INTERNATIONAL STANDARD

ISO 4866

First edition
1990-08-01

AMENDMENT 1
1994-12-01

Mechanical vibration and shock — Vibration of buildings — Guidelines for the measurement of vibrations and evaluation of their effects on buildings

AMENDMENT 1

Vibrations et chocs mécaniques — Vibrations des bâtiments — Lignes directrices pour le mesurage des vibrations et évaluation de leurs effets sur les bâtiments

AMENDEMENT 1

Reference number
ISO 4866:1990/Amd.1:1994(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Amendment 1 to ISO 4866:1990 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures.*

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Mechanical vibration and shock — Vibration of buildings — Guidelines for the measurement of vibrations and evaluation of their effects on buildings

AMENDMENT 1

Page iii

Change the last sentence to: "Annexes A to E of this International Standard are for information only."

Page 17

Add the following annex as annex D and change the present annex D to annex E.

Page 18

Add references [24] to [38] to annex E.

Annex D

(informative)

Predicting natural frequencies and damping of buildings

Introduction

ISO 4866:1990 specifies methods of measuring building response including fundamental natural frequencies. When direct measurements cannot be made or are limited in usefulness by high damping, sub-component resonances or other practical problems, it becomes necessary to estimate natural frequency and damping values.

This annex offers guidance on the ways in which the fundamental natural frequency and associated damping value may be assessed. It draws attention to the uncertainties involved which should be taken into account wherever an estimation of fundamental natural frequencies of a building is used in measuring or evaluation procedures.

D.1 Predicting natural frequencies of tall buildings using empirical methods

There are many empirical formulae for predicting the frequency f, or period T, of the fundamental translation mode; of these the simplest is $f = 10/N$ Hz (i.e. $T = 0{,}1N$ s), where N is the number of storeys. Various other formulae are given in the codes of different countries and these can be grouped into three categories:

$$T = k_1 H \qquad \text{... D.1}$$

where

H is the height, in metres;

T is the period, in seconds;

k_1 ranges from 0,14 sm^{-1} to 0,03 sm^{-1}

(references [24] to [27]).

$$T = k_2 H \sqrt{D} \qquad \text{... D.2}$$

where

D is the width parallel to the force, in metres;

k_2 ranges from 0,087 $\text{sm}^{-3/2}$ to 0,109 $\text{sm}^{-3/2}$

(references [25] and [28]).

$$T = k_3 H \sqrt{D}\ \text{func}(H,D,I) \qquad \text{... D.3}$$

(see, for example, reference [29]).

NOTE 1 k_1 has the units sm^{-1}; k_2 has the units $\text{sm}^{-3/2}$.

A later study [30], considering a sample of 163 rectangular-plan buildings, recommended $f = 46/H$ Hz·m (i.e. $T = 0{,}022H$ sm^{-1}) for the fundamental translation mode, $f = 58/H$ Hz·m for the orthogonal fundamental translation mode and $f = 72/H$ Hz·m for the fundamental torsional mode (sample size of 63 buildings).

NOTE 2 These formulae for f are empirical. They may also be considered as numerical value equations yielding values of f in hertz when values of H in metres are inserted, for instance $f = 46/H$.

Figure D.1 shows the resulting fit of the curve $f = 46/H$ Hz·m to the data and it can be appreciated that large errors are likely to be encountered. It can be seen that errors of ± 50 % are not uncommon, and this is typical of the accuracy which can be expected using empirical formulae. Based on measured data, it appears that the mode shapes of the fundamental modes of tall buildings can be reasonably approximated by straight lines.

D.2 Predicting natural frequencies of tall buildings using computer-based methods

It has long been realised that comparatively large errors are likely to occur using the simple empirical formulae, but it has also been generally accepted that a satisfactory estimate of frequency can be obtained using one of the standard computer-based methods. However, buildings are complicated structures and it is not a simple task to create an accurate mathematical model; consequently it must be accepted that these models will only provide approximate predictions. In a study [30] examining published evidence, the correlation between computed frequencies and measured frequencies was actually considerably worse than the correlation between the frequencies predicted using $f = 46/H$ Hz·m and the measured values. This discrepancy can be attributed to inadequacies in modelling the real properties of buildings. Predictions of fundamental frequencies should therefore be treated with caution.

