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Influence of profile distortion on the shear flexibility of profiled steel sheeting diaphragms

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Abstract

The shear flexibility of diaphragms consisting of profiled steel sheeting can be calculated by means of the ECCS-Recommendations TC7 TWG 7.5. The main component of the shear flexibility accounts for sheet deformation, which consists of profile distortion $c_{1,1}$ and shear strain $c_{1,2}$. The dominant part $c_{1,1}$ is proportional to K_i. The factor $K_i=K_1$ applies with fasteners in every trough and $K_i=K_2$ applies with fasteners in alternate troughs. Both K_1 and K_2 depend on the ratios l/d and h/d of the cross section dimensions d=pitch of the corrugations, h=height of the sheeting profile and l=width of the top flange. For vertical webs K_1 is larger than K_2. This means that larger profile distortion is predicted with fastening in every trough than with fastening in alternate troughs. This is in contradiction to reality. Finite-Element calculations show that the K_2-values given in ECCS-Recommendations TC7 TWG 7.5 are wrong. The correct values for K_2 are given as result of this investigation.

1. Introduction

In the past decades new perceptions and improvements as well as continuative optimization led to a huge boom and a rapid world-wide extension of light-weight constructions. The constant quest for optimization resulted in the possibility to stabilize steel-framed building constructions especially for typical industrial buildings by means of the shear capacity of elements like trapezoidal sheets. User-friendly rules for dimensioning und calculation of shear diaphragms consisting of trapezoidal sheets furthered this development. One of the most

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popular publications are the European Recommendations for the Application of Metal Sheeting acting as a Diaphragm [4], which is among other things based on investigations of Bryan and Davies [2] [3].

2. Basic principles of calculating the shear flexibility of diaphragms

Formulae to calculate the total shear flexibility v of a diaphragm under shear load V are given in [4]. The total shear flexibility v of a shear panel is the sum of components due to different influences.

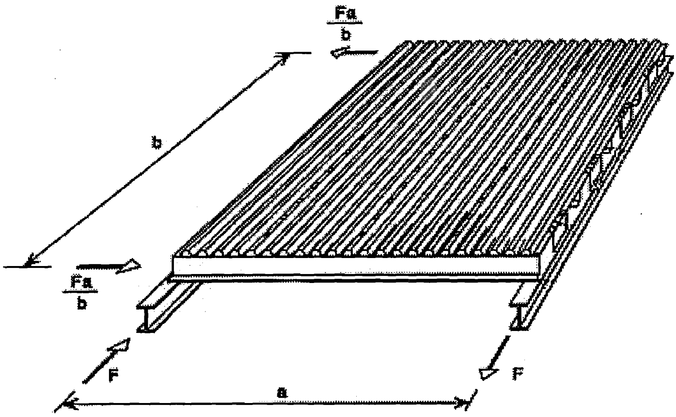


Figure 1: shear load V and shear flexibility v

The dominant part of this shear flexibility – in addition to slip in the fastenings of the diaphragm – is the sheet deformation c_1. c_1 consists of profile distortion $c_{1,1}$ and shear strain $c_{1,2}$. Both parts are shown in figure 2.

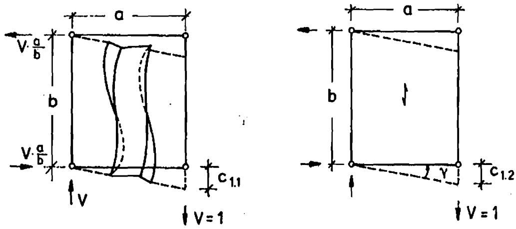


Figure 2: illustration of profile distortion $c_{1,1}$ and shear strain $c_{1,2}$

$c_{1,1}$ and $c_{1,2}$ are obtained from equations (1) and (2).

