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A PHILOSOPHY ON LOADING TESTS

by

D. B. DOREY AND W. R. SCHRIEVER

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A Philosophy on Loading Tests*

By D. B. Dorey and W. R. Schriever

A review of Building Codes indicates a lack of uniformity in loading test specifications. A new approach to the formulation of test loadings and criteria is desirable in the light of technological advance.

A LOADING test provides a means of assessing the structural performance of a building or one of its components. A loading test is desirable, for instance, when there is doubt about the structural adequacy of a construction or when a structure cannot readily or accurately be subjected to engineering analysis. In conducting and evaluating a loading test many questions arise: What should the magnitude of the test load be? Is it adequate to state the test load simply as a multiple of the design live load? What criteria should be used to judge the success or failure of the structure in passing the test? Should it be a certain maximum deflection, a minimum recovery of deflection after loading, or both, or should it be merely the ability of the structure to sustain the test load for a certain time without showing signs of damage? What should the duration of the test load application be? What other details of the loading procedure should be specified?

Most building codes contain specifications on loading tests and describe to varying degrees the test procedure, but there exists a lack of agreement in the test requirements.

The inadequacy of existing loading test specifications has caused increasing concern in the field of civil and structural engineering, both in practice and in research work. The authors believe that these specifications are not in keeping with the present state of knowledge.

A number of existing loading test specifications found in use in various parts of the world were reviewed by the authors. The chief requirements of these have been summarized in Table I.

Review of Building Code Loading Test Specifications

An examination of Table I will show that these specifications differ in principle, detail, and procedure. Some specifications for instance deal with concrete structures only, and use merely the recovery of deflection after the test as a criterion for acceptance. Only two of the specifications listed state a minimum age for the concrete before the test is started.

Many clauses differentiate between a "strength test" and a "performance test" (see third column of Table I) although the use of these terms is not always the same. In the tests referred to as "strength tests," *all* the criteria (no signs of failure, deflection, and recovery) have been used by one code or another. Generally, the term "performance test" is applied to a check on deflection, under a load varying from 1 × live load to $1\frac{1}{2}$ × live load + $\frac{1}{2}$ × dead load. Some codes refer to a "workmanship test," under a load of 2 × live load, with requirements in terms of no signs of failure coupled with a maximum deflection and a minimum recovery in case the deflection (as calculated from accepted engineering formulas) is exceeded. The British Standard Code of Practice is the only code making a clear distinction between a stiffness and strength test, using deflection *and* recovery as criteria in the first case, and recovery in the second. It should also be noted that not all tests apply to all materials.

From their review of loading test specifications, the authors conclude that a fundamental and thorough review of all the factors entering into loading tests on structures is necessary before any significant improvement in the specifications can be achieved.

Purpose and Scope of Loading Tests

There are many factors to consider in the formulation of a loading test specification. It is, therefore, useful and necessary at this point to outline the types of tests, their purpose and scope, and their relation to design principles.

There are three types of loading tests to consider in the formulation of loading test specifications: the *acceptance test*, the *rating test*, and the *research test*. Each test has its own purpose and specific requirements and all three types bear a close relationship to each other.

The *acceptance test* is designed primarily to prove the structural adequacy of a completed structure or part thereof. Such a test may be required by the building official or owner when

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NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication or for the attention of the author. Address all communications to ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa.

TABLE I.—BUILDING CODE—LOADING TEST SPECIFICATIONS.

