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LOAD TESTS OF BUILDING STRUCTURES[a]

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Increased attention is being paid to the improvement of test procedures and to the development of better criteria for the evaluation of load tests of building structures. This topic is of interest to several organizations, including American Society for Testing and Materials Committee E-06 on Field Load Testing of Buildings, a joint committee of ASCE and the International Association of Bridge and Structural Engineers, and Reunion Internationale des Laboratoires d'Essais et de Recherches sur les Materiaux et les Constructions Committee 20-TBS on Testing Building Structures In-Situ. Some years ago, the senior writer conducted a project to study fundamental standards for load tests of building structures. During the course of the project, he consulted many specialists and institutes in different countries. Thus, the project reflected, to a considerable degree, the opinions of specialists in this field. The project was used for the creation of Czechoslovak State Standard CSN 732030, issued January 1, 1969.

The writers believe that this standard (which includes procedures), common to static and dynamic load tests of monolithic and prefabricated building structures and their parts, could be a useful guide to engineers preparing similar codes, standards, or recommendations in other countries and engineers who are responsible for load tests.

GENERAL

Purpose and Arrangement of Load Test.—The purpose of a load test is to assess the actual behavior of a structure or element through determination of its load-bearing capacity or usability in terms of magnitude of deflection and cracking under external loads. The load test must be so organized that it may correspond as closely as possible with the actual behavior of the structure, particularly with regard to the key factors for the state of stress at all critical

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points. The test load should simulate the actual dead and live loads, particularly with regard to their distribution, to ensure that the effects produced by the test coincide with the maximum effects applied to the structure in actual performance in its actual cross sections.

Types of Load Tests.—Load tests are classified as follows: (1) Proof tests to demonstrate the ability of a member or structure to satisfy the given purpose in accordance with design requirements, the suitability of a new construction method, or new construction materials used (e.g., prototype test, approval test, etc.); (2) control tests to demonstrate the ability of a member or structure to satisfy the given purpose in accordance with design requirements that already have been approved (production control tests, acceptance tests, etc.); and (3) all other tests not intended exclusively for the assessment of a single member or structure. Each load test can be executed: (1) To failure of the structure or its part to determine its ultimate load-bearing capacity; or (2) by test loads specified (if not directly stipulated by the respective standards) to prove the usability of the structure or its part with reference to its (a) load-bearing ability, (b) rigidity (deflection), or (c) cracks (deformation).

The assessment of the structure or its part according to the ultimate deformation limit or the crack limit is identical with the proof of usability from the viewpoint of rigidity. Load tests that are proof tests are used particularly as prototype or approval tests.

Load tests are used in extreme cases only, when all other possibilities have been exhausted (e.g., nondestructive strength tests, dimension checks, and survey of the position of reinforcement) or if they are stipulated as the proof of the ability of the structure or its part to satisfy the given purpose (e.g., in the case of bridges).

Authorization and Data for Load Tests.—Load tests are carried out by an authorized testing laboratory that stipulates the extent and manner of execution of the required test, if it is not stipulated by the respective standards, design of the structure, or the party ordering the test. (American practice gives individual structural engineers responsibility for tests.) Load tests carried out by the contractor in his own interest for quality control purposes are an exception to this rule.

The party who has ordered the execution of the load test is bound to supply the testing laboratory that will execute the test with all technical data required for the assessment of the tested structure, including supplements to structural analysis prepared on the basis of the latter's requirements.

Specialized staff, testing appratus, and equipment are provided by the testing laboratory to carry out the test. Auxiliary manpower, ancillary facilities, safety measures (scaffolding, auxiliary galleries, etc.), and possibly the means of loading are provided by the party who has ordered the test in accordance with the requirements of the testing laboratory.

When the load tests are carried out by the contractor for quality control purposes, the contractor provides himself with all necessary testing apparatus, equipment, and safety measures.

