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BUILDING SETTLEMENT DAMAGE CRITERIA, ANGULAR DISTORTION OR DEFLECTION RATIO ?

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Abstract

This paper presents the results of a review of the limiting tensile strain method (LTS) for predicting settlement damage on buildings due to excavation induced settlements. The significant inputparameter in this method, describing the influence of differential settlements on the adjacent building, is either expressed in terms of the angular distortion or the deflection ratio. The difference in the results of the LTS due to the use of these two parameters is shown in this paper and recommendations are made for the practical use.

Key Words

Settlement damage, risk assessment, tunnelling.

1 Introduction

Prediction of settlements and consequently the building damage of the adjacent structures forms an important part of settlement risk management for excavation works in urban surrounding (Netzel et al.; 1999). Analytical, empirical prediction methods are commonly used in the preliminary design stage to determine the risk profile for settlement damage on the surroundings.
The significant inputparameter in the “limiting tensile strain” method (LTS), describing the influence of differential settlements on the adjacent building, is either expressed in terms of the angular distortion or the deflection ratio. The difference in the results of the limiting tensile strain method due to the use of these two parameters is shown in this paper and recommendations are made for the practical use of the parameters.
This paper only focuses on the damage effects of vertikal settlements in sagging zone type deformation modes. Similar considerations for hogging typed deformation modes are currently analyzed by the author. It should be emphasized that horizontal movements have to be considered too in a damage risk assessment with the LTS, but are beyond the topic of this paper.

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2 Principles of the limiting tensile strain method (LTS)

2.1 General

The structural sections of a building are modeled as a weightless, rectangular, isotropic elastic beam of the length L, the height H and the materialparameter E/G. The imposed (horizontal and vertical) ground deformations on foundation level, caused by an external source (tunnelling, excavation etc.), are assumed to be fully transferred to the building regardless soil-structure interaction effects. The fully transfer of the (differential) green field ground movements implies the building to be forced to follow the predescribed differential settlements, causing the largest distortion of the building, thus the highest strain values. The method is therefore considered to provide a conservative estimate for the expected damage. Difference in the damage prediction is made between the sagging and the hogging zone. The imposed tensile strains in the structure are calculated with analytical beam equations for a simply supported beam, which is loaded with a fictive point load (taking into account shear deformations) causing a similar deflection profile, as imposed by the predescribed ground deformations. The calculated diagonal and bending strains in the beam are consequently compared to different limiting tensile strain values representing different damage classes with an indication of degrees of damage (defined in terms of the ease of repair, see BRE (1990)). The method is developed by Burland et al. (1974) and Boscardin et al. (1989).
Figure 1 shows the principle of the method for a building in the sagging zone and the influence of vertical settlements.

