Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 69 (1993)

Artikel: Structural serviceability of buildings

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DOI: https://doi.org/10.5169/seals-52552

Stuctural Serviceability of Buildings

Aptitude au service des bâtiments

Gebrauchstauglichkeit von Gebäuden

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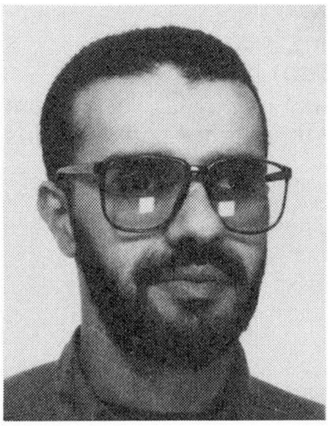

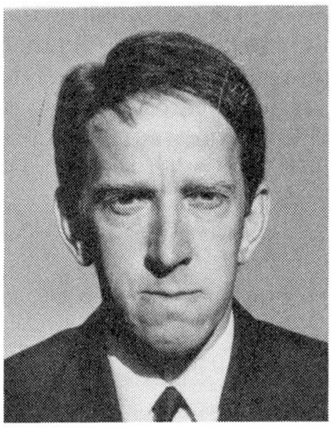

SUMMARY

The paper reports on the main findings as they relate to the provision of deflection limits for serviceability design. A review has been conducted that has shown that numerous serviceability design criteria exist but that these are spread diversely through codes, papers, journal articles, technical reports, standards, or are simply the customary practice of individual engineers.

RESUME

Cette publication présente les principaux résultats obtenus concernant les valeurs acceptables de limites de déformation pour le dimensionnement en service. Une recherche bibliographique montre qui'il y a un bon nombre de critères de dimensionnement en service qui existent déja mais ceux-ci sont diversement éparpillés dans des codes, publications, articles de journaux, rapports techniques, normes, ou sont simplement le fruit du travail d'ingénieurs isolés.

ZUSAMMENFASSUNG

Es werden die Hauptergebnisse einer Übersicht über vorhandene Vorschriften zu Durchbiegungsbeschränkungen für die Gebrauchstauglichkeit vorgestellt. Wie sich zeigte, existieren zahlreiche Kriterien, sind aber in diversen Normen oder anderen Vorschriften, technischen Berichten und Aufsätzen verstreut, sofern sie nicht bloss dem Erfahrungswissen des einzelnen Ingenieurs entspringen.

1. INTRODUCTION

Increasing adoption of limit states based approaches to the design of steel structures has tended to concentrate researcher's attentions on the need to reliably predict load levels corresponding to the attainment of the structure's ultimate static strength. Thus design is based on scientific studies that ensure a suitable margin against plastic collapse, buckling, fatigue failure etc. Although codes and specifications also call for checks at serviceability, these are usually couched in rather simple terms and little real guidance on exactly how such checks be conducted or exactly what they are intended to achieve is provided. There is thus at least the suspicion of a considerable imbalance between the qualities of design for the ultimate condition and design for the serviceability condition.

It was in recognition of this that a three-part programme of research, focusing on static deflections of steel framed buildings, funded by the European Coal and Steel Community (ECSC), was started in late 1990. It comprised of:
– Investigation of the in-service performance of steel buildings (TNO-Bouw)
– Review of existing code requirements and their basis (University of Nottingham)
– Numerical studies and consideration of design models (University of Trento).
A report [1] giving the findings of each aspect of the work has been presented to ECSC. The content of this paper is based on the code review section and is complemented by three other papers at this conference which deal with the other topics.

2. SERVICEABILITY IN CONSTRUCTION

2.1 Problems associated with excessive static deformation

In modern construction a number of problems associated with limit states related to excessive static deformation (deflection, settlements, rotation, curvature, drift etc.) can be identified. Some of the most common are:
– local damage to non-structural elements (eg. ceilings, partitions, walls, doors and windows, etc.) due to deflections caused by load, temperature variation, shrinkage or creep, and moisture changes
– deterioration of the structure by fatigue
– discomfort due to vibrations (produced by use of machines, traffic, etc.)
noticeable deflections causing distress to occupants.

An acceptable structural design must ensure that such problems are properly identified and their occurrence minimised. The use of suitable materials, properly connected components (through efficient bolting and welding), allowing for thermal expansions by providing sufficient separation between deflecting primary structural elements and non-structural components, are all factors that should be addressed.

2.2 Economic aspects

Limiting deflections to an appropriate level is also an important issue as far as economy is concerned. In a recent seminar on "Serviceability limit states for steel buildings" held in Zürich [2], Golembiewski presented a report on this matter. He showed that the limit of h/150 for the lateral deflection of hall structures due to wind, and adopted by the Swiss Steel Construction Standard SIA 161 [3], is a severe demand. A value of h/100 was suggested as being sufficient. This was based on the results of many years of experimental research undertaken in the old GDR, which showed that with this limit, damage was not to be expected. As stated by Golembiewski this difference is in fact significant, since sharpening h/100 to h/150 requires up to 15% more steel in the case of heavy roof claddings and up to 35% in the case of light-weight roof claddings.