Safety Measures.—The testing laboratory that carries out the load test is responsible for the safety of people, protection of property, and other interests in the course of the test. Therefore, the laboratory must prepare and submit to the supervising authority, for approval, a list of all safety precautions and

safety facilities and a plan showing their arrangement and conditions that must be complied with by the equipment with regard to the type of structure and the method of its testing. It is important that the safety scaffolding be situated as close to the structure as possible without hindering its deformation.

If it is not possible to ensure sufficient safety measures and facilities, it is necessary to select a method of loading (e.g., water or air bags, or remote control measuring) and measuring the tested building structure that does not require the presence of people either above or below the tested structure or in its proximity. If, for other reasons, even such measures or facilities are not practical (e.g., in the same types of load tests of bridges), the deformation increments and the general behavior of the tested procedure must be controlled carefully.

Preparation of Load Test

For every load test, a prelimiary analysis is carried out. This analysis determines the direction in which the test is to proceed and must convincingly prove the necessity and desirability of the test itself. For this purpose, the structure and all of its parts are inspected in detail to ascertain whether the construction satisfies, externally, all requirements shown in the design or standard design of the structure or its part of element. In particular, the geometric dimensions, weight, deviations of shape and deformations, quality of materials, quantity, type and position of reinforcement, number and diameters of bolts, rivets, and nails and their fixity, if any, are determined. Also, the joint dimensions and dimensions and quality of welds are checked, and the strengths of high tension bolts are checked at random. Particular attention must be afforded to all joints and nodes, transverse and wind bracings, and the slenderness of the individual compression members. Also all data on the tests of building materials and the production control tests carried out during the execution of the structure are collected.

The manner in which the structures meets the assumptions of the structural analysis is checked. When required, it is necessary to verify the construction of the foundation, i.e., the permissible stress of the foundation soil and whether the climatic, hydrogeological, or other conditions, particularly the position of the ground level, have not changed since the time of the design.

If cracks or any other visible faults can be found in the structure (e.g., aggregate pockets, voids, loose rivets or nails, faulty welds, corroded spots, termites, rots, or excessive moisture content), they are marked clearly on the structure and recorded on the drawing.

The load test may start only after the entire procedure has been carefully planned and after thorough preparations have been made, particularly with respect to the methodology of testing. The progress of the test must be designed so that a clear idea of the results obtained can be determined easily at any moment during the test so that it is possible to predict the behavior of the structure under extant loads or planned load increments.

For this purpose a detailed working schedule must be prepared before every load test, taking into account the specific features of every individual test. It is recommended that this schedule be divided into phases as given subsequently. A detailed specification of operations to be carried out in the individual phases

may be stipulated by other standards or specifications.

Execution of Load Test

Selection and Preparation of Tested Structure.—The selection of the part of the structure to be subjected to a load test is based on the purpose of the test. Particular care must be taken that the influence of the adjoining parts of the tested structure on the deflection or deformation of the tested part be minimal or at least definable.

Individual members of the tested part of the structure must be secured against buckling during the test in the manner statically corresponding with the actual state during the performance of the structure. At the time of the test it must be ensured that other key conditions for the structure (e.g., temperature, humidity, and saturation with liquid) are identical to or very near the conditions prevailing at the time of the performance of the structure.

If the total permanent load is not applied to the structure or some of its parts at the time of the test, an equivalent load must be placed on them as its value may have a decisive influence on the test results (e.g., if a tested part of the structure is involved or in the case of expected great settlement of statically indeterminate structures). Before the test begins, a preliminary load test is carried out (in unclear cases) to determine the interaction of the tested part with adjoining parts (to determine the extent of tranverse distribution, continuity, etc.), and the further progress of the test, e.g., the extent or the magnitude of the load, are adjusted accordingly.

Age of Structure.—The test is carried out only after the structure has attained the required properties, particularly the full strength of the materials used, or after the termination of significant creep or settlement of the structure, or both. In the case of concrete structures, it is recommended that the tests begin after 3 months. If it is necessary to begin the load test earlier, the date of the test is determined by the authorized testing laboratory entrusted with the execution of the test after an agreement has been made with the party who has ordered the test.

