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(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 39/टी-35 **27 जून 2025**

तकनीकी समिति : भूकंप इंजीनियरिंग अनुभागीय समिति , सीईडी 39
प्राप्तकर्ता :

1. **सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य**
2. **भूकंप इंजीनियरिंग अनुभागीय समिति, सीईडी 39**
3. **सीईडी 39 की उपसमितियों और अन्य कार्यदल के सभी सदस्य**
4. **रुचि रखने वाले अन्य निकाय।**

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न है:

प्रलेख संख्या	शीर्षक
सीईडी 39(28254)WC	भूकंप के प्रभावों के लिए संरचनाओं का परीक्षण का भारतीय मानक मसौदा (आई सी एस संख्या : 91.120.25)

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सिविल अभियांत्रिकी विभाग

संलग्न: उपरलिखित

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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WIDE CIRCULATION DRAFT

Our Reference: CED 39/T-35 **27 June 2025**

TECHNICAL COMMITTEE: EARTHQUAKE ENGINEERING SECTIONAL COMMITTEE, CED 39
ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Earthquake Engineering Sectional Committee, CED 39
3. All Members of Subcommittees, Panels and Working Groups under CED 39
4. All others interested.

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	**Title**
CED 39(28254)WC	**Draft Indian Standard Testing of Structures for Earthquake Effects** ICS No. 91.120.25

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 12 August 2025

Comments if any, may please be made in the enclosed format and emailed at ced39@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in.

Thanking you,

Yours faithfully,

Sd/-

Dwaipayan Bhadra

Scientist 'E' & Head

Civil Engineering Department

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. Comments through e-mail to **ced39@bis.gov.in** shall be appreciated.]

Doc. No.: CED 39(28254)WC
BIS Letter Ref: CED 39/T-35
Title: Draft Indian Standard Testing of Structures for Earthquake Effects ICS No. 91.120.25
Last date of comments: 12 August 2025
Name of the Commentator/ Organization:

SI No.	Clause/ Para/ Table/ Figure No. commented	Type of Comment (General/ Technical/ Editorial)	Comments/ Modified Wordings	Justification of Proposed Change

NOTE- *Kindly insert more rows as necessary for each clause/table, etc*

BUREAU OF INDIAN STANDARDS

DRAFT STANDARD FOR COMMENTS ONLY

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Draft Indian Standard

Testing of Structures for Earthquake Effects

ICS No. 91.120.25

Earthquake Engineering Sectional Committee, CED 39 | **Last Date for Comments: 12 August 2025**

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Earthquake Engineering Sectional Committee, CED 39

FOREWORD

(*Formal clause will be added later*)

Understanding and forecasting the behavior of structures during earthquakes poses a significant challenge for structural engineers. Acknowledging this challenge, design methods typically focus on regulating the level of damage that develops in a structure during earthquakes by controlling its deformation and yielding at predetermined locations. Different tools for structural analysis and design are available to earthquake engineers. These tools differ in complexity and accuracy depending on the assumptions in the methodologies adopted. Based on the available state of the knowledge, even the most advanced and rigorous methods of analysis to estimate nonlinear response approximate several inputs, which may be unknown or may be based on empirical understanding. These could be in modelling the material or the structural configuration. In the design of irregular or critical structures and in the verification of proposals of new technologies, it is imperative to verify that the actual response aligns reasonably with the assumed response during design. Given the constraints of current procedures for predicting seismic response, experimental investigations have an important role in understanding the structural behaviour and development of methods of earthquake resistant design.

Experimental investigations are invaluable means to study, understand, mimic and estimate the behavior of materials, members, sub-assemblages and structures subjected to various loads, including the effects of earthquake shaking. Also, they enable the preparation and/or verification of analytical models that are used to represent more complex and complicated structures, for which full-scale testing may not be feasible.

Typically, experimental investigations are performed at three levels, namely material, sub-assemblage and system levels. Investigations at each of these levels help in gathering critical information regarding the behavior of structures, particularly when the structure is expected to resist the load effects in the nonlinear inelastic range.

Standardization of methods of testing for earthquake effects is necessitated by:

a) Emergence of newer materials, structural systems, design methods and construction technologies,
b) Need for performance evaluation under normal and exceptional loads, and
c) Need for consistency in comparison of test results.

The provisions of this standard may be used as guidelines for preparation of test specimens in case of verifying new technologies for design and construction, and development of experimental setup for proof-of-concept for a new procedures which do not have established design methodologies or standards. In such cases, the number of specimens shall be decided by the owner of the new technology.

In the formulation of this standard, effort has been made to coordinate with standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. Assistance has particularly been derived from the following publications:

ACI 374, (2013), *Guide for Testing Reinforced Concrete Structural Elements Under Slowly Applied Simulated Seismic Loads*, American Concrete Institute, USA

ATC 24, (1992), *Guidelines for Cyclic Seismic Testing of Components of Steel Structures*, Applied Technology Council, USA

ATC 40, (1996), *Seismic Evaluation and Retrofit of Concrete Buildings*, Applied Technology Council, USA

FEMA 356, (2002), *Pre-Standard and Commentary for the Seismic Rehabilitation of Buildings*, American Society of Civil Engineers for the Federal Emergency Management Agency, Washington, DC, USA

FEMA 461, (2007), *Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components*, Applied Technology Council, USA

JGJ/T 101, (2015), *Seismic Testing Procedures for Buildings*, Industry Standards, Ministry of Housing and Urban and Rural Development, People’s Republic of China, China

SAC, (1997), *Protocol for Fabrication, Inspection, Testing, and Documentation of Beam-Column Connection Tests and Other Experimental Specimens*, SAC Joint Venture Report No. SAC/BD-97/02, Version 1.1, Applied Technology Council, USA

Also, considerable assistance has been given by Malaviya National Institute of Technology Jaipur, Indian Institute of Technology Kanpur, Indian Institute of Technology Guwahati and Indian Institute of Technology Madras, CSIR Central Building Research Institute (CBRI) Roorkee, and M/s B. G. Shirke Construction Technology Private Limited.

This standard contributes to the following Sustainable Development Goals:

a) Goal 9 Industry, Innovation and Infrastructure towards building resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; and
b) Goal 11 Sustainable Cities and Communities towards making cities and human settlements inclusive, safe, resilient and sustainable.

For deciding whether a particular requirement of this standard is complied with, the final value observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2: 2022 'Rules for Rounding off Numerical Values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard

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Draft Indian Standard

Testing of Structures for Earthquake Effects

Earthquake Engineering Sectional Committee, CED 39	**Last Date for Comments: 12 August 2025**

1 SCOPE

1.1 This standard provides guidance on:

a) testing of materials to characterize materials and extract properties that are used in earthquake capacity assessment of structures,
b) testing of members, sub-assemblages and structures to extract their structural characteristics (like natural periods, mode shapes, initial overall lateral stiffness, overall lateral strength, failure modes, overall lateral deformability and energy dissipation) that are used in refining the analytical tools towards improved estimation of earthquake capacity of structures, and
c) testing of members, sub-assemblages, structures, and energy dissipation devices to study their behaviour that arises from new structural designs, schemes of structural detailing and structural connections towards developing earthquake resistant structures.

1.2 The provisions of this standard assist in the following:

a) Selection of suitable test (that is, field test or laboratory test) to extract a specific structural information as per the objective identified in **1.1**,
b) Finalization of appropriate specimen (that is, full-scale or reduced scale), including consideration of the laws of dynamic similitude,
c) Design of the test set-up and test procedure to capture the desired structural information as faithfully as possible,
d) Determination of the loading method, amplitude and frequency, strong ground motions to be considered with and without scaling, and the loading devices,
e) Design of:

    1) instrumentation (including number, location, type, range and sensitivity of sensors), and
    2) data acquisition system (including number of channels, sampling rate and lag), and

f) Earthquake qualification of the loading devices and sensors.

1.3 The provisions of this standard are applicable for:

a) cast in-situ, precast, prefabricated, and pre-engineered systems, and

b) testing of existing or new structural systems, subsystems or energy dissipation devices towards material and structural evaluation or technology qualification and/or development.

1.4 Before undertaking any of the tests mentioned in **1.1**, structural analysis may be performed to estimate the requirements of:

1) the design of the test-bed,
2) the choice of the loading devices,
3) the determination of the loading protocol, including identifying the most suitable loading devices and sensors, (d) evaluate the safety of the people and facilities during the tests, and
4) evaluate the efficient utilization of the experimental resources.

1.4.1 The method of analysis can be based on time domain or frequency domain:

a) Linear, if the expected performance of the specimen is in the linear range, and
b) Nonlinear, if the expected performance of the specimen is beyond the linear range.

The extent of complexity of these analyses shall depend on the detail being sought through testing.

1.4.2 When performing any of the analyses mentioned in **1.4.1**, the stiffness, strength and deformability considered of the specimen shall be estimated:

a) without applying the partial safety factors for loads and materials,
b) using the material properties estimated using the stress-strain curves of actual materials proposed to be used in the preparation of the specimen, and
c) without making major assumptions, to the extent possible.

2 REFERENCES

The standards listed in Annex A contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standards listed in Annex A.

3 TERMINOLOGY

For this standard, the definitions given below shall apply to all structures, in general. For definitions of terms pertaining to design earthquake hazard and criteria for earthquake resistant design, earthquake resistant design and detailing of structures, and earthquake safety assessment and retrofit of structures. Reference may be made to relevant parts of IS 1893, IS 13920 and IS 13935.

3.1 Cycle — A complete unit of a load or deformation history consisting of two consecutive actions, one in the positive direction and the other in the negative direction.