Special methods have been developed for analysis of core buildings [31], shear buildings [32] and sway frame and frame buildings [33], but with any method it is important to check whether the method has been calibrated using a range of reliable experimental data and to understand what errors are likely to be encountered. If the method has not been proven, then accuracies greater than those obtained for empirical predictors should not be assumed. Only the fundamental frequencies have been discussed, but the predicted frequencies of higher frequency modes will suffer from similar or (more probably) greater errors. This means that, except for special cases where the mathematical model has been tuned to experimental results, predictions involving many calculated modes must be regarded as unreliable.

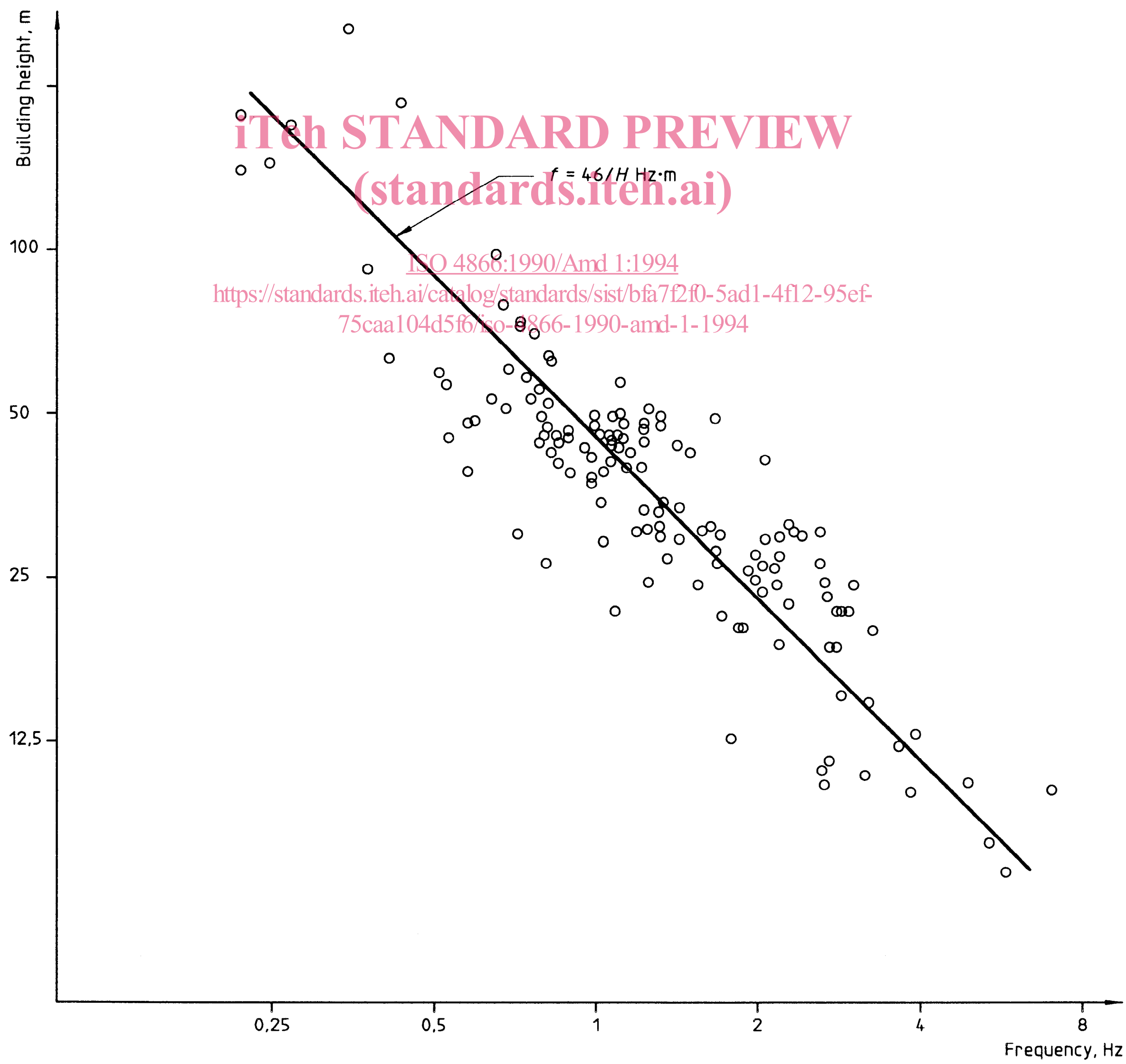

Figure D.1 — Plot of height versus fundamental frequency for 163 rectangular-plan buildings using logarithmic scales

D.3 Predicting damping values of tall buildings

The damping (or rate of energy dissipation) in any one mode limits the motion in that mode, and consequently to estimate the building response to a given load it is necessary to estimate or measure the amount of damping. No proven methods of predicting damping exist and the measured data show that damping values between 