Authority	Material	Type of Test	Time of Test	Superimposed Test Load	Duration of loading, hr	Requirements After Loading	Requirement on Removal of Loading
National Building Code-National Research Council of Canada	Concrete	Strength	Not Specified	1½ live load	24	No signs of weakness or of faulty construction	75% recovery of max. deflection on first test or 75% recovery of max deflection shown during second test
British Standard Code of Practice CP 113 (1948)	Steel	Stiffness	Structure should be loaded with actual dead load for as long as possible before testing	Stiffness: 1½ live load	24	Maximum deflection —not excessive	80% recovery of deflection on first test or 90% recovery of deflection on second test
		Strength		Strength: 2 live load + dead load For 2-story dwellings and schools, 2 live load Wind load: 2 wind load with or without vert. load	24		20% recovery of deflection
British Standard Code of Practice CP 114.100-114.105 (1950)	Concrete	Strength	56 days to be allowed for hardening of concrete	1¼ design live load	24	No evidence of failure	75% of recovery of deflection on first test or 75% recovery of deflection on second test
American Concrete Inst. Building Code (ACI 318-51)	Concrete	Strength	Not specified	2 live load + ½ dead load	24	No signs of failure. Limiting deflection $D = L^2/12\,000t$*	If D is exceeded, residual deflection 24 hr after removal of load must not exceed 40% of max deflection observed under load or 60% of D. Deflection must not exceed $3D$ under load
Uniform Building Code-Pacific Coast Building Officials Conference	Steel	Strength	Not specified	2 design load	No time specified	Sustained load without failure	Determination of elastic properties should be based on deformations at (*1*) 75% of max load which can be sustained or (*2*) a total load equal to 1 design dead load + 1½ design live load, whichever is the larger
		Performance		1½ design live load + ½ design dead load	No time specified	Local distortions should not develop	
Basic Building Code-Building Officials Conference of America, Inc.	All construction materials	Strength	Not specified	2½ live load	No time specified	Sustain load without failure	.....
		Performance		Approved working load	No time specified	Limiting deflections under working load not to exceed: (*1*) 1/360 of span for plaster (*2*) 1/240 of span, unplastered floor construction (*3*) 1/180 of span for unplastered roof Construction	.....
		Workmanship	Not specified	2 live load	24	No signs of failure. Total deflection not to exceed theoretical deflection calculated from accepted engineering formulas	If computed deflection is exceeded, structure must recover 75% of max deflection within 24 hr of removal of test load

* Where D = the maximum deflection of the portion of the structure under test, L = the span of the member under test between faces of supports, and t = the depth of the member under test.

TABLE I—(Cont'd)

Authority	Material	Type of Test	Time of Test	Superimposed Test Load	Duration of loading, hr	Requirements after loading	Requirement on Removal of Loading
Southern Standard Building Code-Southern Building Code Congress	Concrete	Strength	Not specified	1½ live load + ½ dead load	24	No signs of failure. Limiting deflection, $D = 0.001L^2/12t$*	If D is exceeded, structure must recover 75% of observed deflection within 24 hr of removal of test load
	Prefabricated construction (panels)	Strength	Not specified	2½ live load	24	Sustain load without failure	75% recovery of observed deflection within 24 hr after removal of full test load
		Performance		1 live load	...	Measured deflection shall not be more than 1/360 of clear span	.....
National Building Code-National Board of Fire Underwriters	All materials	Strength	Not specified	Not less than 2 design live load	No time specified	.....	75% recovery of max deflection within 24 hr of removal of test load
Chicago Building Code and Index-City of Chicago	All materials	Workmanship	Not specified	2 design live load	24	No signs of failure. Total deflection not to exceed that calculated by theoretical engineering formulas	If calculated deflection is exceeded, structure must recover 75% of observed deflection within 24 hr of removal of test load
State Building Construction Code-State of New York	All materials	Strength	Not specified	2 uniformly distributed imposed load	24	Sustain load without failure	.....
		Performance	Not specified	1 uniformly distributed imposed load	No time specified	Limiting deflections: (*1*) 1/360 of span for plaster (*2*) 1/240 of span, unplastered (*3*) 1/180 of span for unplastered roof construction	.....
		Performance	Not specified	1½ uniformly distributed imposed load	No time specified	Sustain load without structural damage	For floor assemblies, residual deflection after first test shall not exceed 25% max deflection under load. Residual deflection on second test not to exceed 1.1 residual deflection from first test
New Zealand Standard Code of Building By-Laws-New Zealand Standards Inst.	Concrete and Steel	Strength	Ample time to be allowed for hardening of concrete before test	150% of load for which structure has been designed	No time specified	No signs of failure	.....
Uniform Building Regulations-Melbourne, Australia	All materials	Strength	Not specified	1½ live load + ½ dead load	24	Limiting deflection at the end of 24-hour period, $D = 0.001L^2/12t$*	If D is exceeded, structure must recover at least 75% of observed deflection within 24 hr after removal of test load
Model Building Regulations of South Africa	Concrete	Strength	28 days after concrete is placed or on date agreed upon	Slab or beam: 1½ design live load + ½ dead load	24	No evidence of failure. Limiting deflection at the end of 24-hr period, $D = L^2/12\,000t$* D.B.R. Dwg.* BR 602	Residual deflection not to exceed ¼ max deflection at the end of 24-hr period. If there are no signs of failure and allowable deflection was exceeded on first test, second test may be carried out after 72 hr have elapsed