3.2 Deformation Control Parameter — The most pertinent deformation quantity that best signifies the main cause and consequence of damage in a test specimen.

3.3 Deformation Controlled Test — A test performed under gradually increasing or decreasing levels according to a pre-established deformation history.

3.4 Drift Ratio — The ratio of the relative difference of displacement between the top and bottom of a storey, and the storey height.

3.5 Dynamic Test — A test method in which the real earthquake shaking is simulated at the base of the test specimen through a rigid table with the help of displacement-controlled actuators.

3.6 Elastic Model — A mathematical representation of a structure or component, which behaves in a linear manner with a constant stiffness, under applied loads.

3.7 Energy Dissipation Devices — Structural devices meant to absorb the earthquake energy input to the structure.

3.8 Force Control Parameter — The most pertinent force quantity that best signifies the main cause and consequence of damage in a test specimen

3.9 Force Controlled Test — A test performed under gradually increasing or decreasing levels according to a pre-established load history.

3.10 Generic Test Specimen — A test specimen designed to investigate a general behavioral aspect of structural performance.

3.11 Inelastic Model — A mathematical representation of a structure or components, which behaves in a linear manner with a constant stiffness up to the yield point, and with reduced stiffness after the yield point, under external loads or vibration.

3.12 Load — External force or displacement acting on a structure, which can affect its motion and stability.

3.13 Motion Sensor – A device used to measure the dynamic response of a structure by detecting its motion in terms of acceleration, velocity, and displacement.

3.14 Prototype Structure — A full-scale model of a structure that can be used as a reference for design, testing, and validation.

3.15 Pseudo-Dynamic Test — A hybrid test method in which:

a) nonlinear dynamic analysis is performed on an analytical (computer) model under a given acceleration history input at the designated points on the test specimen, and the analytical displacement values are estimated at each instant of time at the other unrestrained points on the test specimen,

b) the analytical displacement histories are imposed instantaneously on the test specimen through reaction equipment(s),
c) the resistance faced at the displacement-controlled reaction equipment(s) are measured and fed to the analytical computations on the computer, and
d) the above three steps are repeated until the entire ground motion history is completed

3.16 Quasi-Static Test — A Test method in which incremental static force or deformation are imposed slowly at specific points of a test specimen so that the dynamic inertia effects or strain rate effects on materials do not develop, over the entire range of likely performance from elastic stage to failure.

3.17 Reaction Equipment — A fixture that imposes a desired load or deformation on the test specimen.

3.18 Scaled Model — A specimen built by scaling the original or prototype structure or component according to theoretical or empirical similitude relationship.

3.19 Yield Force — The force at which significant yielding is considered to have begun.

4 SYMBOLS

The symbols and notations given below apply to the provisions of this standard:

Symbol	*Description*
L	Length
M	Mass
T	Time
L_{sp}	Length of Specimen
L_{st}	Length of Structure
M_{sp}	Mass of Specimen
M_{st}	Mass of Structure
T_{sp}	Time of Specimen
T_{st}	Time of Structure
$S_{\mathrm{L}}, S_{\mathrm{M}}, S_{\mathrm{T}}$	Length, Mass, and Time Scale factors

5 GENERAL PRINCIPLES

5.1 Scope of Tests

Structural testing can be performed to capture the behaviour of materials, members, sub-assemblages, structures, and energy dissipation devices under the chosen levels of strains or displacements that reflect the effects of the chosen intensity of earthquake shaking.

The outcomes of tests consist of quantities that are directly measurable by sensors installed on the specimen, and of quantities that are indirectly derived from the measured quantities. The test outcomes shall be determined in accordance with the test objectives and user requirements. Possible outcomes of the said tests are the characteristics listed in Table 1.

Table 1 Typical Characteristics that can be Captured in Different Tests
(*Clauses* 5.1, 7.1 and 7.2)

Sl No.	**Characteristic Property**	**Test**				
		Material	Member	Sub-assemblage	Structure	Energy dissipation device
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Initial modulus of material	✓				
ii)	Normal strain capacity	✓				
iii)	Material ductility	✓				
iv)	Stress-strain curve					
	a) Monotonic	✓				
	b) Hysteretic behaviour	✓				
v)	Load-deformation behaviour					
	a) Ductility		✓	✓	✓	✓
	b) Hysteretic behaviour		✓	✓	✓	✓
vi)	Lateral Stiffness					
	a) Initial stiffness		✓	✓	✓	✓
	b) Degradation under repeated cyclic loading		✓	✓	✓	✓
vii)	Lateral strength					
	a) Peak Strength		✓	✓	✓	✓
	b) Deterioration under repeated cyclic loading		✓	✓	✓	✓
viii)	Deformability					
	a) Curvature capacity		✓			

Sl No.	Characteristic Property	Test				
		Material	Member	Sub-assemblage	Structure	Energy dissipation device
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	b) Plastic rotation capacity		✓	✓	✓	
	c) Displacement capacity		✓	✓	✓	✓
ix)	Initiation and propagation of damage		✓	✓	✓	✓
x)	Collapse mechanism					
	a) Plastic hinge locations		✓	✓	✓	
	b) Joints behaviour		✓	✓	✓	
xi)	Connection behaviour			✓	✓	✓
xii)	Energy dissipation	✓	✓	✓	✓	✓

5.2 Types of Tests

This standard provides broad guidance on two sets of structural tests (Fig. 1), namely:

a) Field Tests:

1) Ambient vibration test, and
2) Forced vibration test; and

b) Laboratory Tests:

1) Material test,
2) Quasi-static test,
3) Pseudo-dynamic test, and
4) Dynamic test.

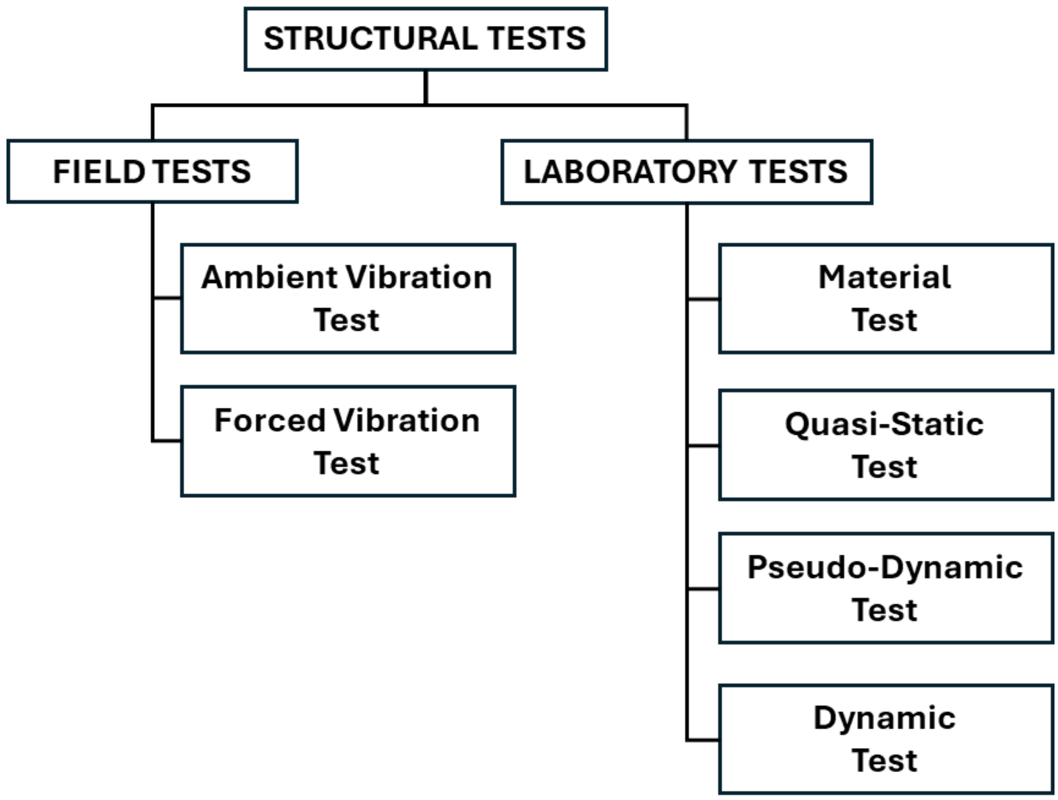


FIG. 1 TWO BROAD SETS OF STRUCTURAL TESTS CONSIDERED IN THIS STANDARD

5.3 Specimen

5.3.1 The test specimen to be used in the laboratory should be as close as practicable to the original structure being studied. It shall be made:

a) of the same or reduced-scale size as the original structure
b) with actual materials and detailing practices used in construction practice, and
c) with boundary conditions close to that of the original structure,

to minimize possible size-effects on the inferences drawn based on the response of the specimen.

5.3.2 A test specimen is intended to simulate a portion, a member or a sub-assemblage of a structure. It shall be designed and built as per applicable standards, and construction practices, workmanship and quality control employed therein. Thus, the constructional aspects when preparing such test specimens shall reflect those used in actual field conditions.

5.3.3 *Size of Specimen*

The test specimen can be full-scale or reduced-scale models.

a) *Full-Scale Specimen*

When performing ambient and forced vibration tests of existing structures, the specimen is of full-scale size. Also, when performing tests to pre-qualify devices, the tests should be performed only on full-scale devices.

b) *Reduced-Size Specimen*

When full-scale tests are not feasible or required, scaled-down models may be employed. In such situations, the effect of scaling should be addressed on the different structural parameters of the model when making the specimen.

