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## **Basis of New Polish Recommendations for Stressed Skin Design**

Base des nouvelles recommandations polonaises du calcul des structures

Grundlagen der neuen polnischen Richtlinien für Tragwerke

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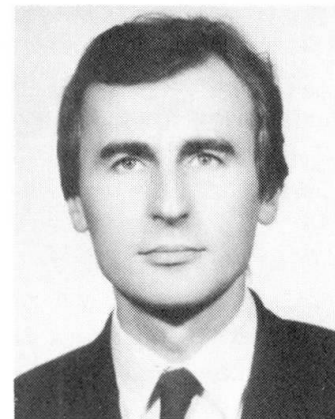
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### **SUMMARY**

The new Polish design recommendations for stressed skin design are based on ECCS recommendations, as well as on the results of extensive theoretical and experimental investigations carried out in Poland. This document includes a simplified procedure of checking the stability of struts and beam-columns, braced by corrugated sheet and braced by girts with corrugated diaphragm. In structures which do not fulfil all recommended requirements many members and fasteners, in particular secondary members, have been found to be overloaded.

### **RÉSUMÉ**

Les nouvelles règles polonaises concernant les structures qui agissent en collaboration avec les tôles d'acier nervurées sont basées sur les recommandations CECM et aussi sur les résultats des vastes études théoriques et expérimentales faites en Pologne. Les règles contiennent une méthode simplifiée d'estimation de la stabilité des poteaux comprimés et des poutres comprimées et fléchies renforcés par la tôle d'acier nervurée et par les traverses avec tôle d'acier nervurée. Dans les constructions qui avaient été calculées sans respecter toutes ces règles, on a constaté une surcharge dans beaucoup de barres et d'assemblages, surtout dans les éléments qu'on traite d'habitude comme secondaires.

### **ZUSAMMENFASSUNG**

Neue polnische Richtlinien für den Entwurf von Stahlkonstruktionen, die mit den Umhüllungselementen aus Trapez-Profilblech zusammenwirken, sind auf den EKS-Richtlinien und auch auf umfangreichen theoretischen und experimentellen polnischen Versuchsergebnissen aufgebaut. Die neuen Richtlinien geben vereinfachte Abschätzungsmethoden für die Stabilität von gedrückten Stäben sowie von druck- und/oder biegebeanspruchten Stäben an, die mit Hilfe von Profilblech oder von Riegeln und Profilblech gestützt sind. In Konstruktionen, die dem Entwurf nach nicht alle Anforderungen der Richtlinien erfüllen, wurde die Überlastung von vielen Stäben sowie Verbindungsmitteln festgestellt, insbesondere in solchen die üblicherweise als untergeordnet betrachtet werden.



## 1. GENERAL REMARKS

The actual Polish Temporary Recommendations were issued in 1979. They are based on the 1975 issue of ECCS Recommendations. In the main they concern only structures that consist of planar bar members and diaphragms of corrugated sheets with framing. There are no formulae given to check stability of members in bending and beam-column braced by corrugated sheet diaphragms. They have also no instructions on analysis of building as a spatial system of steel skeleton with plates of corrugated panels.

Since 1978 year a study on application of finite element method to design of stressed skin structures as well as (since 1980 ) theoretical and experimental research on lateral stability of elements in bending and beam-column braced by corrugated sheet diaphragms has been carried out at Metal Structures Research and Design Centre „Mostostal” in Poland.

## 2. STABILITY PROBLEMS

It is known that diaphragm increases considerably bearing capacity of members in flexural-torsional buckling. Ignoring the influence of this phenomenon during design increases unnecessarily steel expense for building skeleton. For full utilisation of bracing member by a diaphragm in design there is necessary to get a lot of experimental data and calculation methods that are adequate to structures with different parameters of bracing along member length. To get these data procedures were worked out for computers. There were done research of struts in beam-column and beams in bending connected directly with corrugated sheets and struts braced by wall girts to which corrugated sheets were fastened. It has been confirmed that the bending capacity of connections of a corrugated sheet with a bar (or girt with column), determining the bar bracing against distortion, influences greatly the stability. Investigations of Hilti fired pins and self-driving pins with rubber pads in corrugated sheet with bar connections have been carried out. The rotational rigidity  $k_\phi$  of a bar - to corrugated sheet attachment of Hilti pin is represented in Fig. 1.