(a) Deflection of beams due to unfactored imposed load	
Cantilevers	Length/180
Beams carrying plaster or other brittle finish	Span/360
All other beams	Span/200
(b) Horizontal deflection of columns other than portal frames due to unfactored imposed and wind loads	
Tops of columns in single-storey buildings	height/300
In each storey of a multi-storey building	height of story under consideration/300
(c) Deflection of crane gantry girders	
Vertical deflection due to static wheel load	span/600
Horizontal deflection (calculated on the top flange properties alone) due to crane surge	Span/500

Table 1 Deflection limits for certain structural members in accordance with the British BS 5950 : Part 1 [4]

Type of beam	Deflection to be considered	Deflection limit d for span L(1)	Deflection limit d for cantilever L(2)
beam supporting masonry partitions	deflection which occurs after the addition or attachment of partitions	$\delta/L \leq 1/500$ where provision is made to minimise the effect of movement, otherwise, $\delta/L \leq 1/1000$	$\delta/L \leq 1/250$ where provision is made to minimise the effect of movement, otherwise, $\delta/L \leq 1/500$
all beams	total deflection	$\delta/L \leq 1/250$	$\delta/L \leq 1/125$

Table 2a Suggested vertical deflection limits for beams (AS 4100 [5])

Notes:

(1) Suggested deflection limits in this table may not safeguard against ponding.
(2) For cantilevers, the values of δ/L given in this table apply, provided that the effect of the rotation at the support is included in the calculation of δ.

Building clad in steel or aluminium sheeting gantry cranes and without internal partitions against external walls	$\frac{1}{150}h$
building with masonry walls supported by steelwork	$\frac{1}{240}h$

Table 2b Suggested horizontal deflection limits (AS 4100 [5])

3. SERVICEABILITY LIMIT STATES IN CURRENT CODES

Design rules for serviceability may be found in the Standards of many countries. They should, as indicated above, ensure a balance between acceptable performance in service and economical considerations. A full review is available [1]; the following provide some idea of present coverage:

• The British code BS5950:Part 1:1990 [4] makes a provision for serviceability limit states design. Two types of limit states are considered: deflection and durability. For the latter, the code suggests that the following factors should be considered at the design stage:

- the environment
- the degree of exposure
- the shape of the members and the structural detailing
- the protective measure if any
- whether maintenance is possible.

Table 1 lists vertical as well as horizontal deflection limits for beams, columns, and gantry girders. In addition to the fact that this section of the code is advisory, private discussions with engineers in the UK showed that serviceability is rarely considered in design.

• The Australian code AS4100-1990 [5] gives recommendations for vertical deflection limits for beams and horizontal deflection limits for buildings -Table 2. These recommendations, like those of BS5950, are advisory and do not cover a number of serviceability aspects.
A comparison between BS5950 and AS4100 shows that for beams (in general) the deflection limit is L/200 in BS5950 and L/250 in AS4100, which represents a difference of 22% (with BS5950 being more conservative)- see Table 4.

• In the draft European EC3: 1991 code, section 4 on "Serviceability limit states" [6], a description of some serviceability requirements for steelwork is given. These cover:

- deformations and deflections which affect the appearance or effective use of the structure.
- vibration, oscillation or sway which causes discomfort to the occupants of a building or damage to its contents.
- damage to finishes or non-structural elements due to deformations, deflections, vibration, oscillation or sway.

The code, however, does not cover some important aspects of serviceability, e.g. cladding effect on lateral deflections, differential settlements etc. In addition it does not specify the load combination for a particular deflection limit. As specified in section 4.2.1 of the code, the deflection limits are empirical and should not be interpreted as performance criteria. It is worth noting that the limits specified in BS5950 agree well with those in EC3, with the latter appearing to be more specific (see Table 4).

• In 1988 the Building Research Association of New Zealand (BRANZ) published a technical report containing research work undertaken by Cooney and King [7] intended to assist structural engineers establish suitable deflection criteria, in order to ensure serviceability of buildings. The report reviews the following items:

- reasons for limiting deflections
- effect on structural elements
- effect on sensory acceptability
- effect on use
- prevention of damage to non-structural elements.

In addition, the report analysed the sensitivity of deflection components with regard to:

- section modulus
- changes in section
- component end restraint and rotation effects
- loading assumptions (distribution and intensity)
- shear distortions etc.