the structure is incapable of accepted analytical design or when a change in occupancy is requested for an older structure. The purpose of the acceptance test, therefore, is to prove the present quality of the structure and to give a reasonable assurance of safety for the future under normal use.

The *rating test* is designed, primarily, to assist the building official in assigning an allowable load to a particular type of construction, especially new types of construction that are mass produced. The rating test must, therefore, allow for the variability of the specimens in view of the fact that only a certain percentage of all the specimens are tested.

The *research test* is a scientific investigation of the performance of a structure under loading up to and including collapse to correlate actual stresses and displacements with those obtained by calculation or other methods in the design.

An important difference between the acceptance test and the rating test and the research test is that in the former, one is not normally concerned with the economy of the design. The acceptance test serves only to establish that a minimum of strength and stiffness is provided, whereas the rating test (when carried to failure) and the research test, by exposing the load factor of safety through failure, may indicate overdesign and thus provide the designer with a direct tool for economic design.

Two aspects of the performance should be distinguished, strength (or safety against failure) and stiffness (or absence of objectionable deflections under working loads). In some cases a structure designed for a required strength will automatically exhibit a satisfactory stiffness; in other cases it will not.

It is essential that a balance be kept between the requirements for design and those for loading tests, otherwise a properly designed structure may either not pass the loading test or the loading test may sanction an underdesigned structure. The choice of magnitude of the various test loadings is, therefore, very important. Any improvement or refinement in loading test specifications must keep pace with the status of design specifications. However, a loading test specification must be kept simple enough to be used and administered without undue difficulty.

Factors to Be Considered in Formulating Loading Test Specifications

The factors to be considered in formulating test loadings for structures are many, and they depend upon the type of construction and the intended use of the structure. If, for instance, the type of structure is one in which overloading would endanger human lives by failure without warning, such a structure should be subjected to a rigorous loading test schedule involving all possible alternatives in loading. The greater the number of factors entering into the design assumptions, the more important it is to know how that structure will react to the forces acting upon it during its period of useful service, and the more essential it is to arrive at the proper test loading and test procedure.

Sometimes the authorities responsible for a loading test are hampered by the lack of important information necessary for the proper conduct of the test. For example, a loading test may be required on an existing building for which there are no longer any detailed plans.

The factors which should be taken into account in a loading test specification include the following:

Classification of Structures

There are two main groups into which structures may be classified, namely, statically determinate structures, which are relatively simple and straightforward to design, and statically indeterminate structures, which are more complex and in the design of which more assumptions must be made before a theoretical analysis is possible. When the complexity of the calculations discourage efforts of theoretical analysis, the designer may often find it necessary to resort to other methods. In such instances, a loading test is a desirable and important means of assessing the strength and stiffness of a structure.

Many statically indeterminate structures display a reserve of strength after initial relaxation occurs at the joints. Under such conditions of apparent overstressing at the joints, the recovery of deflection will be poor, yet the structure may, if made of ductile material, still be quite safe. In other words, if loading is continued beyond the yield point, additional loading is required to produce failure due to a redistribution of moments. Under similar circumstances of overstressing, however, collapse would likely occur much earlier in the loading in a statically determinate structure.