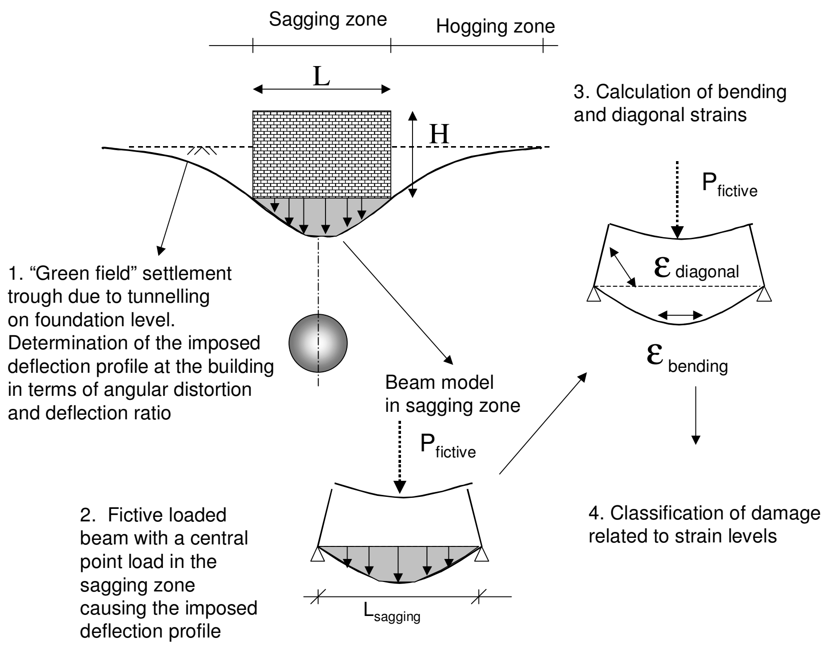


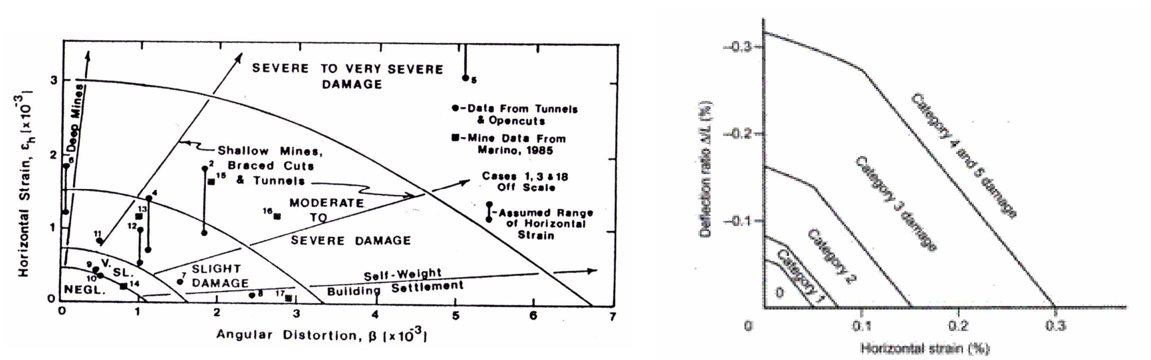
Figure 1 Principle of the limiting tensile strain method for the action of vertikal differential settlements

2.2 Currently used design charts

The limiting tensile strain method is developed by different authors and presented in the form of design charts, which are often used in the design practice. It should be emphasized that the design charts are only applicable for the case of a massive bearing wall in the hogging zone and the L/H-value of 1 ! Thus for a building with

different geometrie (L/H-value) in a sagging zone, the use of the design charts do not give correct results.
Furthermore the Timoshenko-beam equations used as background of the LTS to derive the design charts given below encounter the assumption of a shear form factor, leading to an underestimation of the strains up to 20%. A detailed explanation of this issue and the correct equations are given in (Netzel, 2003). The considerations presented in the following chapters of this paper include the correct shear form factor.

The design chart given in figure 2a is presented by Boscardin et al. 1989. The inputparameters are the horizontal strain as a measure for the impact of (differential) horizontal ground movements and the angular distortion as a measure for the vertical (differential) settlements.
The design chart derived by Burland et al. (2001) is shown in figure 2b.



(a) (b)

Figure 2: Design charts from Boscardin et al. (a) and Burland et. al (b)

A fundamental difference between these two charts is the use of the parameter deflection ratio (figure 2b) or the angular distortion (figure 2a) as measure for the building distortion due to vertical (differential settlements). The influence of these two approaches on the determination of the tensile strains and thus the damage class is discussed in the following chapters of this paper.

3 Angular distortion

By using the LTS method in practical engineering it is recognized, that, dependant on the location of the building in the settlement trough different values for the angular distortions at the outer ends of the building can be derived. This is shown at the example for a building situated assymetrically in the sagging zone of a Gaussian formed settlement trough due to tunnelling.

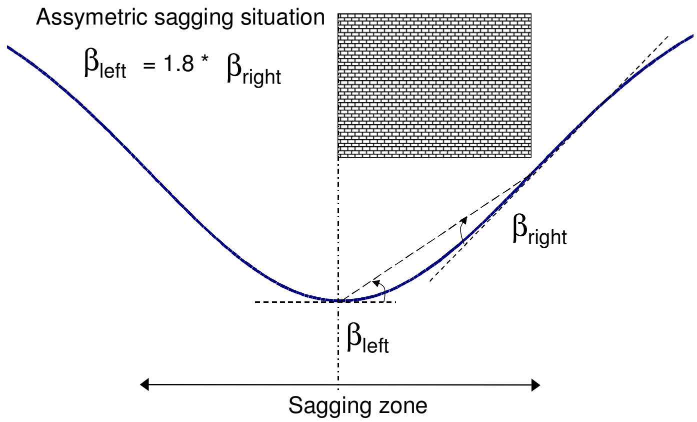
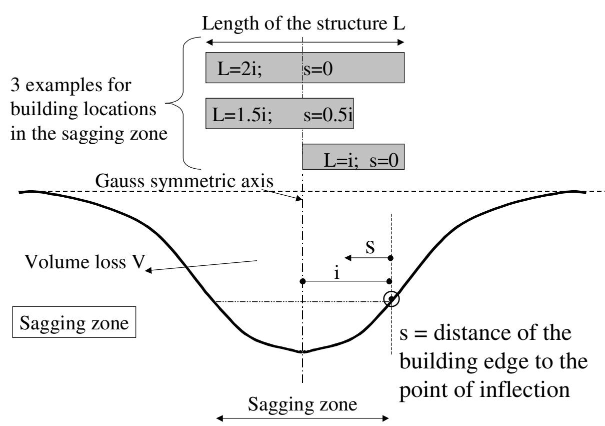