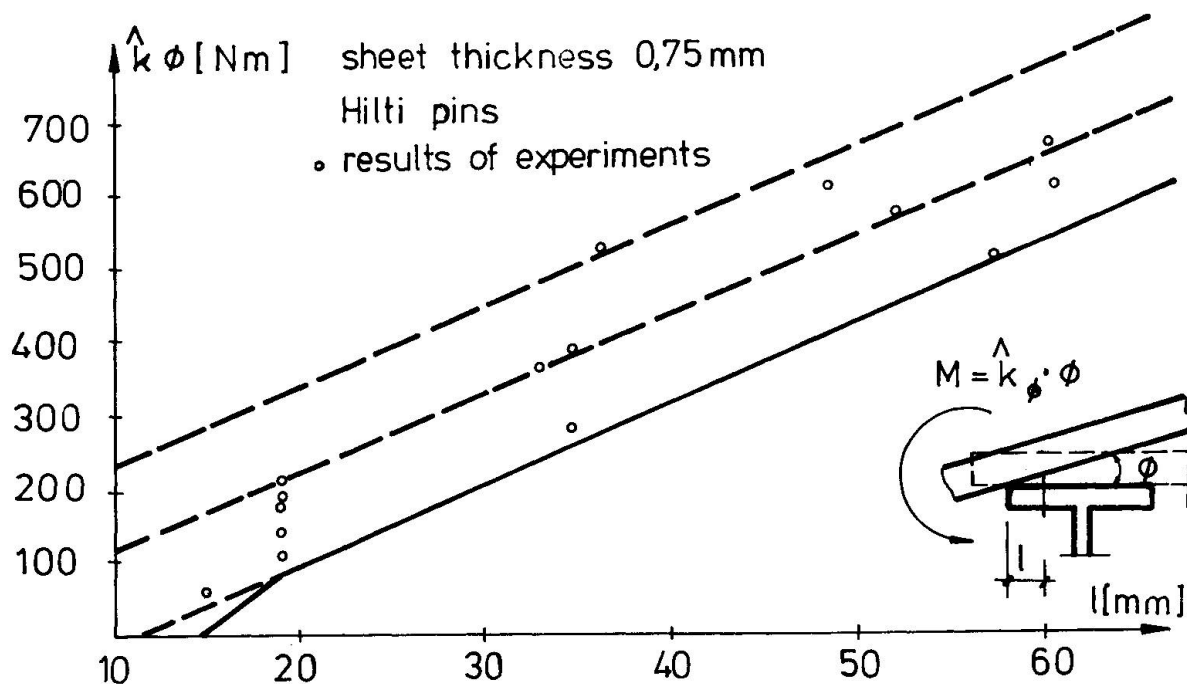


Fig.1. The rotational rigidity of a flange to corrugated sheet attachment.

Experiments on column with girt connections and those on frame girt with purlin connections, in typical projects of steel girder come to the end just now.

During the experimental research analysis the following method of bearing capacity determination has been applied.

For the geometry of skeleton and data of bracing parameters, buckling load and respective bar buckling length have been calculated. Further calculations were carried out according to the standard for the calculation of steel constructions.

For the calculation of bars braced by diaphragm having a varying rigidity along the bar axis or varying load and non typical end conditions the procedures in BASIC language on minicomputer Wang have been worked out:

- for calculation of bars directly connected with corrugated sheet,
- for calculation of bars connected with girts (purlins) to which corrugated sheets are attached.

Experiments and theoretical analysis have given an occasion to elaborate a simplified method of stability calculation.

### 3. SIMPLIFIED CHECKING PROCEDURE FOR I-SHAPED BEAM-COLUMN BRACED BY GIRTS (PURLINS) AND DIAPHRAGM

#### 3.1. Notations

- $A$  — area of I-section;  
 $I_x$  — moment of inertia about x-axis;  
 $K_x$  — shear rigidity of a diaphragm of corrugated sheets for one beam-column;  
 $K_\phi$  — rotational restraint constant of a corrugated sheet diaphragm directly attached to a flange for one beam-column;  
 $K_\phi$  — rotational restraint constant of a girt (purlin) for one beam-column  
 $L = l \cdot n$  — length of a beam-column;  
 $M = P \cdot e$  — bending moment about x-axis;  
 $M_1, M_2, M_3$  — moments about O-axis;  
 $P$  — compression force;  
 $\bar{P}$  — lateral force;  
 $Q$  — reaction force;  
 $a_1, h_1, r$  — geometric dimensions (Fig. 3);  
 $i$  — polar radius of gyration;  
 $n$  — number of girts (purlins) minus one;  
 $u$  — lateral displacement (Fig. 3);  
 $u_1$  — displacement in direction of x-axis;  
 $\sigma$  — compression stress;  
 $\phi$  — rotation about O-axis (Fig. 3).