Intended Use of Structure

If clearly defined, the intended use of a structure will normally dictate what its strength and stiffness should be. A properly designed structure must meet both a standard of strength and a standard of stiffness, but the standard of strength may be so high that the stiffness requirements are achieved without special attention or *vice versa.*

The risk of failure, that is, the losses in human lives and valuable property which would result from failure depends upon the use and occupancy of the structure. The risk involved is far greater in structures designed for public use than it is in structures designed for dead storage. The designer must, therefore, govern his design accordingly from a strength point of view. In respect to stiffness, the designer must also produce a design which, when considered in relation to occupancy and use, will not deform to the extent of causing damage to decorative finishes.

It would not only be desirable to design a structure for a given load limit but also to give it a "design life." Unfortunately, however, it is difficult to assign a definite period of time to the life of a structure. Until such time as sufficient knowledge is accumulated, the useful life of a structure is governed by the loads, or, more generally, the intended use of the structure.

Materials of Construction

The strength and stiffness of a structure during its period of intended use or design life cannot be disassociated from the quality of the materials that go into the construction. For example, a brittle material such as stone, concrete, and even some metals may fail suddenly, whereas a ductile material will usually deform extensively before failure. Many materials are affected by changes in moisture content both in their load-carrying capacity and in their susceptibility to deterioration.

Steel is susceptible to corrosion unless protected. When corrosion takes place, expansion may occur in connections which may stress appreciably the connecting media and promote premature failure. Corrosion of even the simplest sections of steel is detrimental to their strength during the design life of a structure. The danger of failure is reduced when we consider an exact duplicate of a mild steel structure in an identical environment if the second structure is constructed of stainless steel. The stainless steel structure should not be loaded as severely in a loading test.

The physical and chemical properties of a material form a basis for forecasting the type of failure to be expected; that is, failure may be the result of simple overstressing, or the result of chemical decomposition followed by overstressing of the reduced cross-sections. Failures may also occur in fastenings or bonding of materials leading to collapse by the same processes.

Standard of Workmanship

An equally important consideration in respect to the strength and stiffness of a structure is the standard of workmanship maintained during construction. There are many structures where there is little cause for concern because of the nature of the construction while, on the other hand, there are numerous structures where the required strength and stiffness is achieved only by good workmanship and close supervision. Workmanship is particularly important in the field of concrete construction and wood construction. Variability is recognized in good concrete design as being something which cannot be completely overcome. For instance, even under close supervision, reinforcing rods are not always placed in their correct position. Another example is that of composite construction which usually requires a high standard of workmanship during fabrication.

The authors do not advocate that every structure should be penalized during loading tests for inferior workmanship but that extra caution should be exercised where the quality of the workmanship may seriously affect the performance of a structure either directly or indirectly during its design life.

Design Loads and Actual Loads

The recommended design loadings are the minimum values that a designer is allowed to use where a local building code applies. These values are accepted as being representative of actual conditions of use and occupancy. The engineer and architect know, however, that there are many instances where these values are exceeded under unusual circumstances, whereas in other instances the design loadings are never reached. From studies that have been made on floor loadings it has been determined that as the area of a floor is increased, the magnitude of the average loading per unit area decreases. Small areas may be required to sustain nearly twice the recommended design loading whereas larger areas normally support smaller loadings than those specified in the local building code. The contents of libraries, warehouses, and office buildings often induce loadings which are in excess of design loadings. It is therefore suggested that recognition be given to the probable degree of overloading any given structure may have to sustain when considering the magnitude of the test loading. Recognition of this probable overloading with respect to recommended design loadings might apply not only to new structures where there is doubt as to their structural adequacy but also to structures where a change in use or occupancy is requested. This recognition is to acknowledge that it is impossible to police all buildings for changes in use or occupancy.