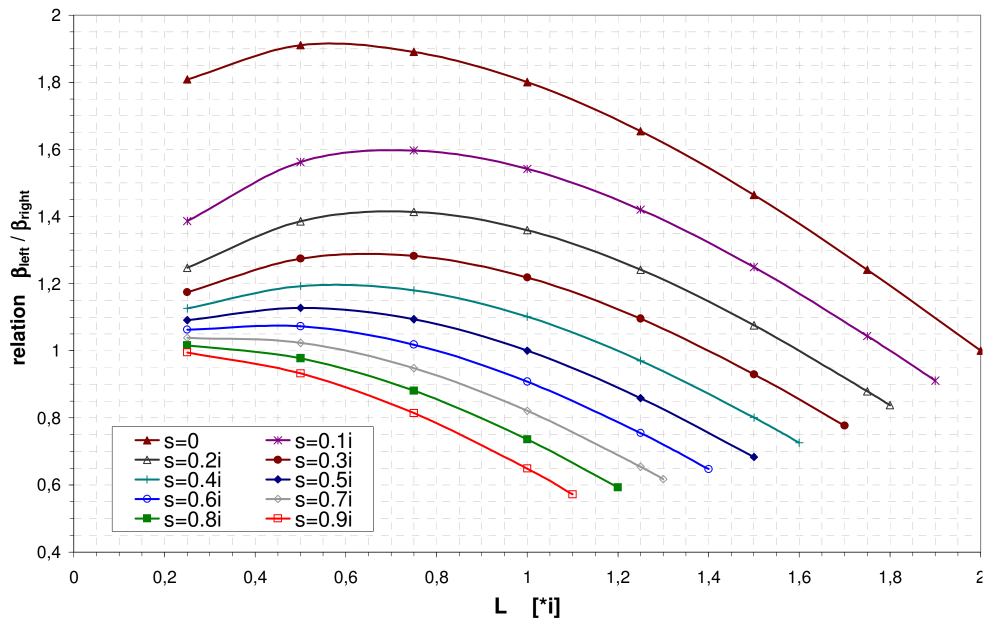
Figure 3: Example determination angular distortion

The example shows a relation of $\beta_{left}/\ \beta_{right}$ of 1.8, or in other words the angular distortion at the left end of the building is 1.8 times bigger than the distortion at the right end. The question raises which of the two values to be used as input for the LTS.

This relation between the angular distortions at the outer ends is analysed for a Gaussian formed sagging zone, dependant on the location of the building in the trough. The design chart in figure 4(b) can be used to directly determine this relation if the Gaussian inputparameters (volume loss V, point of inflection i and the tunneldiameter D) and the location of the building are known. Important inputparameter to define the location of the building is the value s, describing the distance of the right end of the building from the point of inflection (see sketch in figure 4a). The value for s and the length L of the building have to be expressed in terms of i.



(a)



(b)

Figure 4: (a) Definition of inputparameter s; (b) Design chart

4 Deflection ratio

The deflection ratio is defined as the maximum vertical deflection between the tilt line of the building and the imposed settlement curve. It is noted, that the difference between the vertical component and the deflection component perpendicular to the tilt line is negligible for practical values of the tilt (see figure 5).