Methods of Measurements.—In the course of the test, measurements are made of all deflections and deformations necessary for an objective assessment of the behavior of the tested structure. In every case the following characteristics must be determined: (1) Deflections of the individual structural members including, in the case of cantilevers, their rotation at supports; and (2) the time of origin of the first defect and the course of its development including, in the case of cracks, their widths in various loading stages, and possibly, the time of the first indications of the loss of stability of the individual members. It is recommended that the relative deformations of the individual members of the individual members of the structure be followed, particularly in the vicinity of their connections or other critical places.

The permissible error of the apparatus used for the measuring of deformations must not exceed the greater of the following values: (1) 5% of the expected theoretical deformation under standard load; or (2) 0.05 mm. The measuring apparatus is fitted in a way that ensures a safe determination of the relative change of the shape of the structure (or its cross section) due to the test load (with the exclusion of the settlement of the supports, effect of temperature

changes, etc.). The measuring apparatus and the structure supporting them, as well as the tested structure, should be protected from the weather, wind, and direct solar exposure during the test. It is recommended that load tests be carried out in the open air at the time of day when the effects of temperature changes are minimum (in the morning, in the evening, at night).

For a certain period preceding the beginning of the load test, it is recommended that all measuring apparatus be monitored to determine the influence of temperature changes on the deformations of the structure and on the apparatus. Should great changes in the readings of the apparatus be ascertained, additional supplementary measures must be taken to ensure the protection of the structure and the apparatus and their supporting structures. Alternatively, the values of temperature correction coefficients must be determined or continuous temperature compensation for the measured data must be provided.

If the correct functioning of the apparatus has not been provided in any other suitable way, then prior to the beginning of the main test, the structure is loaded with a preliminary load not exceeding, as a rule, 20% of the standard load.

When selecting the measuring apparatus for dynamic tests of structures, keep in mind that the frequency range of the apparatus must ensure that all essential harmonic components of the motion are recorded. The natural frequencies of the tested structure or its part or element due to forced vibrations (on the basis of resonance curves) are investigated for more than one position of the vibration exciter, unless the actual vibration source is stationary. When investigating the vibrations due to the operation of machines, the vibrations of the principal parts of the machines are measured apart from the vibrations of the tested structure.

During the entire load test period, the course of ambient temperature and the temperature of parts of the tested structure exposed to the sun are recorded; in the case of concrete, masonry, and timber structures, the course of the relative humidity of the surrounding environment is recorded.

Types of Test Loads.—For static load testing of structures, loads of various types may be used, if the following conditions have been complied with:

1. The load used for the test must not make an independent load-bearing structure (beams, slabs, etc.). If piece loads are used (bricks, bags, etc.) the arch effect must be prevented. For this reason the bricks or blocks should be applied in the form of separate stacks sized 30 cm × 30 cm to 45 cm × 45 cm in plan, and spaced with 3 cm to 5 cm gaps; bags or other major piece materials are permitted to be placed in stacks with lengths not exceeding 1/6 of the span of the tested member (not more, however, than 1 m) with a gap of 5 cm to 10 cm.
2. The weight of the loading unit must be easy to ascertain (e.g., pieces of regular shape or of uniform dimensions).
3. The load must be easy to transport and easy to remove.
4. No hygroscopic materials may be used for loading on the sites with fluctuating humidity.
5. On slanting surfaces the load must be secured against sliding.

For dynamic load tests of structures, the sources of vibrations used to produce

the dynamic effect should simulate as closely as possible the actual vibration loads anticipated for the structure. When these sources are replaced with any other sources of vibrations, care must be taken that all decisive dynamic, as well as static, characteristics (particularly the frequency range) that will originate during the actual performance of the structure are preserved.

In static load tests of elements or parts of structures it is recommended that the test load be applied by means of hydraulic presses having capacities and accuracies of measurement in relation to the load produced that satisfy the stipulations of CSN 25 0251. When necessary, it is also possible to use other types of loads.