Overdesign for Special Reasons

Overdesign is not unusual, particularly in structures in which the yield stress would otherwise be reached or exceeded during construction. This applies more specifically to buildings. designed for small live and dead loads. Unusual soil conditions may warrant overdesign as a safeguard against differential settlement. Changes in temperature and moisture conditions may also justify overdesigning. Areas subject to earthquakes will necessitate special consideration of the more vulnerable components. Overdesign for the reasons just mentioned does not mean that such structures should be expected to give any added performance during a loading test unless this performance is specified as a requirement and is related to the use and occupancy.

Types of Failure

Failures in structures can be classified into three possible types: (*a*) failure without warning, (*b*) failure occurring after yielding has taken place at a certain load, and (*c*) failure to a state of unserviceability at a certain load but still safe. This classification may appear to be an attempt to oversimplify the actual conditions under which failure occurs, but when the question of risk and the consequences of failure are considered, this means of reference seems justified.

The first type of failure listed, which is typical of brittle materials, is the most dangerous especially when human lives are involved. Before acceptance is given to a structure of this group, especially for public use, extreme caution must be exercised. The second type of failure calls for careful attention, but such failures are not as dangerous as the first type. This type of failure gives a warning of impending collapse.

The third type of failure is the least hazardous. A structure which will behave in this manner under critical loading conditions is said to be ductile, or tough. Where extra precautions against collapse are necessary, this type of structure is preferred. The distortion of the physical shape under critical loadings may render the structure unserviceable; but the safeguard against complete and abrupt collapse eliminates much of the risk common to the first two types.

Factor of Safety

The expression, "Factor of Safety," unless clearly defined can mean either "stress factor of safety" or "load factor of safety"; therefore, a distinction must be made between the two meanings. When we are concerned with the total live load which a structure can sustain without collapsing the expression "load factor of safety" expresses precisely either the theoretical or the actual load that a structure can support divided by the design load, whereas the "stress factor of safety" is the ratio of the stress at failure to the allowable stress of the material used in the structure. The approach to design, particularly in steel and in reinforced concrete, from considerations of failure conditions rather than from the allowable stress criterion, is one of the most important recent developments in engineering and promises considerable economic advantages combined with the actual degree of safety desired. "Limit design" has not yet been adopted in codes in the United States or Canada, whereas it is being used in a number of European and South American countries. There is no doubt, however, that the effect of stress redistribution by plastic flow on the strength of a structure can no longer be ignored, and this consideration will sooner or later enter the codes.

Risk of Failure

The risk of failure or the amount of loss which would result from failure is another factor requiring elaboration. Partial or complete collapse of a structure may be the result of poor design or the result of any number of factors, some of which have been discussed earlier in this paper. The term "risk of failure" in this paper does not mean any possible damage to a structure, such as damage of interior finishes, but is intended to mean the potential danger to human lives and valuable property during the period of useful service of the structure.

The risk of failure is related, among other things, to the type of failure. A failure occurring without warning is much more serious in the case of a grandstand structure supporting a large crowd of spectators than it is in the case of a structure used for dead storage remote from any public or private gatherings. The risk of failure therefore may be much less when the "load factor of safety" is three against failure of the third type than it is when the "load factor of safety" is five against failure of the first type.

Duration of Loading

Generally, most structures subjected to long-term loading tend toward continued redistribution of stresses, accompanied by slow, but measurable, increases in deformation. This tendency, however, may not be of sufficient consequence to warrant concern unless the structure has been poorly designed, in which case, progressive deformation may lead to eventual collapse of the system.

Long-term loading considerations are of such significance in wood construction, for instance, that a decrease in strength is allowed for in most cases in the working stresses of the material. Conversely when the maximum load is of known short duration, advantage is sometimes taken of the increased strength characteristic by increasing the allowable working stresses.

Progressive deformation under long-term loading in an improperly designed structure can lead to a disruption of attached finishes. This form of secondary failure may be caused by creep in the structural material or through slippage between materials of composite construction. It is, therefore, important to recognize any possible weaknesses of this kind in a structure and take appropriate steps to bring such faults to light during a loading test.

The question then arises as to how long-term loading can be represented in a test of short duration. This question can only be answered in terms of allowable working stresses. When a long-term loading condition has not been considered in the selection of allowable working stresses, then an increase may be required in the magnitude of the test loading.