#### 3.2. Introduction

The exact checking of stability of a beam-column braced by girts (purlins) and corrugated sheets (Fig. 2) is possible only by means of a computer procedure [1]. A simpler method given in [2] can be used merely for columns, when a number of girts is less than six. The objective of this paper is to report equally simple but a more versatile method, presented first time in [3].

#### 3.3. Simplifications

- Stiffness of a beam-column is neglected; it is fictitiously cut in x, y plane at connections with girts (purlins);
- A beam-column is hinged at the ends;



—  $e, P, \bar{K}_x, K_\phi = \text{constant.}$

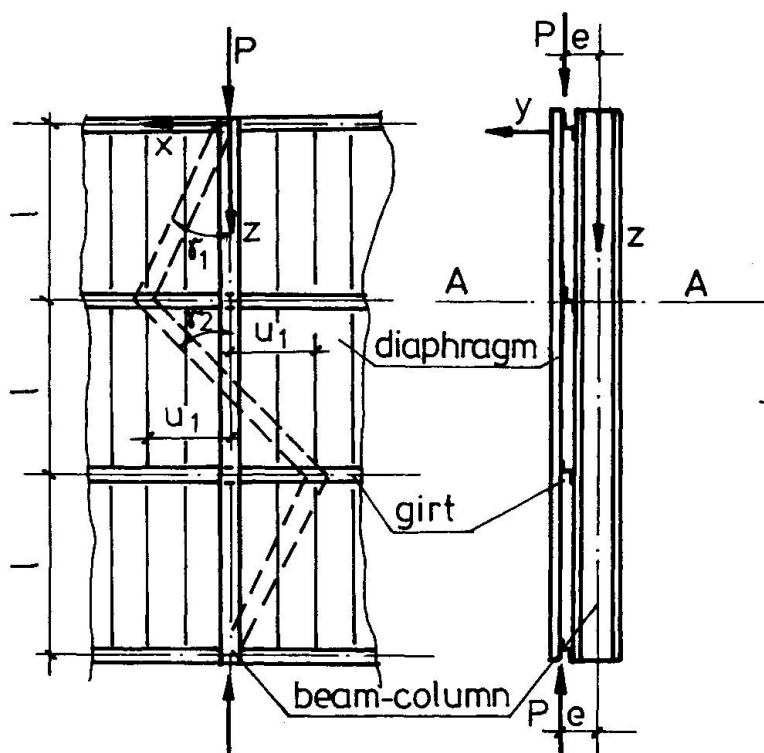


Fig. 2. A beam-column and its bracing

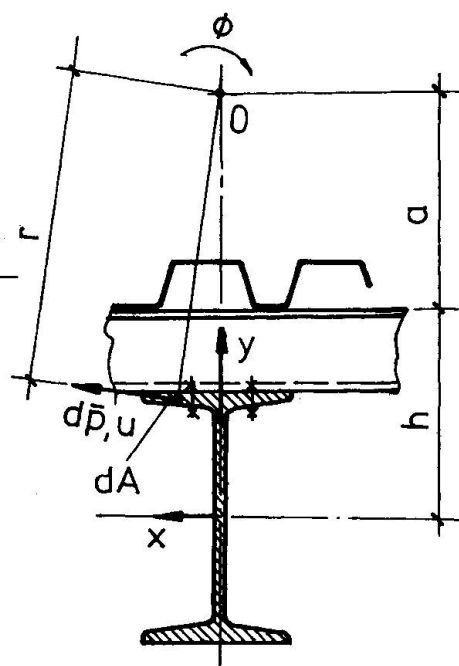


Fig. 3 A-A section

### 3.4. Conditions of stability

From Fig. 2 and Fig. 3  $d\bar{P}$  force can be stated as

$$d\bar{P} = \sigma \cdot dA \cdot \ell \cdot u/l, \quad /1/$$

in which  $u = \phi r$ ,  $\sigma = P/A + M \cdot \gamma/J_x$ ,  $\ell = 3$  for  $n = 3$ .  
A moment about O-axis is given by

$$\bar{M}_1 = \int_A d\bar{P} \cdot r \quad /2/$$

The result of putting /1/ into /2/ is

$$\bar{M}_1 = \phi \ell P [i^2 + (a_1 + h_1)^2 - 2e(a_1 + h_1)]. \quad /3/$$

A girt reaction is given by  $\bar{M}_2 = -K_\phi \phi$ .