When reduced-size specimens are adopted the specimen shall:

1) comply with the original structure in terms of mass, stiffness, strength and deformability. Here, the laws of dynamic similitude shall be considered to design the specimen, choose suitable materials (of appropriate elastic modulus, mass density and strength), and determine the loading to account for the scaling effects. The reduction in scale can be in terms of length (L), mass (M) and/or time (T). Thus, the ratios of these quantities of the specimen and the original structure should be known. If S_{L}, S_{M} and S_{T} are the length, mass and time scales (that is , ratios of the quantities of the specimen and corresponding quantities of the structure), then the characteristics of the reduced scale specimen should be obtained by multiplying the values of the original structure with the factors specified in Table 2. Generally, length scaling is adopted.

2) be large enough to accommodate actual materials and details such that the construction practices adopted in the actual structures are replicated within the acceptable range.

In reduced scale specimen the structural parameters would match in the elastic range, but the interpretation of the testing results of these parameters in the inelastic range needs justification based on the structural behaviour in that range.

Interpretation of results in the inelastic and nonlinear range of behaviour is sensitive to the scaling ratios adopted. Hence scaled specimen testing requires expert judgement.

Table 2 Scaling of Quantities when adopting a Reduced-size Specimen in Tests
(*Clause* 5.3.3)

Sl No.	Parameter	Dimension	Scaling Factor
(1)	(2)	(3)	(4)
i)	Length	L	$S_{\mathrm{L}} = \frac{L_{\mathrm{sp}}}{L_{\mathrm{st}}}$
ii)	Mass	M	$S_{\mathrm{M}} = \frac{M_{\mathrm{sp}}}{M_{\mathrm{st}}}$

iii)	Time	T	$S_{\mathrm{T}} = \frac{T_{\mathrm{sp}}}{T_{\mathrm{st}}}$
iv)	Velocity	$\frac{L}{T}$	$\frac{S_{\mathrm{L}}}{S_{\mathrm{T}}}$
v)	Acceleration	$\frac{L}{T^2}$	$\frac{S_{\mathrm{L}}}{(S_{\mathrm{T}})^2}$
vi)	Mass Density	$\frac{M}{L^3}$	$\frac{S_{\mathrm{M}}}{(S_{\mathrm{L}})^3}$
vii)	Force	$\frac{ML}{T^2}$	$\frac{S_{\mathrm{M}}S_{\mathrm{L}}}{(S_{\mathrm{T}})^2}$
viii)	Moment	$\frac{ML^2}{T^2}$	$\frac{S_{\mathrm{M}}(S_{\mathrm{L}})^2}{(S_{\mathrm{T}})^2}$
ix)	Modulus of Elasticity Stress	$\frac{M}{LT^2}$	$\frac{S_{\mathrm{M}}}{(S_{\mathrm{T}})^2 S_{\mathrm{L}}}$
x)	Vibration Frequency	$\sqrt{\frac{\left(\frac{M}{LT^2}\right)}{M}}$	$\frac{1}{S_{\mathrm{T}}\sqrt{S_{\mathrm{L}}}}$
xi)	Vibration Period	$\sqrt{\frac{M}{\left(\frac{M}{LT^2}\right)}}$	$S_{\mathrm{T}}\sqrt{S_{\mathrm{L}}}$

5.3.4 *Minimum Number of Specimen*

The number of specimens to be deployed in the study depends on the intended use of the outcomes of the test. It shall be at least:

a) 1, when the specimen is full scale and the overall system performance is required to be examined,
b) 2, when a concept is being verified with reduced scale, and when repeatability of the response is required to be achieved,
c) 3, when a concept is being verified with reduced scale, and when repeatability of the response is not achieved in 2 tests. In parametric studies, at least 3 tests are required, and
d) 30, when a design provision is proposed to be arrived at based on the results of the tests, for example, when extracting properties of materials.

This standard may be used as a guideline for the development of experimental setup for proof-of-concept of new design and construction procedures which do not have established design methodologies or standards. In such cases, the number of specimens shall be decided by the project authority.

5.4 Loading

5.4.1 *Loading Type*

Full-scale specimens shall be subjected to the following loading histories in forced vibration field testing of structures:

a) Sine-sweep loading imposed by the loading devices at select locations on the structure,
b) Frequency domain test by applying random excitation loading imposed by the loading devices at select locations on the structure, and
c) Impulse-based loading imposed by the impact hammer at select locations on the structure.

Laboratory specimens shall be subjected to the following loading histories in earthquake testing of structures:

a) Strain-based loading imposed by the universal testing machines (UTMs) at the ends of the standard material test specimen during material tests,
b) Displacement-based loading imposed by the loading devices at select locations on the specimen during member, sub-assemblage, system and device tests in:

    1) Quasi-Static Tests (which are monotonic or reversed-cyclic tests), and
    2) Pseudo-Dynamic Tests (which are oscillatory motion tests arising from earthquake ground motion shaking at the base of the structure); and

c) Acceleration-based loading imposed by the shake table at the base of the specimen in dynamic tests, reflecting shaking at the base of structures; these acceleration ground motion histories are imposed at the base of the structures in pseudo-dynamic tests also, even though numerically. Also, depending on the intent of use of the results, these acceleration histories shall reflect:

    1) Far-fault earthquake shaking conditions, and/or
    2) Near-fault earthquake shaking conditions.

Co-loads (gravity, lateral loads, etc.) shall be included to represent their effects as per the actual site conditions.

5.4.2 *Loading Devices*

5.4.2.1 Equipment and devices used in structural testing should be capable of imposing the appropriate earthquake demand to ascertain the desired characteristics specified in **5.1**.

a) In forced vibration tests, the loading shall be harmonic vibrations arising from:

   1) circular movement of eccentric mass,
   2) linear alternating motion of a guided mass, and
   3) impact load causing impulse excitation from a blast, a collision, a dropped mass, or from a sudden release of a restraint. The impact load should not cause any local or global damage to the structure and the amplitude impulse response signal should be sufficient to be measured by the adopted motion sensors.

The capacity of the harmonic oscillator should neither cause any damage nor jeopardize the safety of the structure.

b) In quasi-static tests and pseudo-dynamic tests, the actuators employed to apply the load on the specimen should:

   1) have load capacity more than the lateral strength of the specimen,
   2) have displacement capacity more than the lateral deformability of the specimen,
   3) have fatigue rating to provide the dynamic force and displacement to the specimen at the required rate, and
   4) be based on the type of test mentioned in **5.2**, size and capacity of test specimen in **5.3.3** and test bed based on the loading history mentioned in **5.4.3**, and the available power pack capacity.

c) In dynamic tests, the shake table (together with all the actuators used under the tables) should have:

   1) sufficient payload capacity to excite the specimen placed on it with the acceleration imposed at its base and the amplification likely in the specimen owing to its dominant natural period, and
   2) fatigue rating to provide the dynamic force and displacement to the specimen at the required rate.

5.4.2.2 Adequate protection shall be provided during testing to avoid instability of the test specimen and thereby ensuring safety of lives and facilities, by:

a) installing barriers to prevent trespassing, additional lateral props and supports to increase redundancy against lateral overturning, and automated backup of sensor data, and
b) performing the test a low level of excitation to check:
   1) the elastic properties of the test specimen,
   2) the boundary conditions of test setup, and
   3) the efficiencies of loading devices, and measuring devices.

5.4.2.3 *Capacity*

The maximum capacity required of the loading devices shall be determined based on the overall lateral load-deformation curve estimated during the analytical study mentioned in **1.4**.

5.4.2.4 *Actuators*

a) When displacement loading is employed, the loading devices need not be fatigue-rated devices. The range of frequency rating of these actuators can be small (<10 Hz). The ranges of force and displacement capacities of the actuators shall depend on the force and displacement capacities of the specimen being tested, with leeway for sufficient margin.
b) When acceleration ground motion is employed, the loading devices (namely the actuators) shall be fatigue-rated devices. The range of frequency ratings of these actuators shall:

    1) include 0.1 Hz to 33 Hz, when full-scale specimens are tested, and
    2) be commensurate with the laws of dynamic similitude, when reduced-scale specimens are tested.

5.4.2.5 *Gravity load*

When constant vertical load is required to be imposed and the member displaces laterally, the test fixtures shall ensure that the verticality of loading shall be maintained even when the member is out of plumb owing to lateral displacement. In such cases, the stability of the test specimen shall be ensured by installing additional barriers and supports to avoid sudden collapse of the specimen.

5.4.3 *Loading History and Loading Rate*

5.4.3.1 *Displacement loading*

a) When displacement loading is employed, the loading devices, namely the actuators, shall be operated:

    1) in force-control loading at the beginning of the test, to estimate elastic stiffness and to avoid damage to the specimen; in this case, the range of force shall be such that there is no damage in the specimen, and
    2) only in displacement-control mode during the main testing.

b) When displacement loading is employed, the following shall be its characteristics of:

    1) The amplitude scale of the loading shall be determined by the yield displacement, Δ_y and ultimate displacement, Δ_u capacities estimated during the analytical study mentioned in **1.4**.
    2) They shall reflect the characteristics of the site of the proposed structure with respect to the major fault system, namely far-fault type loading or near-

fault type loading.