Repeated Loading and Vibration

Repeated loading and vibration are other factors worthy of attention in the formulation of loading tests. Recent developments in design indicate a trend toward the use of higher allowable stresses or a reduction in the over-all load factor of safety. In a structure designed for static loads, this tendency would appear to be justified. However, a reduction in the load factor of safety may be carried too far, for, if the working stresses are increased in respect to static loads, the fatigue strength of the material remains the same. If one structure is subjected to static loads only, whereas a second identical structure has to support dynamic loads, the second structure should be loaded more severely during a loading test because of the fact that fatigue may occur and appreciably shorten the intended design life.

A New Approach to Loading Tests

It has been shown that, in most instances, the existing full-scale loading test specifications lack adequate recognition of the various factors, in accord with the present state of knowledge. This fact may be confirmed by a critical review of existing specifications. The variation shown in the magnitudes of test loadings suggests that rather arbitrary figures have been chosen. It appears that there is no defined process by which the magnitude of the test loading is derived, other than by assuming a certain multiple of the design load, plus a portion of the dead load in some instances. As economy plays so important a role in engineering and architectural design, this method of judging structural adequacy must be questioned.

Modern tools of research and contemporary knowledge afford almost unlimited possibility for precision in determining the behavior of a structure undergoing a loading test. Present specifications properly stress the importance of deflection and recovery after unloading, but fail to agree on the allowable deflections or on the required amount of recovery after unloading.

The strength and stiffness of a structure depend upon a number of factors as previously mentioned. It is difficult to separate any one factor and test the structure for that factor alone. The authors believe, however, that it is possible to arrive at a loading test specification which, based on a quantitative assessment of the various factors affecting the strength and stiffness of a structure, will enable those who are responsible for loading tests to choose an appropriate magnitude of the total test loading for a specific structure.

The question then arises as to how to make up a loading test to include all the pertinent factors relative to assessing the structural sufficiency of a structure.

A Proposal on the Formulation of Test Loadings

The authors wish to emphasize at this point that the proposed outline in the following paragraph is a suggestion only and has been prepared as a basis for discussion.

The magnitude of the test loading in an acceptance test is made up of three parts which, when added together, make up the total test load to be applied to a given structure. The first part consists of the total live load plus any necessary dead load additions; the second part is a certain minimum overload expressed as a percentage of the total live load; the third part is an additional portion, expressed as the sum of individual percentages representing the factors which distinguish one structure from another (Fig. 1).

The first portion of the test loading indicated by A in Fig. 1 is 100 per cent of the design live load plus any additional dead load which may not be supported by the structure at the time of the test. If the test is required to approve a change in use or occupancy of an existing structure, portion A of the test load consists of the newly assigned live load only, unless renovations impose an additional dead load.

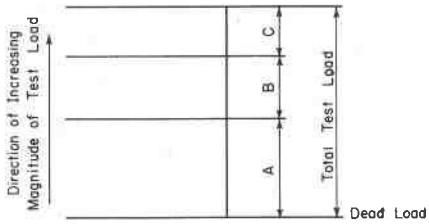

Fig. 1.—Formulation of Test Load

Acceptance Test

Part A of test load = 100 per cent live load + any additional dead load

Part B of test load = percentage overload from Fig. 2

Part C of test load = summation of percentages of live load

Magnitude of total acceptance test load = A + B + C

Rating Test

Magnitude of total rating test load = A + B + C from Acceptance Test + probability factor (percentage of live load)

The second portion of the test loading indicated by B in Fig. 1 is a basic overload, expressed as a percentage of the live load. B depends upon the risk of failure and is a function of two independent variables, namely, use and occupancy (indicating the seriousness of a collapse) and the type of failure (or warning before failure). Figure 2 suggests a way of plotting this basic overload employing use and occupancy as an independent variable and the type of failure as a parameter. The use and occupancy ordinates vary with increasing risk. The three curves correspond with the types of failure expected and increase in severity of percentage of overload from type (*c*) to type (*a*). The percentage of overload to be applied to a given structure can be obtained by following the curve appropriate to the type of failure expected to the point where the curve crosses a horizontal line through the appropriate use and occupancy. The percentage of overload is then indicated by a vertical line through this point on the curve.