$$c_{1,1} = \frac{a \cdot d^{2.5} \cdot K_i}{E \cdot t^{2.5} \cdot b^2} \qquad (1)$$

$$c_{1,2} = \frac{2a \cdot (1+\upsilon) \cdot [1+(2h/d)]}{E \cdot t \cdot b} \qquad (2)$$

with E modulus of elasticity
and ν Poisson's Ratio

The profile distortion $c_{1,1}$ is proportional to K_i. The factor K_i is given in table form in [4]. K_1 applies for fastening in every trough and K_2 applies for fasteners in alternate troughs. Both K_1 and K_2 depend on the ratios l/d and h/d of the cross section dimensions d=pitch of the corrugations, h=height of the sheeting profile and l=width of the top flange (see figure 3).

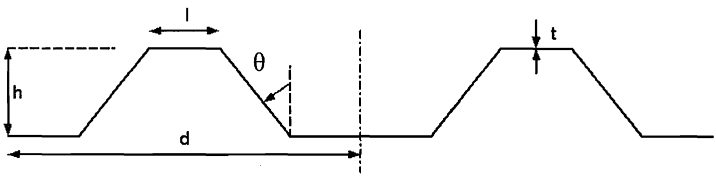


Figure 3: definition of the cross section dimensions

3. Inconsistencies with K_2

In case of vertical webs (θ=0) the tables in [4] give larger values for K_1 than for K_2. This means that larger profile distortion is predicted with fastening in every trough than with fastening in alternate troughs.

The following diagrams demonstrate this inconsistency of the K_2-values taken from [4].

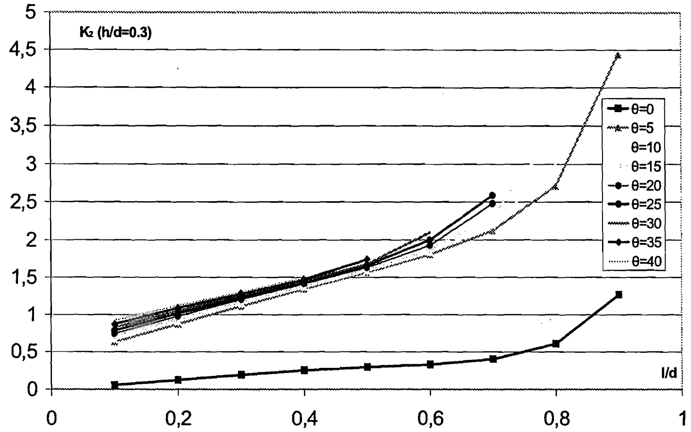


Diagram 1: variation of K_2 with l/d and θ for h/d=0.3

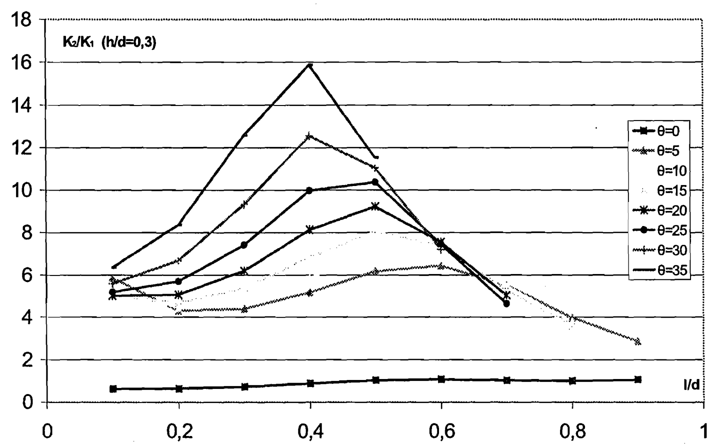


Diagram 2: variation of K_2/K_1 with l/d and θ for h/d=0.3

Both diagrams show that the values for θ=0 do not match with the other results. Diagram 2 even shows that the ratios for θ=0 are less than 1 for small values of l/d. This means that profile distortion for fastening in every trough is larger than for fasteners in alternate troughs.