0,5 % and 2,1 % critical can occur (see figure D.2). Higher values may also be encountered in buildings where soil/structure interaction is significant. Simple steel frames are likely to have much lower damping. Methods of predicting damping have been developed (see refs. [34] and [35]) but, again, the expected accuracy is not quoted.

Figure D.2 shows a plot of damping versus building height for a selected sample of buildings [36]. It can be seen that large differences in damping can be obtained for orthogonal translation modes of the same building. Damping is partly a function of construction procedures and workmanship involved and cannot be predicted accurately. Consequently, large errors in estimation must be anticipated.

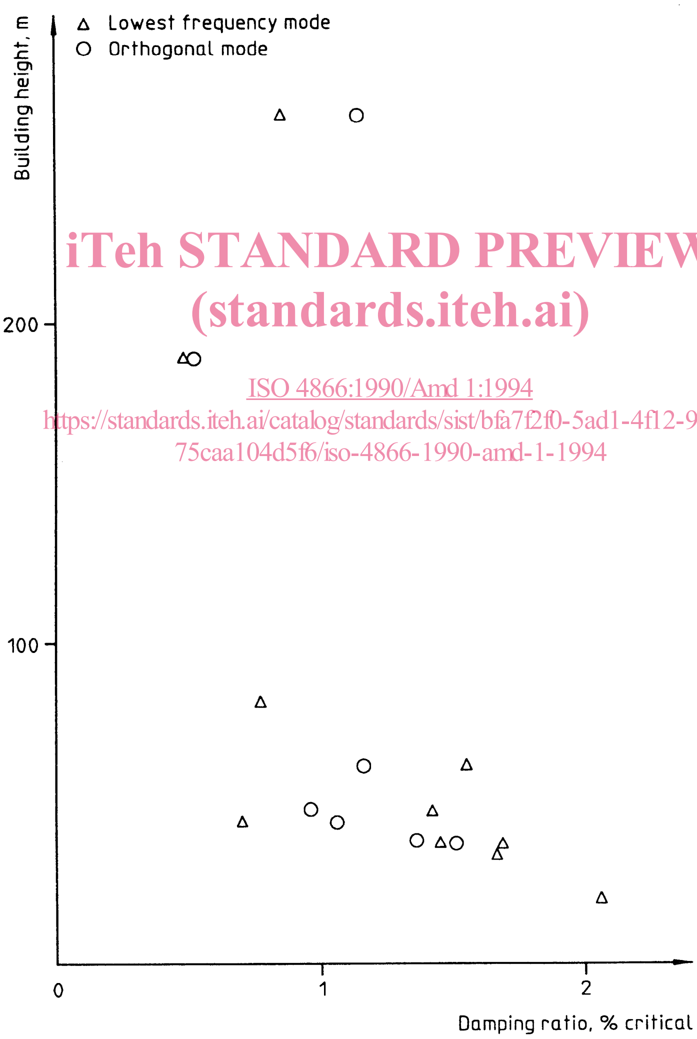

Figure D.2 — Building height versus damping ratio for the fundamental translation modes of 10 buildings where soil/structure interaction was negligible (from decay measurement)

D.4 Natural frequencies and damping values in low-rise buildings

The characteristics of 96 low-rise buildings are presented in references [37] and [38]. The buildings were located in the USA and are described as 1, 1½ and 2 storey buildings with basements, partial basements or crawl spaces. The data show that the average measured frequency decreases with building height.