The third portion of the test loading indicated by C in Fig. 1 is the summation of applicable percentages of live load which take into account the material and such factors as workmanship, deterioration, fatigue, long-term loading, impact loading, and vibration. The applicable number of percentages varies

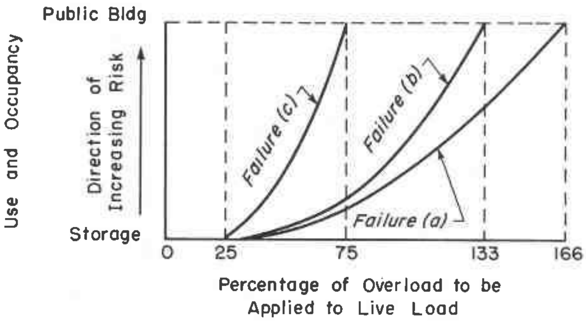

Fig. 2.—Acceptance Test and Rating Test

Percentage of live load to be used in Part B of test load

(*a*) Failure without warning
(*b*) Failure occurring after yielding has taken place at a certain load
(*c*) Failure to a state of unserviceability at a certain load but still safe.

with the type of construction and gives weight to the factors peculiar to a given structure. Values for these percentages could be listed in tabular form, giving numerical values for each of the factors just mentioned for different construction materials. These values should be selected by code-writing authorities in consultation with research organizations and industry.

The rating test differs from the acceptance test in that the magnitude of the rating test load depends upon the number of specimens represented by one test specimen. If every specimen were tested, the two tests would be identical, except that the rating test might be carried to failure. The rating test may be conducted on the site or in a testing laboratory. The variation in the strength of a given number of specimens would be taken into account by a probability factor expressed in terms of a percentage of the live load and would be added to part *C* of the acceptance test load. The choice of the value of this factor should be done on the basis of loading test statistics on similar materials and constructions. Values for these percentages could be listed in tabular form for each material, giving the values to be set also by the code-writing authorities in consultation with research organizations and industry for each of three conditions of specimen selection. The suggested member of specimens selected would be in relation to three ratios, namely, 1 in 1 (acceptance test), 1 in 10, and 1 in 100.

Criteria for Assessing Structural Adequacy

The next consideration should be how to judge whether or not a structure has passed the acceptance or rating test. The acceptance and rating tests can be dealt with in the same manner, except for the test load (as for the rating test a higher test load is used depending on the number of specimens tested) and the fact that the rating test might be carried to failure.

The structure must meet one or both of the requirements of strength and stiffness. According to present design procedure (that is, excluding limit design), the strength requirement is met if, after the proper choice of the test loading, no point of the structure shows excessive stress (or strain) or imminent instability. Thus, in a loading test, the strains developed would have to be measured at all critical points and deformations would have to be determined in compression members and other places of possible instability. In some structures, such as complicated frameworks and thin-webbed members, this would call for elaborate instrumentation and is not practical in the case of the normal acceptance test because of the complications and the cost involved, and because of the possible inaccessibility of the critical points in the finished structure. Consequently, for the acceptance test, other means of assessing structural adequacy from the strength point of view must be obtained, using (*a*) deformation or deflection, (*b*) recovery of deflection after unloading, (*c*) signs of damage or distress, or a combination of these as a criterion.

Another question which must be decided is whether the same test loading should be used for strength and stiffness. This may not seem very important at first, as usually a structure should not reach yield conditions in the strength test so that we can assume that deformations are proportional to load. Thus it might seem of little consequence whether the deformations are measured at the design live load or at the test loading. The magnitude of the deflections at a loading corresponding to the design live load is of special interest however. The design specifications often state a maximum deflection under design live load. At this load the structure under test should also be checked for the absence of minor damages, such as cracks in plastered ceilings or walls, as such cracks could justifiably be allowed to occur at the higher loadings used for the strength test.