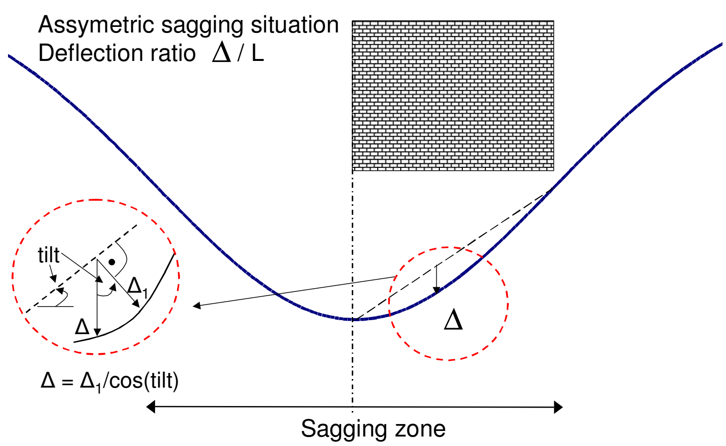


Figure 5: Deflection ratio

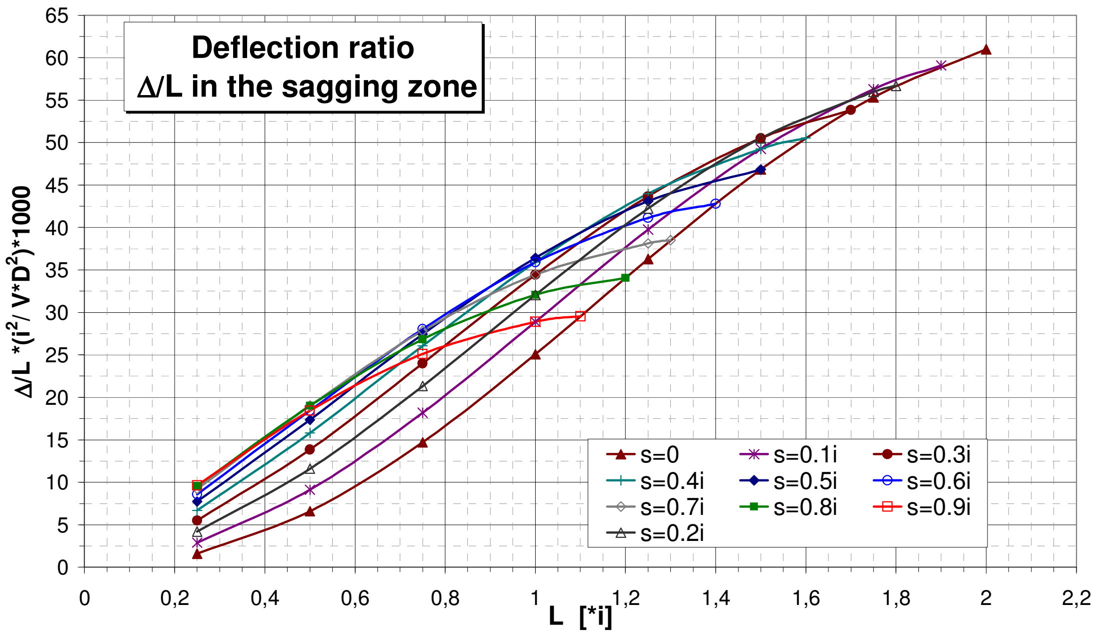


Figure 6: Design Chart to determine the deflection ratio for a Gaussian settlement profile

Figure 6 shows a design chart for direct determination of the maximum deflection ratio for each location of a building in a Gaussian sagging zone. The inputparameters (V,s, i and D) and are the same as described in the previous chapter.

5 Influence of the deflection ratio or angular distortion on the tensile strains

5.1 General approach

Two situations of buildings in the sagging zone are considered. One situation where the building is located symmetrically in the sagging zone and the other example represents an assymmetric sagging situation. For both situations three type of calculations for different L/H-ratio's are made:

- A. Numerical Timoshenko-beam calculations with the fully imposed ground deflection profile, serving as the "correct" reference for the tensile strains.

- Analytical calculation of the tensile strains with the LTS (fictive point load approach) and the angular distortion (B) or the deflection ratio (C) as inputparameter.

Reference is the beam calculation A with the fully imposed Gaussian as it represents the correct strains for including the varying curvatures along the Gaussian profile. Modificationfactors are derived representing the differences in tensile strains according to the deflection ratio fit (model B) and the angular distortion fit (model C) with the tensile strains from the real imposed Gaussian deflection curve (model A). A modificationfactor >1 means that the fictive point load approaches overstimate the

correct strains from model A. The principle of this study is shown for the symmetric sagging situation in figure 7.