For test loads of up to 1,500 kp/m^2, flexible containers filled with water or loading bags with compressed air are recommended. When producing loa by means of hydraulic cylinders or compressed air, care must be taken lest the tested structure be influenced by their reactions. It is not permitted to use any type of load that does not satisfy the preceding requirements, e.g., sand or any other loose material in bulk (with the exception of the cases when the structure is subjected to such loads in its actual performance). When uniform piece loads are used, the weight of the individual pieces may differ maximally by 5% from an arithmetic mean determined by weighing at least 10 pieces selected at random. When nonuniform piece loads are used every individual piece must be weighed separately and visibly marked with its weight. The error in the magnitude of the total load must not exceed ±5%.

Location of Test Loads.—The location of the test loads on the tested structure must correspond with the load for which the structure has been designed or to which it will be exposed. If it is impossible to achieve this, equivalent loads that will produce the same state of stress or strain as the actual load must be used. An equivalent load may be used in cases when the function of the member or structure during the test is different from that in its actual performance conditions (e.g., because of the change of the manner of bearing). The use of the selected location and the magnitude of the equivalent load must be justified by analysis, preferably by limit design methods.

The load must be placed into position as quickly as possible, without any impact or vibrations; as a rule, the load should be applied in several stag determined in accordance with the type of structure. For building structures, the individual loading stages should not exceed 25% of the test load.

When testing simply supported or fully fixed and uniformly loaded slabs with a ratio of sides, $l_1/l_2 \geq 3$, supported only in the longer direction, l_1, the slab is loaded in a zone $1.5l_2$ wide on both sides of the investigated point. When an equivalent load is used, it is possible to proceed according to the working schedule given subsequently. When testing slabs continuous in the direction of l_2 with the ratio of sides, $l_1/l_2 < 3$, the load is applied to a zone $3l_2$ wide with the center in the investigated point in the measured span and at least in another two spans with a free span in between each two.

The distribution of the load in the tests of girders (floor beams, roof trusses, etc.) is selected in accordance with the structural pattern of the structure and the actual effectiveness of the transverse connection, preferably by means of a preliminary load test of transverse load distribution or spatial ineraction.

In structures consisting of main load-bearing members and transverse bracing, a preliminary load test to ascertain transverse load distribution or spatial

interaction is carried out. In other structures the procedure is analogous, according to the static behavior of the tested structure. The test of transverse load distribution or spatial interaction is intended to determine the percentage of the applied load sustained by the investigated member. For this test the investigated member is loaded and the deformations of the adjoining affected load-bearing members are measured; alternatively, only the deformation of the investigated member is ascertained under gradual loading of the adjoining affected members. In this test the stress of any affected member must not exceed 50% of the ultimate load stress. At the same time, the stress of the investigated member must exceed 30% of the ultimate load stress, except in cases in which the test load allocation for one member would exceed 80% of the standard value of live load. In the test of transverse load distribution or spatial interaction it is possible to assume that the sum of the deformations of the same type of measured members (e.g., deflections in the same place as the beams) equals the deformation that would originate under the same load applied to an independent member separated from the remainder of the structure. In this process, wherever possible, all members with an influence exceeding 2.5% should be considered (i.e., the members with deformations exceeding 2.5% of the sum of the deformations of the measured members). If the members are of different rigidity, the measured deformations of the individual members are reduced as the ratio of their rigidities.

According to the results of the transverse distribution tests all affected members are loaded. However, if the strength of the transverse connection permits it, only the investigated member is loaded, with the load increased as the ratio of the sum of deformations of the deformation of this member increases. In the tests of thin-walled structures, the load subsequently is applied to all positions that can result in the loss of stability of the structure.

Magnitude of Test Load.—The magnitude of the test load for the test of the total load-bearing capacity (the test load replacing the effect of live load) is not limited and is increased to an ultimate load causing the failure of the structure or its part.

If the load-bearing capacity of a single element of a structure is tested, the load is increased in stages until the element fails, even in the case when the purpose of the test is to assess the element according to the ultimate deformation limit or the crack limit.