The authors believe that not one criterion, but a combination of maximum deflection and minimum recovery, coupled with the absence of any signs of distress in the main structural parts under the test loading, should be used as a strength requirement, whereas the stiffness requirement should consist of a maximum deflection and the absence of any signs of damage under one times live load.

Stiffness Requirement

Values of acceptable deflections or deformations should be formulated in the usual way as certain allowable deflection-span ratios, such as $\frac{1}{360}$ of the span as commonly used for floors.

During the application of one times live load, it should be ascertained that there are no signs of damage to either the structural members or the architectural finishes.

The actual values of acceptable deflections and deformations would have to be selected by code writing authorities based on recommendations by a committee of experts.

Strength Requirement

As already mentioned, the recovery of deflection after the removal of the total test loading is normally the most simple means of detecting whether the structure has exceeded the yield point. If, however, the observation of recovery and of possible signs of failure is not considered to be sufficiently indicative of satisfactory structural performance, the building official may require strain and deformation measurements to be made by accepted methods at critical points of the structure to prove that no excessive strains or signs of instability are occurring at these points.

The total test load should be sustained by the structure being tested for a minimum period of time, such as 24 hr, without any signs of structural failure. After removal of the test load the recovery within 24 hr from the beginning of the unloading should be a minimum percentage of the deflection under the test load, for instance, 75 per cent.

If the structure does not pass this test but shows a minimum recovery of, say, 60 per cent, retesting should be allowed. Some of the residual deflection after the first loading normally is of no serious consequence as it is due to "bedding down" at supports, joints, etc. The retesting should be started as soon as possible and the total test load should again be applied for at least 24 hr. After unloading the recovery within the following 24 hr from the beginning of the unloading should be almost complete, say 90 per cent of the deflection measured during the second loading.

These recovery figures should, of course, be adapted to different types of construction and materials taking into account such factors as creep of the material under load.

If the amount of creep which is estimated to develop in the structure under service conditions, is considered to be of consequence, the building official might require that the loading period be extended and that the deformations be measured at intervals under load to permit plotting of the time deflection curve.

Other Considerations

A number of details of the testing procedure should also be covered by a loading test specification. Among these are the required refinement and accuracy of the measurement of deformation, the minimum and maximum age of a new structure at the time of testing, and special conditions such as the selection of specimens for the rating test.

Further details of a specification might relate to the following: The loads should be applied in increments of a given fraction of the design live load and the deformation should be measured after each load increment has been in position for a given time. In the rating test each of the specimens should satisfy the strength and stiffness requirements. After unloading, each specimen should be reloaded and the loading continued in regular increments until failure occurs. The complete load deformation curve and a detailed description of the way in which failure occurred should be submitted to the appropriate authority.

Conclusion

An attempt has been made in this paper to draw attention to the shortcomings of existing loading test specifications and to combine some principles outlined by the authors in a philosophy on loading tests which, in its broader aspects, will be in closer harmony with the present state of scientific knowledge. The authors, although conscious of the difficulties which lie ahead in the task of evaluating the various factors and in choosing numerical values believe that the views and principles incorporated in this paper are shared by many who are interested in the safety and efficiency of structures.

The authors are encouraged in this belief by many references in papers such as those listed at the end of this paper, and in particular by the following quotation from the Report of the British Building Research Board for the year 1953.

"In recent years there has been an increasing tendency for structural engineers to consider a new approach to design. In this, the old method of checking that the stresses throughout a structure, for the assumed conditions of working load, are less than certain permissible values, is largely abolished. In its place a design philosophy is being developed of which the main principles are (*1*) that the load that will just cause failure of the structure is sufficiently greater than the working load, so that the probability of failure during the required life of the structure is less than a specified limit, (*2*) that for working-load conditions through the required life, the deformations of the structure shall not be such as to impair its safety or efficiency, and (*3*) that economic considerations in the design of structures shall include full allowance for the need for, and cost of, maintenance during the life of the structure."

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[a] This report was published after the authors finished their paper.

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