5.4.3.2 *Acceleration loading*

a) The acceleration histories employed in pseudo-dynamic and dynamic tests on full-scale specimen shall have the following characteristics with one or more being selected based on the test objectives:

   1) The chosen real or synthetic ground motion shall be originated from a source with similar characteristics and tectonic settings as the area of interest,
   2) The ground motion employed shall be compatible with the design spectrum applicable for the region.
   3) Often, it is not possible to get a single ground motion that is compatible in the acceleration-sensitive, velocity-sensitive and displacement-sensitive ranges of the response spectrum. Hence, depending on the natural periods of the specimen which are likely to be excited during earthquake shaking, the ground motions selected shall be compatible in the appropriate natural period range(s).
   4) Pulse inputs, such as full or half-cycle sine waves, with durations ranging from 0.3 second to 5 second.

b) The acceleration histories employed in pseudo-dynamic and dynamic tests on reduced-scale specimen shall be the same as in **5.4.3.2**(a), with appropriate scaling in keeping with the laws of dynamic similitude.

c) When *acceleration* ground motion is employed,

   1) the loading devices, namely the actuators, shall be operated:

      i) in force-control mode at the beginning of the test, to avoid damage to the specimen; in this case, the range of the acceleration shall be scaled down such that the force induced in the specimen is about 1 percent of its capacity, and
      ii) only in displacement-control mode during the main testing.

d) When acceleration ground motion is employed, the ground motions recorded along three cartesian directions in the tectonic area of interest shall be used.

   1) In case single direction actuators are used, then only one component of the ground motions is required; and
   2) In Dynamic Tests, where the shake table has:

      i) unidirectional capability, only one component of ground motions is required, and
      ii) bi-directional or tri-directional capability, two or three components, respectively, of the ground motions shall be used.

5.4.3.3 *Requirements for individual tests*

a) *Material Tests*

1) These tests can be performed as monotonic loading tests, unidirectional cyclic or reversed cyclic loading. In all cases, the strain rate of loading shall not exceed 10 micro-strain/s.
2) In unidirectional cyclic or reversed cyclic loading, the loading history shall be as specified in Fig. 2.

b) *Member, Sub-assemblage and System Tests*

1) These tests are usually performed as reversed cyclic or random loading.
2) In reversed cyclic loading,

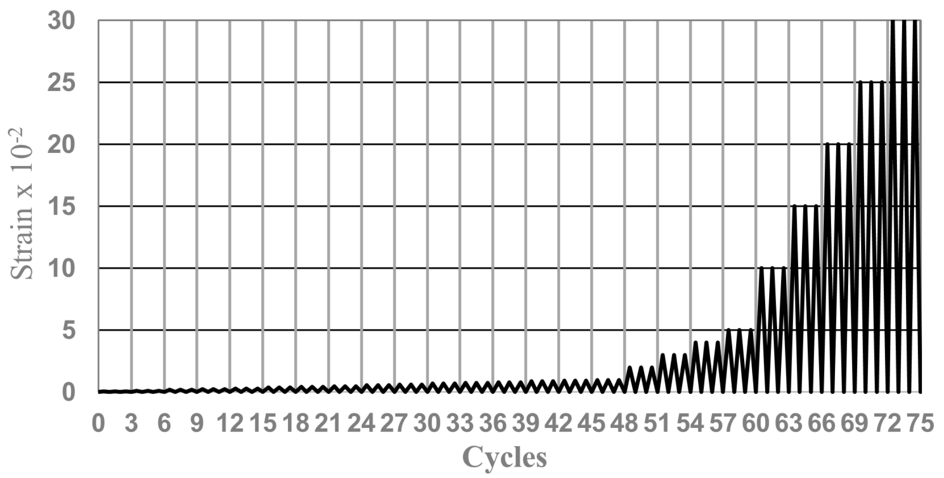
   i) the loading history shall be as specified in Fig. 3, with displacement applied in relatively small excursions, with at least three repetitive cycles at each displacement excursions, and
   ii) the rate of displacement loading shall not exceed 1.0 mm/s.

3) In random loading,

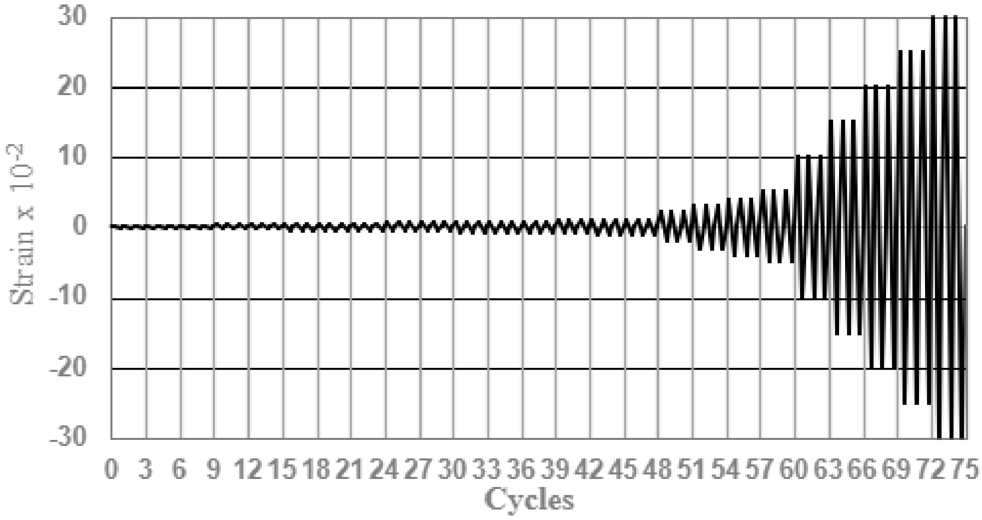
   i) the loading history shall reflect the earthquake shaking depending the focus of the study – it can be either near-fault or far-fault earthquake motion, and
   ii) the strain rate of loading shall be subject to the laws of dynamic similitude mentioned in **5.3.3**(b) especially if the specimen is of reduced scale.

c) *Energy Dissipation Device Tests*

1) These tests are usually performed as reversed cyclic tests.
2) The loading history and the strain rate of loading shall be as specified in the standard approving the use of the energy dissipation device being studied.

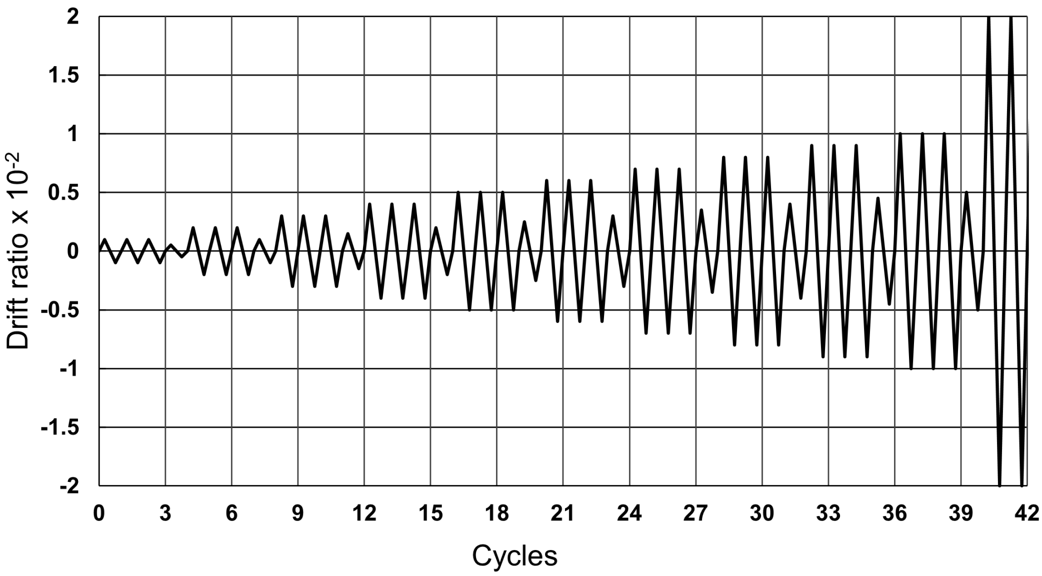


2A UNIDIRECTIONAL CYCLIC

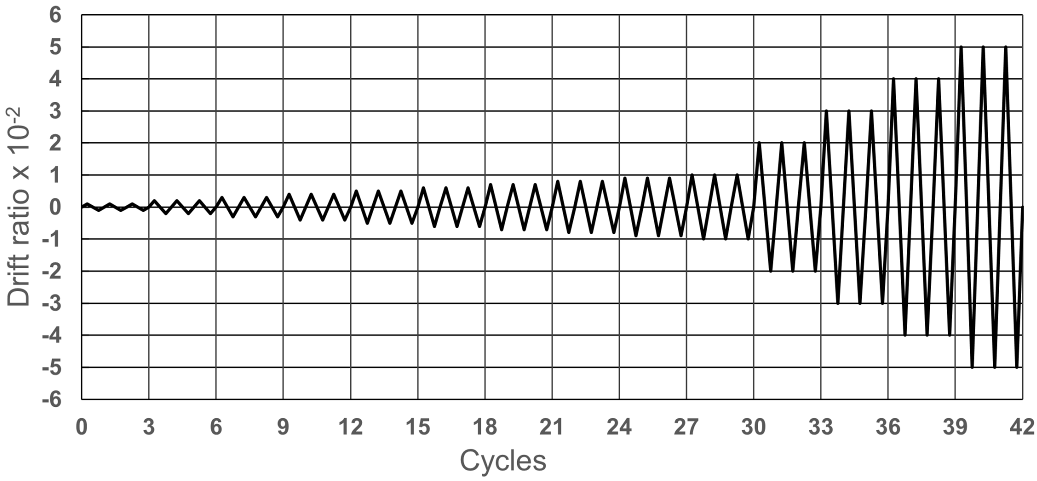


2B REVERSED CYCLIC TESTING OF MATERIALS

FIG. 2 STRAIN-BASED HISTORY



3A CONCRETE, BOLTED STEEL AND MASONRY STRUCTURES



3B WELDED STRUCTURES

FIG. 3 CYCLIC DISPLACEMENT HISTORIES TO IMPART FAR-FAULT GROUND SHAKING IN THE STRUCTURE IN MEMBER, SUB-ASSEMBLAGE AND SYSTEM TESTS

5.5 Sensors

5.5.1 The sensors used for measurement should be:

a) robust for repeated field and laboratory use,
b) sacrificial for temporary measurement, may become non-functional after the test,
c) connected to a data acquisition system, and
d) have suitable range with high resolution, which is based on the analytical study performed before the test as mentioned in **1.4**.