In testing the usability of a structure or a part with reference to its load-bearing capacity, the value of the test load, Z, equals the required standard live load, P_n, multiplied by an average of 1 plus the load factor n, i.e.

$$Z = 0.5\, P_n (1 + n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

[The load factor (>1) is defined in Czechoslovak Standard CSN 73 0035 as a factor compensating the possible deviations from the design load, varying for different structural materials and purpose of the structure from 1.1 to 1.4.] In testing the usability of a structure or a part with reference to its rigidity, the value of the test load equals the required standard live load, P_n, and the test load, Z, is determined by Eq. 1. In testing the usability of a structure or a part with reference to cracking, the value of the test load equals the required standard live load, P_n.

In all cases, it is assumed that the total dead load is in place before the beginning of the test. If any part of the dead load has not been applied before

the beginning of the test, an additional load amounting to the design value of the respective part of the dead load must be applied to the structure. This additional load is applied in one stage, in the cases of concrete, masonry, timber, light alloy, plastics, glass, and composite structures at least 72 hr before the main test and in the case of steel structures at least 3 hr before the beginning of the main load test, unless stipulated otherwise by other standards for the test of building structures. This additional load is left on the structure until the very end of the main load test.

In dynamic load tests of structures, the magnitude and position of the dead load must correspond exactly with the performance conditions. Otherwise the results of the test must be corrected with regard to the actual load. If the structure has been designed to withstand dead load only (e.g., a window lintel) the test load equals the design dead load minus the deadweight of the structure. In the case of members and structures used in moist environment or in an environment with increased air humidity, the dead load for the test is increased by the value corresponding with the possible changes of moisture. If the value of the live load comprizes two or more short-time loads, the sum of the test loads is multiplied by a reduction coefficient of 0.9. However, if the reduced sum of the test loads is less than any individual test load, the maximum test load is used for the test without any reduction.

In dynamic tests of structures, the influence of the live load on the natural frequences of structures and the amplitudes of forced vibrations are considered. When investigating the vibrations due to the operation of machines it is necessary to: (1) Evaluate the influence of the effect of the individual machines or groups of machines affecting the structure or a part by their gradual elimination; (2) assess the state of the machines, particularly when the vibrations of the structure become excessive; and (3) take into account the circumstance that the number of revolutions of some machines changes according to operational requirements, while in the case of some other machines, the magnitude of exciting forces changes in dependence on the variable loading of the machine, while its number of revolutions remains constant.

Period of Application of Test Load.—In the course of the test, individual loading stages are introduced only after the deformation due to the preceding loading stage has stabilized. The deformation is considered stabilized, if its increment in a 5-min period is less than 15% of the preceding increment for the same period or less than the permissible error of the measuring apparatus used. The shortest period of application of the full test load in the usability test of the structure is selected by considering the type of material of the tested structure, as follows: (1) For structures of all types of concrete with compressive moduli of elasticity exceeding 100,000 kp/cm^2 and for reinforced concrete structures, 24 hr; (2) for structures of lightweight concrete with compressive moduli of elasticity less than 100,000 kp/cm^2 and for masonry structures, 48 hr; (3) for timber structures, 72 hr; (4) for steel structures, 1 hr; (5) for light alloy structures, 3 hr; and (6) for structures of plastics, glass, and composites, until the stabilization of deformation, usually more than 72 hr. These periods must be increased if the deformation has not stabilized. If the actual loading period of the structure in actual performance conditions is less than the period stipulated, it is possible to reduce the period of load application during the test accordingly. However, in no case must the period of test load application

be less than the actual loading period in actual performance conditions of the structure. The full test live load is removed in one stage.

Period of Measurements under Load.—In the course of the whole period of application of the full test load, the deformation is measured continuously or in identical intervals that, as a rule, do not exceed one-quarter of the periods stipulated above.

Period of Measurements after Load Removal.—In the usability test of the structure, the deformation is measured after the removal of the test load, as a rule during the same interval as that during which the full test live load is measured according to "period of measurements under load." If the deformation is measured in intervals, the last interval may be double. If the tested structure does not satisfy the criteria stipulated in the first test, the second test may be started after 72 hr in concrete, masonry, timber, light alloy, plastics, and composites structures and 3 hr after the load removal in the first test in steel structures.