Figure D.3 shows a histogram relating the number of buildings to their measured frequencies. It is important to note the range of frequencies which is encountered and thus the error involved in using an empirical prediction. There is no obvious tendency for the frequencies to vary with the age or location of the houses, and there is no correlation of the frequencies with plan dimensions.

Figure D.4 shows a histogram relating the number of buildings to their damping ratios. This indicates generally higher damping ratios than for taller buildings and shows the range of damping values which may be encountered. No obvious relationship between damping and building geometry exists.

D.5 Non-linear behaviour

The previous clauses discuss the natural frequency and the damping of each mode and this might give the impression that these quantities are invariant. However, they do vary with amplitude of motion and for earthquake analyses this might be important (albeit difficult to quantify). In general, wind loading induces small amplitude motion (in comparison with large earthquakes) and the changes in natural frequency and damping over the range of amplitudes normally encountered is small. In one building which was subjected to forces equivalent to a range of winds from light to hurricane force, changes of 3 % in frequency and 30 % in damping were recorded [36]. It can be appreciated that these changes are perhaps not significant and can be ignored for design purposes.

D.6 Final comment

The general conclusion which can be reached from this annex is that theoretical predictions are likely to involve considerable inaccuracies. Consequently, theoretical analyses should consider these possible inaccuracies by carrying out parametric variation and, for important structures, the design calculations should be verified using experimental measurements when the structure is complete.