5.5.2 The response of the specimen should be collected by suitable sensor based on the objectives of the test, namely:

a) accelerometers to capture acceleration history,
b) velocity meters to capture velocity history,
c) displacement meters to capture displacement history, and
d) strain rosettes to capture strains on select surfaces of the specimen.

The range, resolution and sensitivity of these sensors shall be determined based on the type of test and the expected responses of the specimen. Also, photographs and video footage should be collected during the test.

5.6 Data Acquisition

The data acquisition system should have an analog to digital converter, a processor to capture the digital data and save it on a memory device, and the memory device to store the information collected. The digital data from:

a) the actuators employed to apply the strain or deformation history on the specimen, and
b) the sensors employed to capture the responses of the specimen,

should be collected at a specified sampling rate, which depends on the dynamic characteristics of the specimen.

6 FIELD TESTS

Generally, these tests shall be performed on existing structures as well as laboratory specimens.

6.1 Ambient Vibration Test

The response of the structure to the ambient vibrations of the ground on which it rests, and to the forces induced by the different functional equipment operating on it at different elevations, shall be considered sufficient to cause vibrations that can be captured. The following are the salient aspects of the test:

a) *Test-Setup*

This involves the structure being studied, and sensors placed at locations where the desired response can be collected (*see* Fig. 4).

b) *Sensors*

Motion sensors, either acceleration or velocity, with adequate sensitivity shall be employed to capture the structural responses arising out of ambient excitations.

c) *Test Outcomes*

The outcomes of the test are the following dynamic characteristics of the structure:

1) Natural periods of the dominant modes of oscillations,
2) Mode shapes associated with natural periods of the dominant modes of oscillations, and
3) Damping ratio associated with the dominant modes of oscillations.

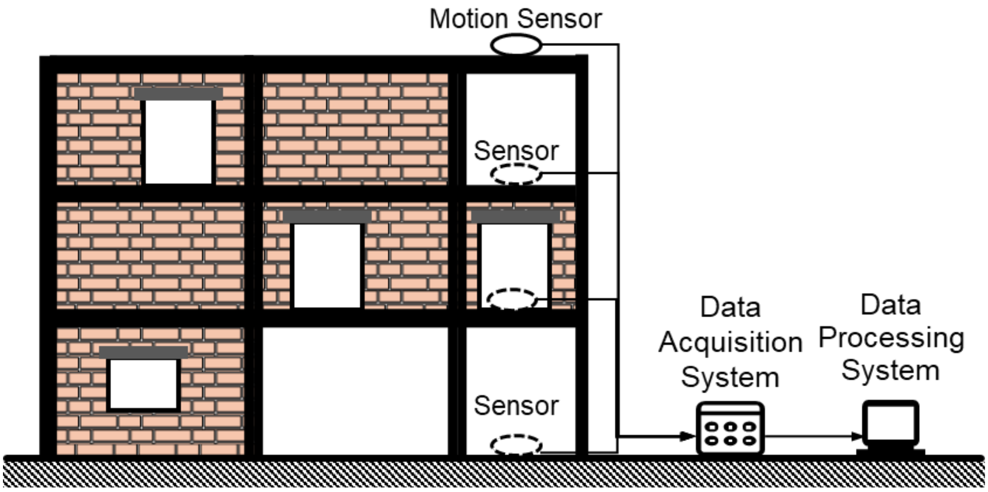


FIG. 4 AMBIENT VIBRATION TEST

6.2 Forced Vibration Test

The response of the structure shall be enhanced above its ambient vibrations using a frequency-based force shaker with a controller having a feedback mechanism.

The following are the salient aspects of the test:

a) *Test-Setup*

This involves the structure being studied, and sensors placed at locations where the desired response can be collected (*see* Fig. 5).

b) *Loading Devices*

The following shall be the requirements of the loading device:

1) Single or multiple loading devices (electrodynamic linear shaker or mechanical eccentric mass shaker) may be used to shake the structure at frequencies ranges corresponding to the dominant modes of oscillation of the structure.
2) Unless justified by adequate theoretical analysis or previous tests, the force induced by the shaking device shall not be more than 0.1 percent of the weight of the structure, such that the induced low magnitude vibration does not cause any local or global damage
3) The location of the loading devices shall be ascertained based on the behaviour of the analysis model.
4) The loading device(s) shall be operated through a feedback loop controller, such that the response of the structure to the vibrations of the shaker does not affect the shaker in return.

c) *Sensors*

Even though a forcing device is used to oscillate the structure, the response is relatively small, and hence motion sensors with adequate sensitivity, measurement range, and broadband resolution may be considered to capture the structural responses arising out of forced excitations. The sensors can be:

1) uniaxial, biaxial or triaxial, based on the requirement and analytical investigation, and
2) placed in locations, based on the analytical results, to capture the desired structural response.

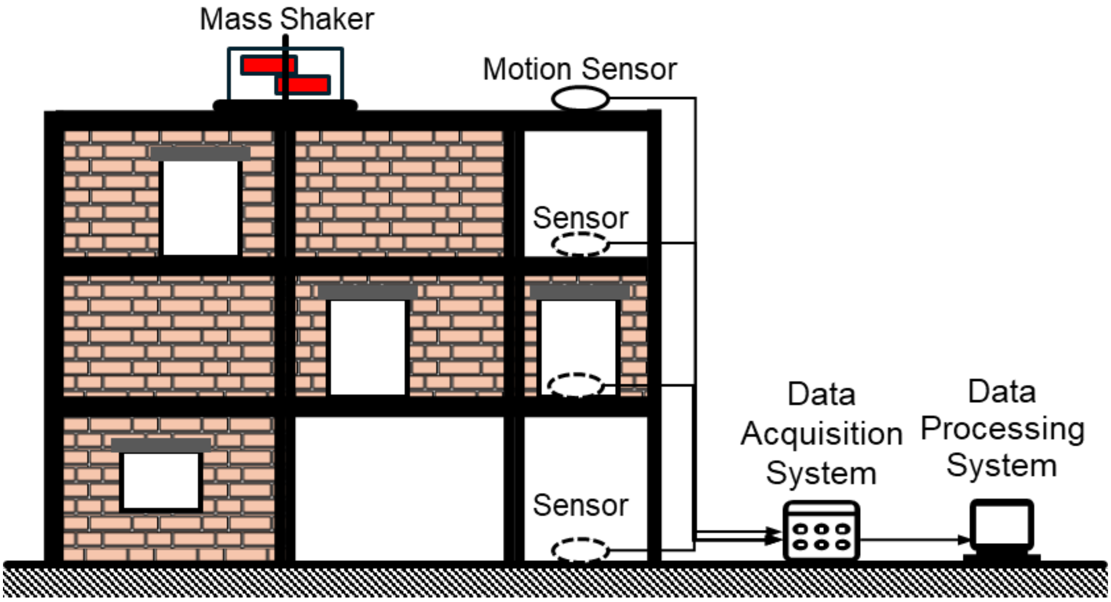


FIG. 5 FORCED VIBRATION TEST

d) *Loading Protocol*

The loading shall be monotonic or reversed cyclic as per the requirements specified in **5.4.3.3**(a) for material tests.

e) *Test Outcomes*

The response of the structure to the frequency sweep around the dominant natural frequencies shall be recorded as the frequency-response behaviour. The following dynamic characteristics of the structure shall be derived from its frequency-response behaviour:

1) natural periods of the dominant modes of oscillations,
2) mode shapes corresponding to identified natural periods, and
3) damping ratio associated with the dominant modes of oscillations.

7 LABORATORY TESTS

The earthquake related tests conducted on members, sub-assemblages and structures at material- and system-level shall comply with the requirements specified hereunder.

7.1 Material Test

The tests associated with the material of test specimen shall be performed as per the relevant Indian standard, with the caveat of employing stain-controlled loading to capture till failure the post-peak performance stress-strain behaviour of the material. As a minimum, monotonic stress-strain properties of material shall be determined before earthquake testing, as specified in **7.2**, **7.3** and **7.4**. The following are the salient aspects of the test:

a) *Specimen and Test-Bed*

The specimen shall be prepared as per the relevant Indian standard addressing the specific test in focus related to the material. The test-bed involves the standard specimen material whose characteristics are being extracted, the loading device and sensors placed at locations where the desired response can be collected.

b) *Loading Devices*

The following are the requirements of the loading device:

1) a universal testing machine (UTM) with capability to apply both compression and tension strains on the standard material test specimen,
2) the displacement to be imposed and force to be induced by the UTM shall be estimated a priori, considering the maximum strength of the material, and the UTM chosen accordingly, and
3) The UTM shall be operated through a feedback loop controller, such that the strain response of the material test specimen shall be maintained steadily even when the material has gone past it peak strength.

c) *Sensors*

The sensors shall be:

1) Extensometers and strain gauges to measure strains imposed in the specimen, and
2) Load cells to measure the loads induced in the specimen.

d) *Loading Protocol*

The loading shall be monotonic or reversed cyclic as per the requirements specified in **5.4.3.3**(a) for material tests.

e) *Test Outcomes*

The expected outcomes of the material test are listed in Table 1 for member, sub-assemblage, and structure tests. All efforts should be made to capture these typical characteristics.