Evaluation of Test

Analysis of Structure.—The analysis of the test is carried out with regard to all decisive influences in accordance with the following. If it is impossible to determine reliably the actual value of dead load, the analysis is based on the dead load values given in the respective standard. If part of the dead load is replaced for the test period by an additional load, its actual value is considered in the analysis. Live load is considered with its actual test value.

The degree of constraint considered in the analysis of elastically constrained or continuous structures is best determined by means of a preliminary loading test. In this test the stress of the investigated member, as a rule, should be between 30% and 50% of the design stress; however, the test load must not exceed 80% of the standard live load.

When determining the span, effective slab width, centroid location, etc., for the analysis, the stipulations of the respective standards for the design of a building structure are observed. The magnitude of transverse distribution or spatial behavior considered in the calculation is best determined by means of a preliminary loading test.

For the numerical determination of the ultimate load limit of the tested structure, the procedure stipulated by the individual standards for the design of a building structure is used in conjunction with the following: (1) In the analysis, the average of the actual key characteristics of the material of the structure are used whenever possible (compressive strength of concrete, yield limit of steel, etc.) and are determined by nondestructive tests or some other suitable methods; and (2) the analysis is carried out, whenever possible, with regard to the actual distribution of bending moments and forces ascertained during the load test. The analysis of the structure for the test load is carried out in accordance with the respective standards for the design of a building structure. When determining the deformation, the modulus of elasticity is considered with its actual value determined by a nondestructive test in the structure or some other suitable method.

Numerical and Graphic Evaluation of Measured Data.—The progress of every load test is recorded in detail in a test record containing all ascertained data

on the member or the structure before, during, and after the test is completed. The measured data are processed numerically and graphically to provide a basis for obtaining a clear picture of the behavior of the structure in the whole course of the load test. In numerical evaluation, the data are reduced with regard to the settlement of supports or the effect of temperature or moisture, or all of these. The results are tabulated in a clear form and the calculation of permanent elastic and total deformations from the basic readings is carried out. In this process, the final values of the individual quantities measured during the whole duration of the test or during the whole period of measurements after the load removal are considered.

The principal relations elucidating objectively the behavior of the structure under load and after its removal are expressed on the basis of numerical values and graphically, preferably by means of three-component diagrams (e.g., load × deformation × time).

Criteria for Load Test Evaluation.—The criteria for load test evaluation differ principally according to whether the evaluation concerns a test carried out to failure or a test using a lesser test load. The tested building structure is assessed with regard to its: (1) Load-bearing capacity (when loaded until it fails); or (2) usability, i.e., (a) with reference to its load-bearing ability, (b) with reference to its rigidity under the test load, and (c) with reference to cracks under the test load.

Further supplementary criteria may be stipulated by the standards for the design or erection of the individual types of building structures or further standards for their testing. When using more detailed methods of load test evaluation, their suitability for the given case must be proven. The tested structure is considered satisfactory with regard to its load-bearing capacity if it complies with the condition that the actual load under which it has failed is higher than or at least equal to the ultimate design load, at the same time being: (1) Higher than 95% of the theoretical value determined by analysis if the structure has failed due to the exhaustion of its strength; or (2) higher than 100% of the theoretical values if the structure has failed due to the exhaustion of its stability.

The load under which the structure has failed is the load under which the structure has lost its ability for further use due to one of the following causes: (1) Complete failure of the structure or its part or section or the rupture of reinforcement (in the case of reinforced concrete structures); (2) loss of stability of the structure or its part or element; (3) local failure that continues to grow without any increase in load; (4) the deformation increments under the same load measured three times in succession at identical intervals do not decrease; (5) the deformation increment due to the last loading state equals the sum of the deformations due to the first five equally high loading stages or exceeds it; (6) the deflection equals or exceeds 1/50 of the span; (7) in deformed concrete structures, the width of cracks equals or exceeds 1.5 mm provided these cracks are at least 200 mm long; (8) the failure of concrete structures by slanting cracks in the proximity of supports or point loads; or (9) loss of bond between reinforcement and concrete.