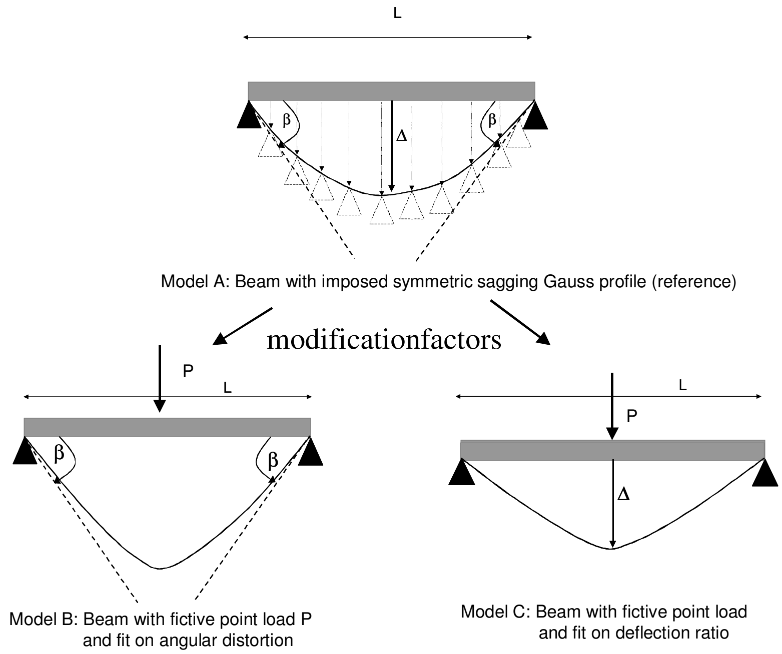


Figure 7: Principles of the analyses

5.2 Results for the symmetric sagging situation

The results for the modificationfactors for the symmetric sagging situation are shown in figure 8 and 9. It is distinguished between the influence of model B (deflection ratio fit) and C (angular distortion fit) on the bending strains and the diagonal strains.

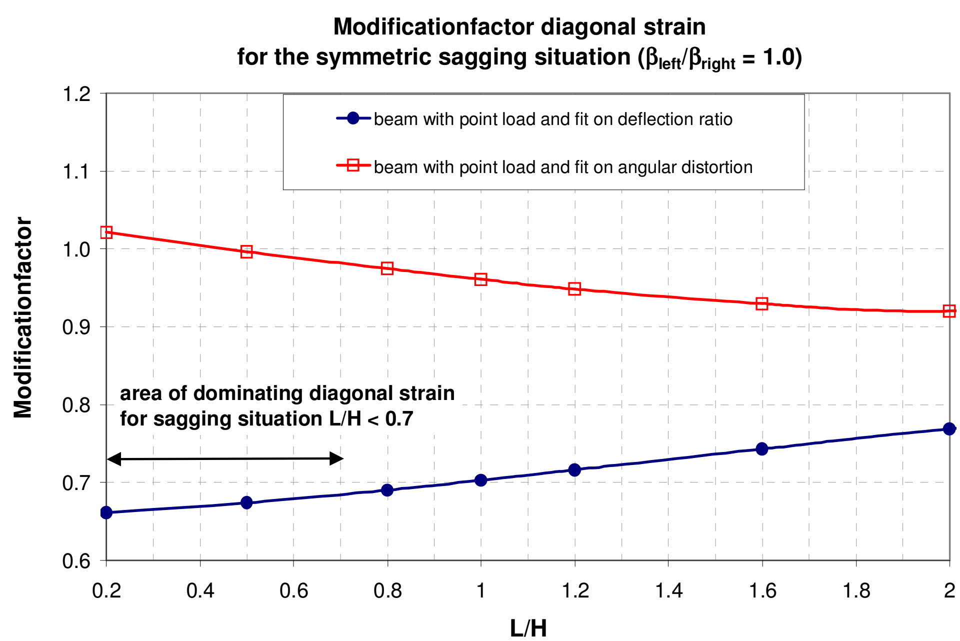


Figure 8: Modificationfactor for diagonal strains in the symmetric sagging situation