7.2 Quasi-Static Test

These tests can be performed on members, sub-assemblages, structures or energy dissipation devices that can be handled in the laboratory. The following are the salient aspects of the quasi-static test:

a) *Specimen and Test-Bed*

The specimen can be of full scale or reduced scale. When employed, a reduced-scale specimen must accurately represent the strength and deformation characteristic of the corresponding real structure in keeping with the laws of dynamic similitude mentioned in **5.3.3**(b). The test-bed involves the specimen whose overall structural characteristics are being extracted, the loading devices placed at locations where the desired displacement is required to be imposed on the specimen, and sensors at locations where the responses are intended to be collected (Fig. 6).

The test set-up shall be desired to meet the specific intent. For instance:

1) if the frame action is being studied with emphasis on beam column, then the specimen can be a T-joint or L-joint [Fig. 6(a)],
2) if the relative behaviour of beams and columns are being examined, then the specimen can be a single-storey portal frame [Fig. 6(b)], and
3) if the behaviour of all joints within a storey are being examined, then the specimen can be a three-storey building sub-system [Fig. 6(c) and Fig. 6(d)].

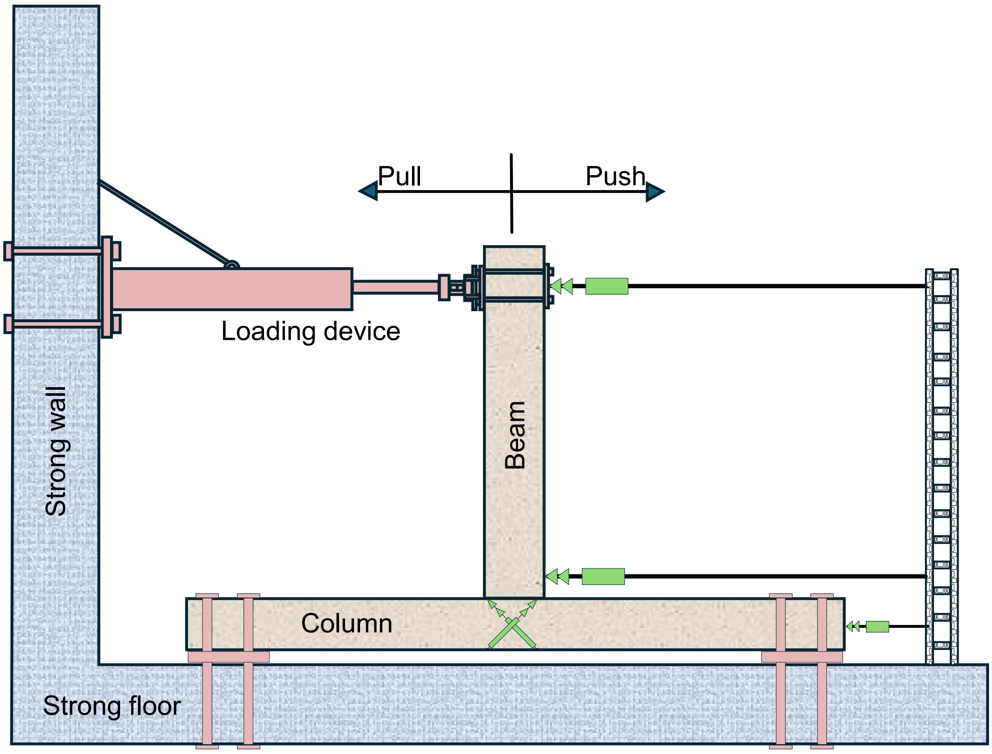
In addition, special attention should be paid to the preparation of the arrangement for holding the specimen with the loading devices to facilitate cyclic loading actions. The boundary conditions of the specimen should not be altered to jeopardize the intent of the test, by improperly holding the specimen at incorrect locations by either the loading devices or the support fixtures. For instance,

1) with respect to Fig. 6(a), the length of the beam and column stub should be such that the flexural actions are permitted by the available free lengths of the beam column stubs; spurious end effects arising from short shear stubs are not generated;
2) with respect to Fig. 6(b), the loading device should be anchored to the slab, but not to the beam-column joint or the middle of the beam; and
3) with respect to Fig. 6(c), the loading device should be anchored to the slab at the top of the third storey and the specimen should be held at the bottom of the bottom storey to leave the middle storey entirely free to transfer the forces through the joints and members, with no device or support restricting its free deformation.

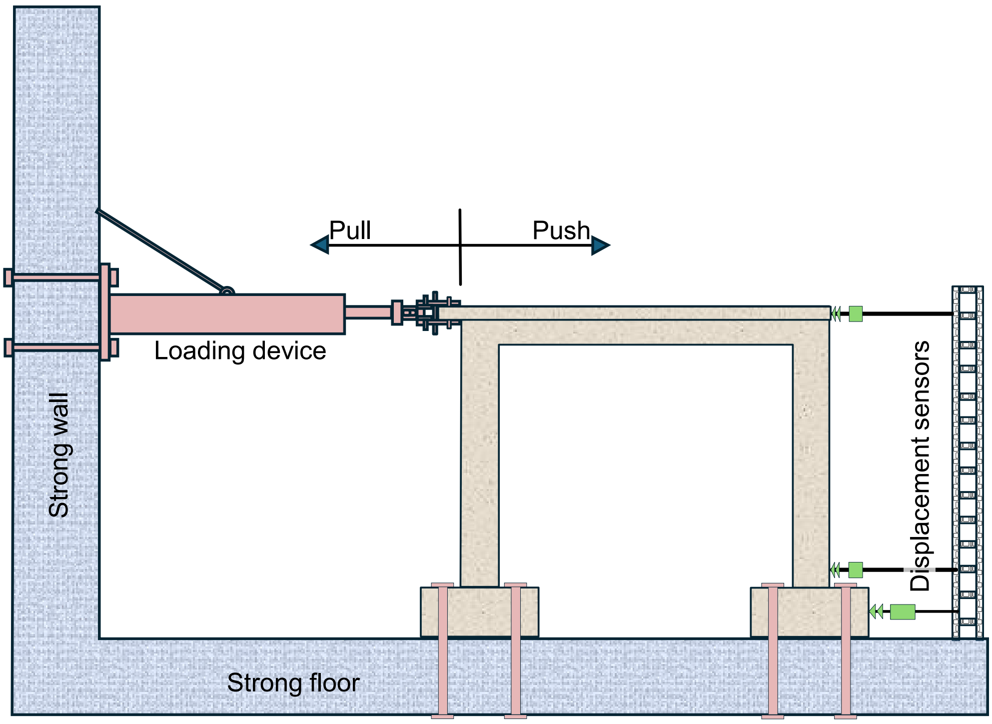
Also, the loading arrangement shall comply with the following requirements:

1) The test bench, reaction wall, and reaction frame shall be sufficiently rigidity to withstand reaction force without too much deformation, and itself remain stable throughout the test; and

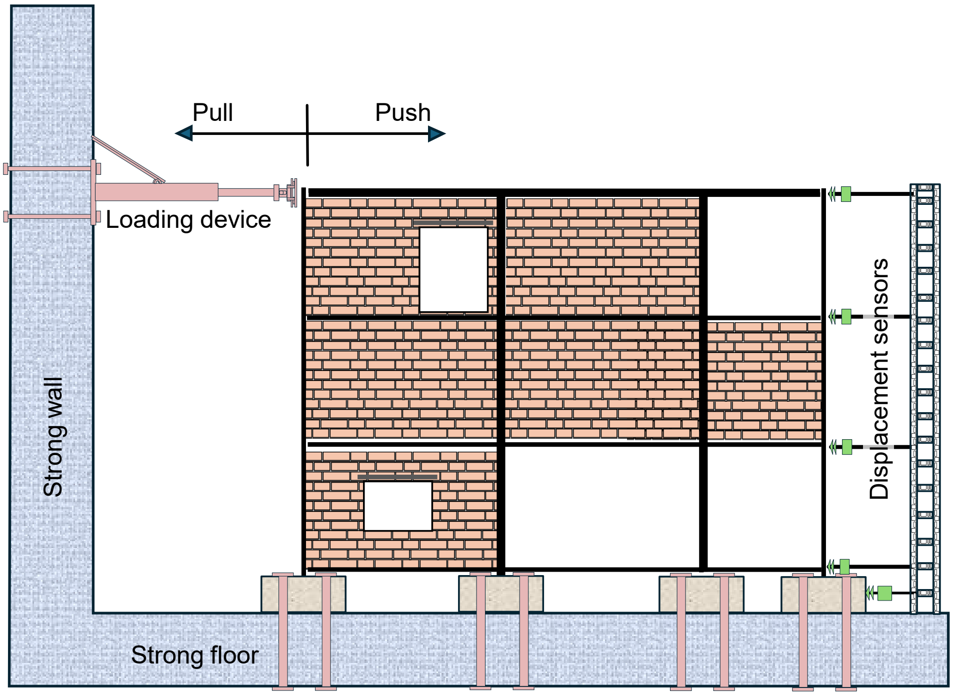
2) The deformation should be limited of the specimen in the direction normal to the direction along which the loading devices are active, especially when the specimen is planar and the loading is in its plane.