4. Numerical Analysis

Numerical analyses were performed with the Finite-Element program ANSYS 7.1 to find the correct solution to this problem.

Shear diaphragms were modeled with a/b-ratios varying from 0.5 to 2.0. The model, which is related to the assumptions in [1] to [4] is depicted in figures 4a and 4b.

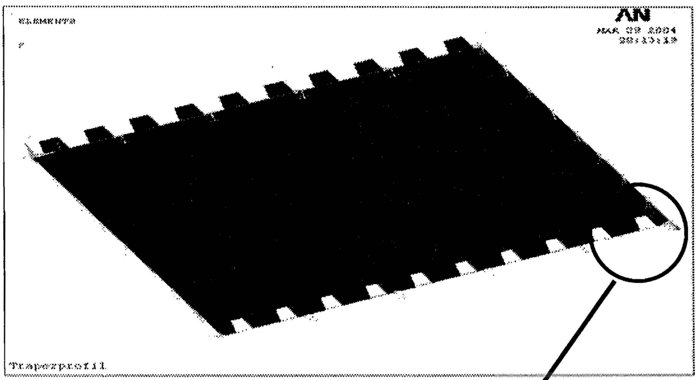


Figure 4a: FE-model with single load and boundary conditions

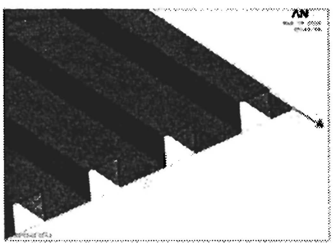


Figure 4b: detail of FE-model

Different types of geometry with $0.1 \leq l/d \leq 0.9$, $0.1 \leq h/d \leq 0.8$ and $\theta = 0$ were investigated in a parametric study. This investigation was restricted to $\theta = 0$ because it was expected from diagrams 1 and 2 that the error was only with the values for this slope.
Figure 5 shows the example of a deformed finite element model with $l/d = 0.4$ and $h/d = 0.4$ together with the applied loading at the edge rib.

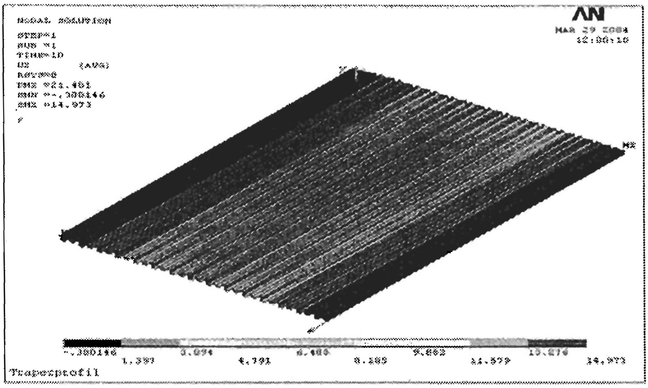


Figure 5: deformation of a loaded shear diaphragm with a/b=0.75

For the evaluation of the numerical analysis the displacement c_{FEM} of the diaphragm was determined.

Subtracting the displacement due to the shear strain according to [4] gives the displacement due to profile distortion with the factor K_i included. Thus the factor K_i is obtained from the results c_{FEM} of the Finite Element analysis with

$$K_i = \frac{b \cdot t^{1.5}}{a \cdot d^{2.5}} \cdot \left\{ c_{FEM} \cdot E \cdot t \cdot b - 2a \cdot (1+\upsilon) \cdot [1 + \frac{2h}{d}] \right\} \quad (3)$$

The factors K_2 resulting from the numerical analysis are shown in table 1.