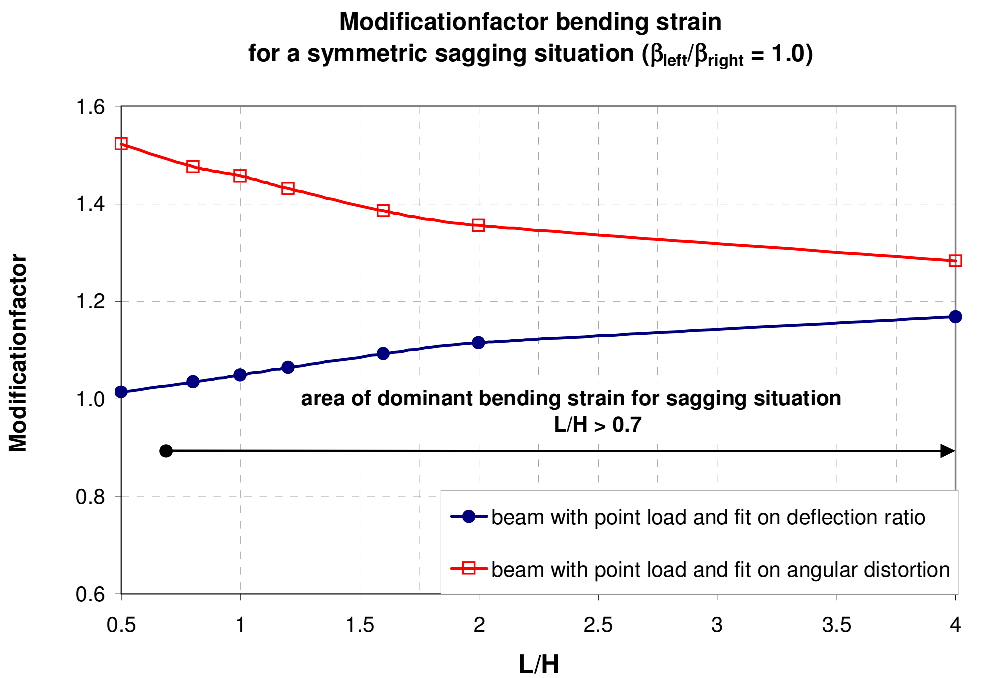


Figure 9: Modificationfactor for bending strains in the symmetric sagging situation

The figures show that the use of the deflection ratio as fitting parameter for the fictive point load leads to a significant underestimation of the diagonal strains up to 35%. The angular distortion fit shows however a very good agreement with a negligible differences of circa +/- 3% for the diagonal strains (in the dominant L/H-area up to 0,7).

The bending strains show other effects. The deflection ratio leads to an overestimation of the tensile bending strains from 2 to 18% (dependant of the L/H-ratio). The angular distortion fit however overestimates the bending strains between 30 and 50%.
In can be concluded that for the situation in the symmetric sagging zone the angular distortion should be used to determine the diagonal strains and the deflection ratio should be used to determine the bending strains. The use of one damage parameter for both strains leads to significant under-and overestimations of the strains.

5.3 Assymmetric sagging situation

As mentioned in the previous chapter, the value for the angular distortion derived from a Gaussian profile is not straightforward, because different values can occur at the outer ends for an assymmetric situation. In the figures 10 and 11 there are four modification lines given, taking into account the deflection ratio fit and the fit on the maximum, minimum and the average value for the angular distortion for an asymmetric sagging situation.

