moments and forces; units depend on structural member considered
S = snow load; units depend on structural member considered
TL = test load per ACI 318 before 1971; units depend on structural member considered
TL_{05} = TL_{99} = test load per ACI 318-71 through ACI 318-05 = $0.85(1.4D + 1.7L) = 1.19D + 1.44L$; units depend on structural member considered
TLM = test load magnitude (including dead load already in place); units depend on structural member considered
U = required strength to resist factored loads
U_{99} = required strength per ACI 318-99 = $1.4D + 1.7L$
U_{05} = required strength per ACI 318-05 = $1.2D + 1.6L$
α_i = slope of secant line of point i in load-deflection envelope, degrees
α_{ref} = slope of reference secant line in load-deflection envelope, degrees
$\Delta\varepsilon_s$ = strain difference in longitudinal reinforcement
Δ_i = deflection of point i in load-deflection envelope for computation of I_{DL} acceptance criterion (Fig. 6.2)
Δ_{max} = measured maximum deflection, in. (mm)
Δ_{ref} = reference deflection for computation of I_{DL} acceptance criterion (Fig. 6.2)
$\Delta_{r\,max}$ = measured residual maximum deflection, in. (mm)
Δ^A_{max} = maximum deflection in Cycle A under maximum test load, in. (mm)
Δ^A_r = residual deflection after Cycle A under minimum test load, in. (mm)
Δ^B_{max} = maximum deflection in Cycle B under maximum load, in. (mm)
Δ^B_r = residual deflection after Cycle B under minimum test load, in. (mm)
ϕ = strength-reduction factor as per ACI 318

2.2—Terminology

The following definitions are important to the understanding of this report.

acceptance criteria—a set of explicit and quantitative rules to determine whether or not a structure (or a portion of it) passes a load test.

dead load (*D*), total—in this report, a distinction is made between dead load due to self-weight and superimposed