Reason for limiting deflections	Deflection limitations	Load combination	Examples and Comments
water accumulation (ponding) on roofs etc.	$\delta < L/250$ for beams parallel to line of roof slope	D (allow for creep) plus rainwater or snow melt	
beams that support surfaces which should drain water	$\delta < L/250$ $\delta < L/350$ $\delta < L/600$	D + L or D + S D + L or D + S D or D + S	–reinforced concrete or steel beams supporting slabs –trafficable deck supported by timber beams –non-trafficable deck supported by timber beams (always check that water flows as designed) L = live load; D = dead load; S = snow load
differential settlement	$\delta < L/300$ $\delta < L/150$		–beams supporting masonry walls –beams supporting walls other than masonry

Table 3a Examples of limiting deflection values for horizontal components in the BRANZ Manual, New Zealand [7]

Reason for limiting deflections	Deflection limitations	Load combination	Examples and Comments
sway of columns due to wind	$\delta < h/500$ and < 4mm per storey	D + W	applies especially to multi-storey buildings D = dead load; W = wind load
frame deflection due to wind and earthquake	horizontal deflection at eaves $\delta < L/200$ x frame spacing; and < 40 mm in end bay	W	W = wind load
differential settlement	$\delta < h/300$ $\delta < h/150$		–masonry –other material

Table 3b Examples of limiting deflection values for vertical components in the BRANZ Manual, New Zealand [7]

Tables 3a and 3b give some deflection limits for typical components (see also Table 4 for comparison with other codes).
• A translation of a Dutch document on serviceability requirements [8] has been provided by the CISTI (Canada Institute for Scientific and Technical Information) [9]. In summary, the report recommends the following for the effects of static deformations and their allowable values:
- water accumulation (on roofs): it can be prevented by judiciously determining the point of water discharge.
- subjective aspect: becomes more significant if the deformations become visible.
- use aspect: this is to ensure permanent serviceability of the floor structure. Requirements depend on each individual situation and there is no general rule.
- construction aspect: floor and roof static deformations in structures may give rise to cracking or other damage in members which are supported by these structures (a typical example is the cracking in partitions). As a recommendation for beams or floors supported on two or more ends, the following conditions were suggested:

$\delta_{add}/L \leq 500$ to 600   L = span parallel to the partition wall

and also $\delta_{add} < 10$ to 20 mm

where, δ_{add} = additional deflection occurring after installation of the wall

Before closing this section it is worth mentioning that the CIB (Conseil International du Batiment) has launched a review exercise designated W85 dealing with structural serviceability [10]. It is mainly concerned with phenomena such as deformations, vibrations and damage to non-structural components. The findings of the research should be available by 1993.

4. COMMENTS

It is clear from the extract from the review [1] given in the previous section that the present treatment of just one aspect of serviceability design – the provision of deflection limits given in steel building codes – is not presented in a consistent fashion world-wide. This contrasts with attempts to base strength design on more of a common treatment e.g. use of the multiple column curve concept. It is believed that the deflection issue is, however, actually less clearly provided for, than cursory examination of the evidence would suggest.
The reason for this is the potential for significant differences between "true" and "design" treatments of each of these quantities:

- loading
- model used for calculations
- limiting criteria

This review has looked only at the third of these but the real issue is:

> What deflection limit is appropriate for use with the set of design loads used for the serviceability condition and the method employed for calculating such deflections in order that the actual structure loaded by its in service loading does not suffer unsatisfactory performance?

Clearly there is a link between loading – model – limit. Thus the information presented herein should be accepted within the context of the wider study [1]. Only by examining true behaviour and design-type check calculations for a range of building types can a suitable design package, that will ensure acceptable in service behaviour of the real structure, emerge.

5. CONCLUSION

The investigation carried out on the serviceability requirements has shown the importance of the issue. A review, undertaken for a limited number of codes, showed the complexity of the issue when considering the limiting criteria to be used in the design for serviceability. It is clear from the extracts from the review that present treatment of just one aspect of serviceability design –the

Code	Deflection limits		
	Beams in general	Tops of columns in buildings	
		Single storey	Multi storey
BS5950	L/200	h/300	h/300
AS4100	L/250	h/240	-
EC3	L/200	h/300	h/300
BRANZ	L/250	-	-

Table 4 Deflection limit examples in different codes

provision of deflection limits given in steel building codes– is not treated in a consistent fashion worldwide. This contrasts with attempts to base strength design on more of a common treatment basis. It is believed that the deflection issue is, however, actually less clearly provided for than even this cursory examination of the evidence would suggest.

6. ACKNOWLEDGEMENTS

The work reported in this paper was undertaken as part of the ECSC financed project "Serviceability requirements for steel framed structures" conducted jointly by the University of Trento, the University of Nottingham and TNO-Bouw and coordinated by Centrum Staal. Specific support to the University of Nottingham was provided through contract No.7210-SA/828.

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