The tested building structure is considered usable with reference to its load-bearing ability if it has fulfilled simultaneously the following conditions.

1. The magnitude of permanent deformations does not exceed the following

percentages of the total deformation under test load: (a) Steel structures, 15%; (b) prestressed concrete structures, 20%; (c) reinforced concrete, masonry and composite (steel and concrete) structures, 25%; (d) timber structures, 30%; and (e) plastic and composite structures, 40%.

2. The state of failure due to the design load is stabilized, while the width of cracks in concrete structures does not exceed 0.3 mm, if they are protected against weather, and 0.2 mm, if they are exposed to weather.

If the permanent deformation in the first test exceeds the preceding values, but does not attain for metal structures 40%, for reinforced concrete, composite, prestressed concrete, and masonry structures 50%, and for timber, plastic, and composite structures 60% of the total deformation under test load, another load test may be carried out during which the conditions must be met. If the structure does not appear satisfactory even after the second test, in especially justified cases, it may be appropriate to carry out a third load test, in which the permanent deformations must not exceed 1/3 of the values given in the following. If the permanent deformations exceed the preceding stipulations, the structure is not satisfactory.

The tested building structure is considered usable with reference to its load-bearing ability on the basis of the second load test if it satisfies the following conditions:

1. The magnitude of permanent deformation does not exceed the following percentages of the total deformation under the test load: (a) Metal structures, 7.5%; (b) prestressed concrete structures, 10.0%; (c) reinforced concrete, composite, and masonry structures, 12.5%; (d) timber structures, 15.0%; and (e) plastic and composite structures, 20.0%.

2. No new failures originate and the existing failures do not extend (in the case of reinforced concrete structures the cracks do not increase either in length or in width).

If the first test is discontinued for any reason and the full test load has been applied for at least one-half the stipulated period, the structure is assessed during the repeated test according to the these values; if not, then according to the preceding values.

The tested building structure is considered usable with reference to its rigidity (deformation), if it satisfies simultaneously the following conditions:

1. The measured elastic deformations under test load must not exceed the k multiple of the theoretically determined value; in which the value of k according to Table 1 depends on the mean load factor, deduced from its values n for live loads and on the material of the tested structure (see CSN 73 0035 or further standards).

2. The fulfillment of the preceding deformation conditions, with the exception of precast reinforced concrete elements, which will be tested earlier than after the elapse of 3 months, and to which the stipulations of the special standard on the testing of precast reinforced concrete elements apply.

3. Total deflections or other total deformations under standard live load must not exceed the limit deflections or deformations given in the respective standards

for the design and erection of building structures and reduced according to the magnitude (type) and period of application of the load.

4. Total deflections or other total deformations under test load must not exceed the limit deflections or deformations more than k times; the values of k are given in Table 1.

A test structure of reinforced concrete is considered usable with reference to the origin and development of cracks, if it satisfies simultaneously the following conditions: (1) The crack width under standard live load must not exceed the values stipulated by the standards for the design of structures; (2) the distance between cracks under standard live load must not exceed the values stipulated by the standards for the design of structures; (3) the cracks do not appear under loads less than 0.9 of the theoretically determined load for the origin of the first crack according to the theory of elasticity; and (4) after the removal of the load, the cracks close to a width less than 1/3 of the prescribed value.

TABLE 1.—Values of k

Mean value of load factor n for considered live load (1)	k				
	Steel (2)	Reinforced concrete and masonry (3)	Prestressed concrete (4)	Timber (5)	Plastics and composites (6)
1.0	1.05	1.10	1.05	1.10	1.10
1.1	1.05	1.12	1.07	1.12	1.11
1.2	1.05	1.15	1.10	1.15	1.13
1.3	1.05	1.17	1.12	1.17	1.14
1.4	1.05	1.20	1.15	1.20	1.16

NOTE: Intermediate values may be linearly interpolated.