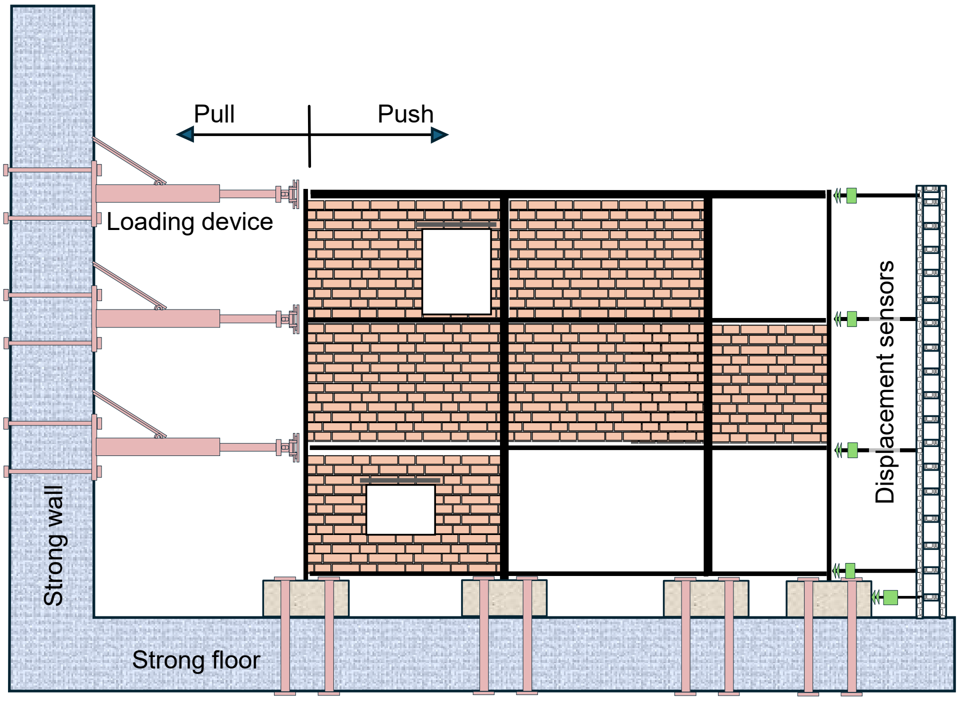
6A TEST ON A T-JOINT OF A BEAM-COLUMN JOINT



6B TEST ON A SINGLE-STOREY PORTAL FRAME



6C TEST ON A THREE-STOREY BUILDING SUB-SYSTEM WITH LOADING AT TOP LEVEL



6D TEST ON A THREE-STOREY BUILDING SUB-SYSTEM WITH LOADING AT ALL LEVELS

FIG. 6 TEST SET-UPS OF A TYPICAL QUASI-STATIC TEST

b) *Loading Devices*

The details of loading type and loading devices shall be considered as per **5.4.1** and **5.4.2**, respectively.

Also, additional cautions may be exercised in following situations as per objectives of the test:

1) When one or more actuators are required to be employed,

    i) the capacity of the hydraulic power supply should be verified to provide hydraulic fluid at the flow rate required by all the actuators performing together,
    ii) the need for making the actuators act in tandem may be examined, and when needed, appropriate programming of the controller may be undertaken; and

2) When gravity loads need to be imposed on the specimen, use of kentledges or vertically oriented force-controlled jacks may be employed; in these cases, due attention shall be paid to stability of these loads and jacks.

c) *Sensors*

The sensors shall include one or a combination of the following type as per the test objectives:

1) Contact (for example, linearly varying displacement transducers (LVDTs) and wire potentiometer) and non-contact sensors (for example, laser sensors and ultrasonic sensors) to capture displacements with respect to a reference axis,
2) Strain gauges to capture strains at different locations in the members,
3) Gauges to measure the widths of cracks, and
4) High speed camera with image processing system.

d) *Loading Protocol*

The loading history and loading rate shall be considered as specified in **5.4.3**.

Further, a pre-load test should be performed with low amplitude strain or displacement input to:

1) ascertain the initial elastic characteristics of the specimen, and
2) ascertain the efficacy of loading device(s).

e) *Test Outcomes*

The expected outcomes of the quasi-static test are listed in Table 1 for member, sub-assemblage, structure or energy dissipation device tests. All efforts should be made to capture these typical characteristics.

7.3 Pseudo-Dynamic Test

These tests can be performed on sub-assemblage and structural systems with mass that can be handled in the laboratory. The specialty of this test is its hybrid nature – it is an analytical computation of the behaviour of the structure with the stiffness characteristics alone being extracted from the physical test on a specimen in the laboratory. The following are the salient aspects of the pseudo-dynamic test:

a) *Specimen and Test-Bed*

The specimen can be of full scale or reduced scale. When employed, a reduced-scale specimen should accurately represent the strength and deformation characteristic of the corresponding real structure in keeping with the laws of dynamic similitude mentioned in **5.3.3**(b).

The test-bed involves the specimen whose overall structural stiffness characteristics are being extracted (measured) from the physical test, inertia and damping forces estimated analytically on a computer, the loading devices placed at locations where the desired displacement is required to be imposed on the specimen, the said computer interfaces with the loading devices, and sensors at locations where the responses are intended to be collected (Fig. 7).

b) *Loading Devices*

The details of loading type and loading devices shall be considered as per **5.4.1** and **5.4.2**, respectively.

Also, additional cautions may be exercised in following situations as per objectives of the test:

1) When one or more actuators are required to be employed,

   (i) the capacity of the hydraulic power supply should be verified to provide hydraulic fluid at the flow rate required by all the actuators performing together,
   (ii) the need for making the actuators act in tandem may be examined, and when needed, appropriate programming of the controller may be undertaken; and
2) When gravity loads need to be imposed on the specimen, use of kentledges or vertically oriented force-controlled jacks may be employed; in these cases, due attention shall be paid to stability of these loads and jacks.

c) *Sensors*

The sensors shall include one or a combination of the following type as per the test objectives:

1) Accelerometers at different mass levels,

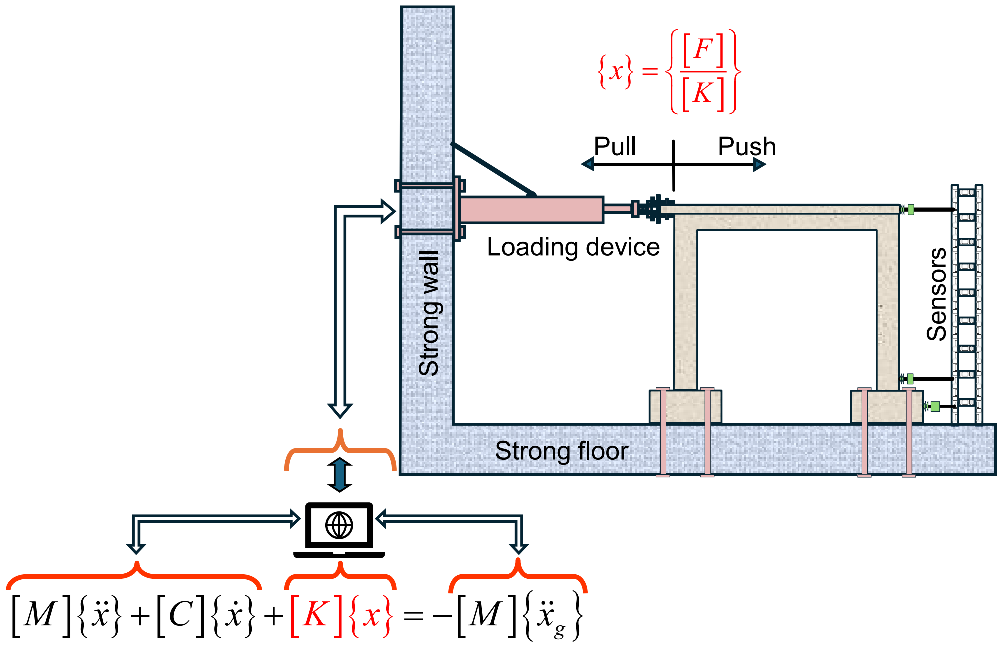
2) Contact (for example, linearly varying displacement transducers (LVDTs) and wire potentiometer) and non-contact sensors (for example, laser sensors and ultrasonic sensors) to capture displacements with respect to a reference axis,
3) Strain gauges to capture strains at different locations in the members,
4) Gauges to measure the widths of cracks, and
5) High speed camera with image processing system.