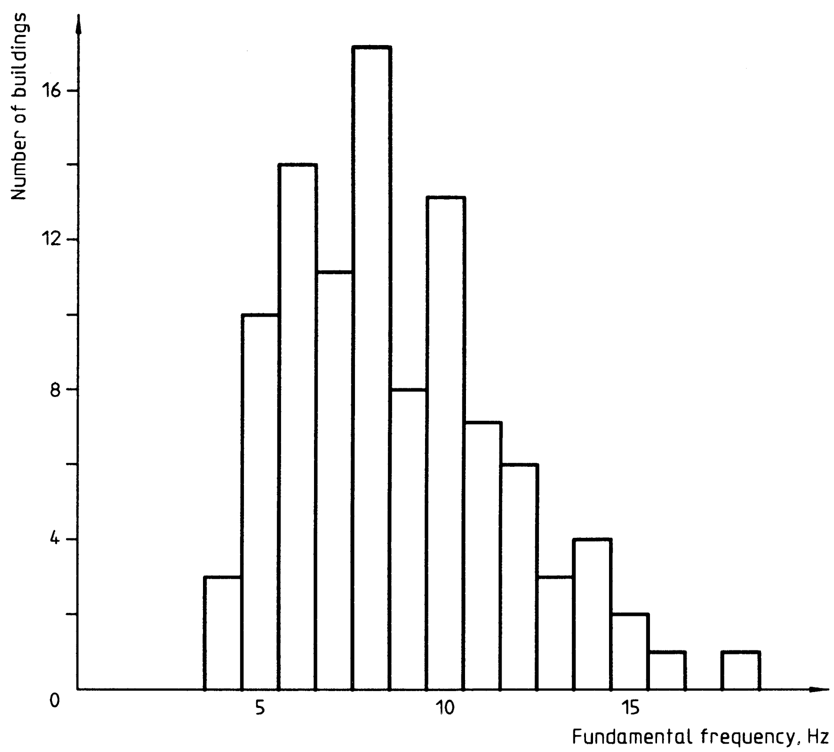

Figure D.3 — Frequencies measured in 96 low-rise buildings

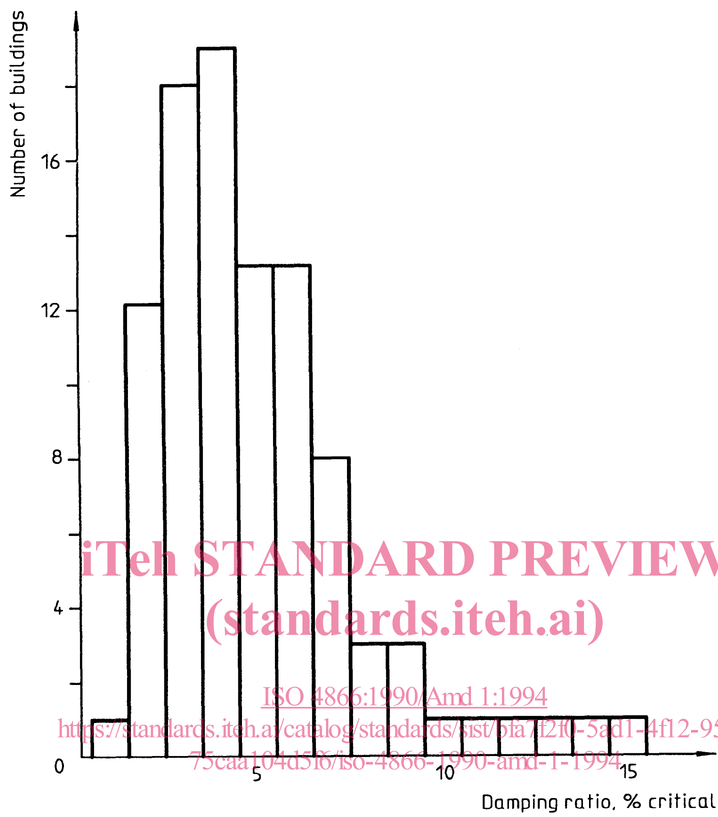

Figure D.4 — Damping ratios measured in 96 low-rise buildings

Bibliography

[24] KAWECKI, J. Empirical formulae used for calculating the natural periods of vibrations of buildings. *Czasopismo Techniczne,* **Z 7-B** (129), 1969.

[25] STEFFENS, R.J. *Structural vibration and damage.* Building Research Establishment Report, UK, 1974.

[26] BARKADZE, E.I. Problems of determining the results of instrumental measurements of natural periods of buildings. *Soobs AN Groz,* **39** (6), 1962.

[27] NAKA, T. *Structural design of tall buildings in Japan.* ASCE-IABSE Joint Committee Report: Planning and design of tall buildings, Proc. 3rd Regional Conference, Tokyo, Sept. 1971.

[28] ANDERSON, A.W. et al. Lateral forces of earth-quake and wind. *Proc. ASCE,* **77** (Separate) No. 66, 1951.

[29] *Recommendations Association Française du Génie Parasismique – 90.* Presse des Ponts et Chaussées, Paris.

[30] ELLIS, B.R. An assessment of the accuracy of predicting the fundamental natural frequencies of buildings and the implications concerning the dynamic analysis of structures. *Proc. Inst. Civ. Eng.,* **69**, Sept. 1980.

[31] ESDU 81036, *Undamped natural frequencies of core buildings.* ESDU, London, Nov. 1981.

[32] ESDU 79005, *Undamped natural vibration of shear buildings.* ESDU, London, May 1979.

[33] ESDU 82019, *Undamped natural vibrations of sway frame buildings and frame structures.* ESDU, London, Aug. 1982.

[34] ESDU 83009, *Damping of structures — Part 1: Tall buildings.* ESDU, London, May 1983.

[35] JEARY, A.P. Damping in tall buildings — A mechanism and a predictor. *Earthquake Engineering and Structural Design,* **14**, 1986.

[36] ELLIS, B.R. *Dynamic soil-structure interaction in tall buildings.* Ph.D. Thesis, University of London, 1984.

[37] MEDEARIS, K. *The development of rational damage criteria for low-rise structure subjected to blasting vibrations.* Report to National Crushed Stone Association, Washington DC, Aug. 1976.

[38] SISKIND, D.E. et al. *Structural response and damage produced by ground vibration from surface mine blasting.* US Dept. of Interior, Bureau of Mines, RI 8507, 1980.