The criteria for the evaluation of dynamic tests are determined individually, usually after a consultation with a specialized institution, unless they are stipulated by other standards for load testing of building structures.

Final Evaluation of Load Test.—In the final evaluation of the loading test, the conclusions drawn from the processing of the load test results are given. The conclusions must be unambiguous. If the structure or its elements has not satisfied the stipulations of the respective standards or specifications valid for the product, an explanation of the reasons must be given, within the given possibilities.

Working Schedule

It is recommended to divide the working schedule into the following phases: (1) General stipulations; (2) methodology; (3) investigations proper; (4) processing of results; and (5) conclusion.

The general stipulations of the schedule are of a guiding character. They formulate the purpose of the test, determining the individual phases of investiga-

tions accordingly. In this respect it is decided according to which criteria the structure or its part will be assessed. According to the structural analysis, comprizing also the calculation of deformations, the preparation of the test is carried out so that the test results can be compared or the analysis can be adjusted according to the results obtained in the course of the test. Moreover, the method of loading, the magnitude, and the type of load or other effects that must be known are stipulated so that it is possible to assess the behavior of the structure. Finally the considerations of the expected results are given.

The methodology of work is governed by the characteristics accepted as the basis of the assessment of the load-bearing ability and usability of the structure according to the individual criteria. A working program is compiled, stipulating the loading procedure and the duration of the individual stages, type and mounting of the individual apparatus, the methods and the required accuracy of measurements, etc. Also the procedure that will ensure the uniformity of the individual apparatus and eliminate the influence of such factors as would distort the measurements (temperature, humidity, etc.) is stipulated; justification should be given here for the recording of special unusual deformation characteristics of the structure.

Before the investigation proper, the testing apparatus and their mounting, as well as their proper functioning after their mounting, are checked. Further, all other ancillary plants are checked together with the load and the accuracy of the testing apparatus must be verified. The load test proper, which proceeds according to a previously prepared time schedule, is recorded in detail, the record forming an annex to the final report on the test. The results of the measurements are processed preliminarily in the course of the test to enable the checking of the assumptions of the analysis and, should it be necessary, an adjustment of the analysis or the further progress of the test on the basis of the results obtained, or both.

The processing of the results of the investigation (measurements and evaluation of the load test) is carried out in accordance with this standard. Whenever possible the results are processed by the methods of mathematical statistics and anomalous results are explained. All deductions drawn from the processing of the results of the load test are given in the final report.

Conclusions

Although full-scale testing has been largely a simple, but often expensive, technical means of making a legal demonstration, it is becoming a valuable evaluational tool for structural engineers. This paper has presented recently developed European test procedures in hopes of encouraging this progress. Hopefully, those engineers engaged in routine or research testing, when practical, will consider the application of these procedures to their work.

11322 LOAD TESTS OF BUILDING STRUCTURES

KEY WORDS: Buildings; **Buildings (codes); Loading tests;** Loads (forces); Measuring instruments; **Quality control;** Safety; **Structural engineering;** Testing

ABSTRACT: European practice in load testing buildings is a valuable guide for American structural engineers. Although load tests often are used as legal measures, they can provide valuable insight into structural behavior if this aspect is properly considered. Procedures outlined are for a test project and include a preliminary structural analysis and detailed planning. Consideration of variations in properties of materials is important, as is the static or dynamic characteristics of the service loads. Magnitude, distribution, and duration of test loads are essential factors examined. The actual execution of the test involves three major aspects: (1) Recording of accurate and significant data; (2)safety of personnel and protection of structure; and (3)economy. Even a perfectly executed test needs proper analysis and application of results before it can be considered successful. Some criteria for evaluating test results are given.

REFERENCE: Bares, Richard, and FitzSimons, Neal, "Load Tests of Building Structures," *Journal of the Structural Division,* ASCE, Vol. 101, No. ST5, **Proc. Paper 11322,** May, 1975, pp. 1111-1123