d) *Loading Protocol*

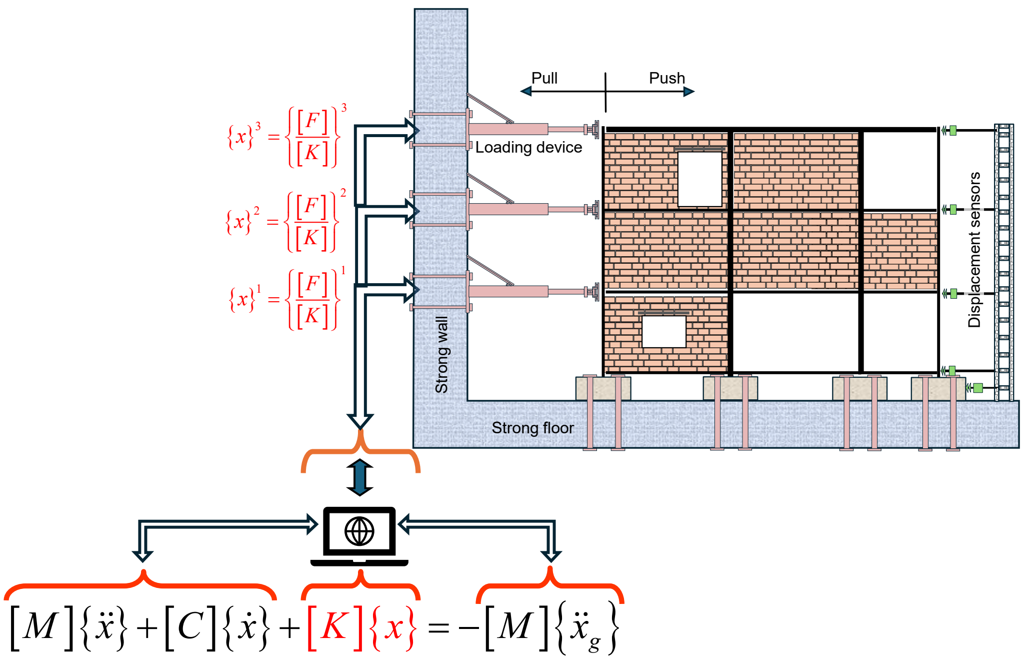
The acceleration history required to be used in the analytical calculation of inertial forces shall be taken as per the loading protocol specified in **5.4.1**(c) for laboratory specimen. The loading history and loading rate shall be considered as specified in **5.4.3**.

e) *Test Outcomes*

The expected outcomes of the pseudo-dynamic test are listed in Table 1 for sub-assemblages and structure tests. All efforts should be made to capture these typical characteristics.



7A TEST ON A SINGLE-STOREY BUILDING WITH SCALED MASS PLACED ON THE ROOF SLAB AND SINGLE ACTUATORS



7B TEST ON A THREE-STOREY BUILDING SYSTEM WITH SCALED MASSES PLACED ON THE FLOOR AND ROOF SLABS AND MULTIPLE ACTUATORS

FIG. 7 SCHEMATIC OF TEST SET-UPS OF A TYPICAL PSEUDO-DYNAMIC TEST

7.4 Dynamic Test

These tests can be performed on full structures with mass that can be handled on the shake table. The specialty of this test is that it is a true dynamic test with all actions occurring in the structure as they would during an earthquake. The following are the salient aspects of the dynamic test:

a) *Specimen and Test-Bed*

The specimen can be of full scale or reduced scale. When employed, a reduced-scale specimen should accurately represent the mass, strength and deformation characteristics of the corresponding real structure in keeping with the laws of dynamic similitude mentioned in **5.3.3**(b).

The test-bed involves the specimen which is anchored on a stiff shake table, the loading devices under the table apply the pre-determined earthquake ground shaking at the base of the specimen reflecting the earthquake ground motion recorded in a tectonic region of interest, a computer that interfaces with the loading devices, and sensors at locations where the responses are intended to be collected (Fig. 8).

b) *Loading Devices*

The details of loading type and loading devices shall be considered as per **5.4.1** and **5.4.2**, respectively. The actuators used under the shake table shall have sufficient force and displacement capacities to resist the amplified response of the structure and to induce inelastic actions in the specimen.

c) *Sensors*

The sensors shall include one or a combination of the following type as per the test objectives:

1) Accelerometers at the different mass levels,
2) Contact (for example, linearly varying displacement transducers (LVDTs) and wire potentiometer) and non-contact sensors (for example, laser sensors and ultrasonic sensors) to capture displacements with respect to a reference axis,
3) Strain gauges to capture strains at different locations in the members,
4) Gauges to measure the widths of cracks, and
5) High speed camera with image processing system.

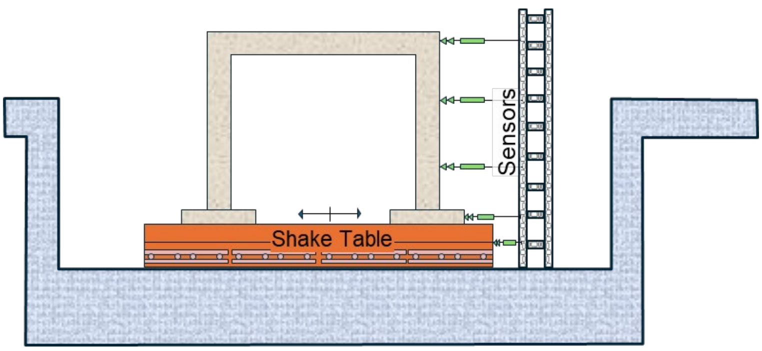
d) *Loading Protocol*

The acceleration history of real ground shaking required to be used as input at the base of the structure taken as per the loading protocol specified in **5.4.1**(c) for laboratory specimen. The loading history and loading rate shall be considered as specified in **5.4.3**.

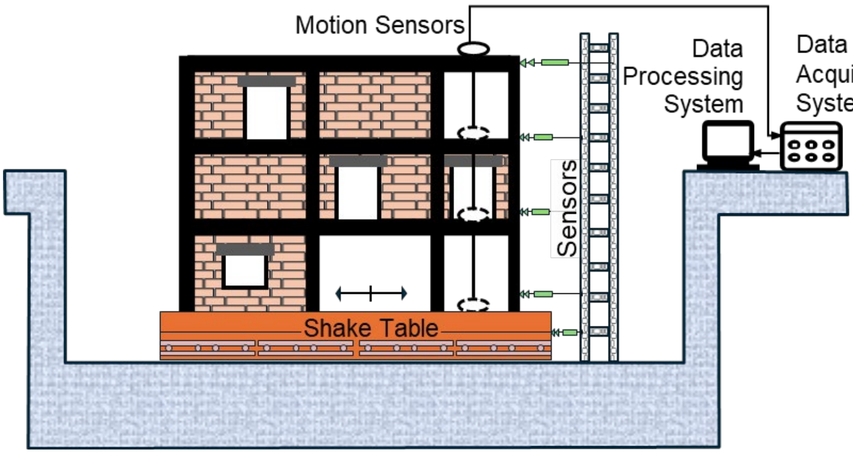
If required, synthetic ground motions aligning the amplitude and frequency content of potential near- and far-field ground motions in the region shall be considered. The input history shall be designed to satisfy the displacement, velocity, acceleration, and frequency limits of the shake table.

e) *Test Outcomes*

The expected outcomes of the dynamic test are listed in Table 1 for structure tests. All efforts should be made to capture these typical characteristics.



8A A SINGLE-STOREY BUILDING WITH SCALED MASS PLACED ON THE ROOF SLAB AND SINGLE ACTUATORS



8B A THREE-STOREY BUILDING SYSTEM WITH SCALED MASSES PLACED ON THE FLOOR AND ROOF SLABS

FIG. 8 TEST SET-UP OF A TYPICAL DYNAMIC TEST ON SHAKE TABLE

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ANNEX A
(*Clause* 2)

LIST OF REFERRED STANDARDS

IS No.	*Title*
IS 1893	Design earthquake hazard and criteria for earthquake-resistant design of structures — Code of practice
(Part 1) : 2025	General Provisions (*under publication*)
(Part 2) : 2025	Liquid-retaining structures (*under preparation*)
(Part 3) : 2025	Bridges (*under preparation*)
(Part 4) : 2025	Industrial structures (*under preparation*)
(Part 5) : 2025	Buildings (*under publication*)
(Part 6) : 2025	Base-isolated buildings (*under preparation*)
(Part 7) : 2025	Long-distance pipelines (*under preparation*)
(Part 8) : 2025	Dams (*under preparation*)
(Part 9) : XXXX	Steel towers (*under preparation*)
(Part 10) : XXXX	Costal structures (*under preparation*)
(Part 11) : XXXX	Tunnels (*under preparation*)
(Part 12) : XXXX	Earth-retaining structures (*under preparation*)
IS 13920	Earthquake-resistant design and detailing of structures — Code of practice
(Part 1) : 2025	General provisions (*under publication*)
(Part 2) : XXXX	Liquid-retaining structures (*under preparation*)
(Part 3) : XXXX	Bridges (*under preparation*)
(Part 4) : XXXX	Industrial structures (*under preparation*)
(Part 5) : 2025	Buildings (*under publication*)
(Part 6) : XXXX	Base-isolated buildings (*under preparation*)
(Part 7) : XXXX	Long-distance pipelines (*under preparation*)
(Part 8) : XXXX	Dams (*under preparation*)
(Part 9) : XXXX	Steel towers (*under preparation*)
(Part 10) : XXXX	Costal structures (*under preparation*)
(Part 11) : XXXX	Tunnels (*under preparation*)
(Part 12) : XXXX	Earth-retaining structures (*under preparation*)
IS 13935	Assessment and retrofit of structures for earthquake safety — Code of practice
(Part 1) : 2025	General provisions (*under preparation*)
(Part 2) : XXXX	Liquid-retaining structures (*under preparation*)
(Part 3) : XXXX	Bridges (*under preparation*)

IS No.	*Title*
(Part 4) : XXXX	Industrial structures (*under preparation*)
(Part 5) : 2025	Buildings (*under preparation*)
(Part 6) : XXXX	Base-isolated buildings (*under preparation*)
(Part 7) : XXXX	Long-distance pipelines (*under preparation*)
(Part 8) : XXXX	Dams (*under preparation*)
(Part 9) : XXXX	Steel towers (*under preparation*)
(Part 10) : XXXX	Costal structures (*under preparation*)
(Part 11) : XXXX	Tunnels (*under preparation*)
(Part 12) : XXXX	Earth-retaining structures (*under preparation*)