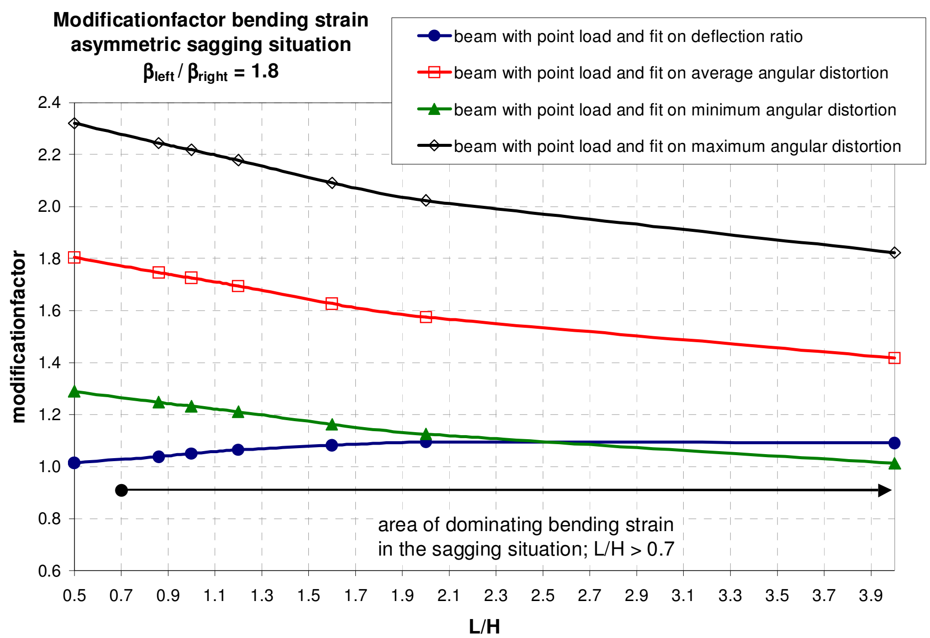


Figure 10: Modificationfactor for bending strains in the asymmetric sagging situation

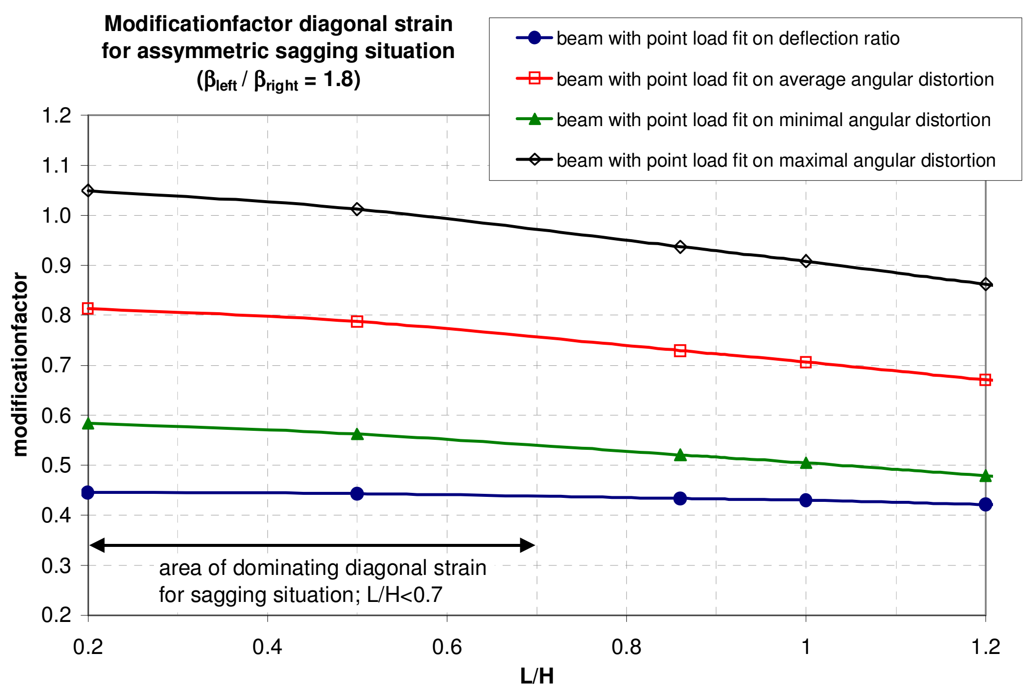


Figure 11: Modificationfactor for diagonal strains in the asymmetric sagging situation

The deflection ratio fit leads to a good agreement of the bending strains (overestimation of up to 10%). The use of the maximum value for the angular distortion to determine the bending strains leads to an overestimation of up to 120% !

In the assymmetric sagging situation the use of the deflection ratio shows a significant underestimation of the diagonal strains of circa 55%. The use of the maximum angular distortion leads to a very good agreement of the diagonal strains with the reference (+/- 3%).

6 Conclusions

The influence of the damage criteria on the calculation of the tensile strains according to the limiting tensile strain method is investigated and the following conclusions can be drawn:

- The use of the deflection ratio as damage parameter in the LTS can lead to a significant underestimation of the diagonal tensile strains in the sagging zone of Gaussian formed settlement profiles (up to 55%).

- The use of the maximum angular distortion at the location of the building in the LTS can lead to a significant overestimation of the bending strains of Gaussian formed settlement profiles (up to 120%).

The author recommends to use the maximum angular distortion for the determination of the diagonal tensile strains and the deflection ratio to determine the bending tensile strains with the LTS for Gaussian formed settlement profiles. This approach leads to correct determination of the tensile strains with the limiting tensile strain method within practical acceptable bandwidthes (+/-10%).

Acknowledgments

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