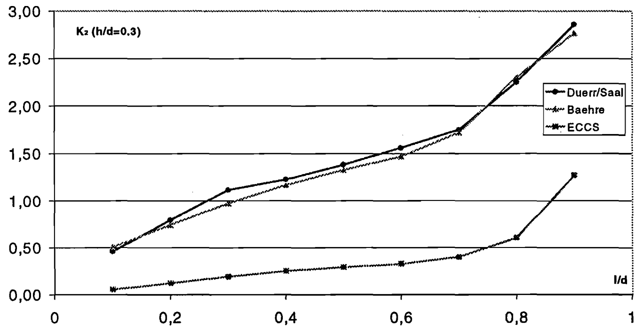
	l/d								
h/d	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
0,1	0,1	0,13	0,18	0,23	0,25	0,27	0,32	0,40	0,61
0,2	0,25	0,42	0,53	0,66	0,74	0,83	1,04	1,29	2,05
0,3	0,46	0,80	1,12	1,23	1,39	1,56	1,75	2,25	2,86
0,4	0,74	1,19	1,77	2,15	2,39	2,63	2,94	3,76	5,31
0,5	1,44	2,16	2,58	2,93	3,48	3,70	4,09	5,06	8,38
0,6	2,75	3,54	4,51	4,99	5,98	6,35	6,60	7,93	11,63
0,7	4,49	5,33	6,54	7,35	8,07	8,56	9,36	11,06	15,36
0,8	6,44	7,28	9,06	10,40	10,35	11,33	12,61	14,46	20,44

Table 1: factors K_2

5. Comparison and review of the calculated results

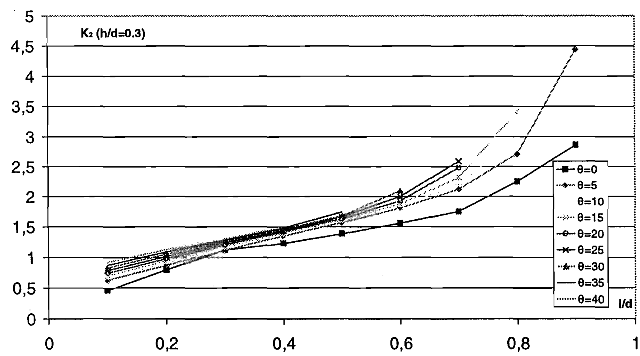
To classify the results, which resulted from the numerical analysis, it is necessary to compare them to results from other sources existing on this subject matter.
K-factors for calculating the shear flexibility of diaphragms are also given by Baehre in [1]. These factors were verified with test results of shear diaphragms. The following diagram shows the K_2-factors of [1] and [4] in comparison to the results of table 1.

Diagram 3: comparison of different K_2-factors for θ=0 and h/d of 0.3



It is obvious that the factors from our numerical analysis agree with the values of [1].
If the ECCS-values for θ=0, which are definitely shown to be incorrect, are substituted by our results or those from [1], it will be found that these values match much better with the K_2-factors for sloping webs. Diagram 4 shows this.

Diagram 4: K_2-values for h/d-ratio of 0.3 with changed values for θ=0



6. Conclusions

The present paper shows the inconsistency of the K_2-values of [4] for calculating the profile distortion of shear loaded diaphragms consisting of trapezoidal sheeting. By means of Finite-Element calculations more realistic values for alternate fastening in combination with vertical webs were found and given in table 1 of chapter 4 for $\theta=0$. The results of the study were verified by comparison to [1]. The values of [1] to [4] for $\theta>0$ are confirmed by this analysis.

The authors recommend to substitute the K_2-factors, which are printed in ECCS-Recommendations TC7 TWG 7.5 for alternate fastenings and vertical webs, by table 1 of this present paper.

7. References

[1] Baehre, R., Kaltgeformte, leichte Stahlprofile als Tragwerkskomponenten in bautechnischer Anwendung, Forschungsbericht zum Forschungsauftrag Nr. 111 der Studiengesellschaft von Eisen und Stahl e.V., 1985

[2] Bryan, E.R., The Stressed Skin Design of Steel Buildings, London, 1973

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[4] ECCS Recommendations for the Application of Metal Sheeting acting as a Diaphragm, European Convention for Constructional Steelwork TC7 TWG 7.5, Brussel, 1995, First Edition