From Fig. 2 a diaphragm reaction can be stated as

$$\bar{M}_3 = Q \cdot a_1 = -(\gamma_1 + \gamma_2) \bar{K}_x \cdot a_1 = -\ell \phi \cdot a_1 \bar{K}_x / l.$$

The condition of stability is given by

$$\bar{M}_1 + \bar{M}_2 + \bar{M}_3 \leq 0 \quad /4/$$

If the condition /4/ is fulfilled then a beam-column is supported immovable in  $x, \phi$  directions at connections with girts (purlins). It can buckle only in  $y$  direction or between the connections — for the buckling length equal to  $l$ .  $\ell$  — factor calculated from static analysis is given in Table 1.

n	2	3	4	5	6	7	9	11	$\infty$
$\ell$	2	3	3.41	3.63	3.73	3.8	3.88	3.92	4

Table 1

From the condition of a minimum of the total potential energy  $\partial K_{\phi} / \partial a_1 = 0$ . Solving this for  $a_1$  and putting it into /4/ gives

$$K_{\phi} \geq \ell \cdot P [ i^2 + h_1^2 - 2eh_1 + P(h_1 - e)^2 / (\hat{K}_x - P) ] / l. \quad /5/$$

The second condition of stability is

$$\hat{K}_x > P. \quad /6/$$

For  $\beta = [ 2eh_1 - (h_1^2 + i^2) ] / (e^2 - i^2) > 0$  there is only one condition of stability given by

$$P \leq \beta \cdot \hat{K}_x \quad /7/$$

### 3.5. Effect of stiffness of a beam-column

Stiffness of beam-column increases buckling resistance of girts (purlins) and a diaphragm. A buckling load can be presented as

$$P_{cr} = P_{1cr} + P_{2cr}, \quad /8/$$

in which  $P_{1cr}$  buckling load for a beam-column braced by corrugated sheets attached directly to a beam-column flange, calculated for a buckling length  $L$  and constants  $\hat{K}_{\phi} = 0, \hat{K}_x \cdot P_{2cr}$  is an increase of a buckling load in consequence of girts (purlins) stiffness. Putting  $(\bar{M}_1 + \bar{M}_2 + \bar{M}_3)$  equal to zero and  $(P - \hat{K}_x)$  equal to  $(P_{1cr} + P_{2cr} - \hat{K}_x)$  yields

$$P_{2cr} = (-B + \sqrt{B^2 - 4AC}) / 2A, \quad /9/$$

in which  $A = e^2 - i^2$ ,

$$B = [ i^2 + h_1(h_1 - 2e) ] (\hat{K}_x - P_{1cr}) + K_{\phi} \cdot l / \ell$$

$$C = -l \cdot K_{\phi} (\hat{K}_x - P_{1cr}) / \ell$$

### 3.6. The checking procedure

The procedure for „The New Polish Recommendation for Stressed Skin Design of Steel Structures” was developed from /5/ and /9/ expressions by putting into them safety factors and taking into account elasto-plastic characteristics of a beam-column material. A numerical confrontation of the reported method and the method from [ 2 ] for a compressed column braced by a diaphragm and four girts yielded very approximate results.

## 4. CONCLUSION

Ample studies deal with the static analysis of building, as a bars and plates system. In such a system the construction of windows and gates was neglected. The flexibility of connecting pieces was added to the flexibility of corrugated sheet and the flexibility of diaphragm was determined according to the ECCS Recommendations. Main columns and gable walls columns, frame girts and summer girts, girder flanges and lattice columns flanges are assumed as elements having six degrees of freedom, other skeleton members as bracing, cross-braces, window girts etc. are assumed as elements having three degrees of freedom. The model of corrugated sheet was made by means of orthotropic elements with nodes having two degrees of freedom



(see ref.4) in the sheet plane. The co-action of corrugated sheet with steel skeleton level down considerably the building horizontal deflexion and the forces acting in the main skeleton columns (upon over a dozen per cent), when their directions are parallel to the composants direction of corrugation waves. However the lattice stifeners of roof and walls are considerably overloaded. Also number of which, on account of standard wind load in many areas of the building, should be greater than the number resulting only from the vertical loads action.

Co-action of corrugated sheets with steel skeleton gives many advantages (reduction of horizontal deflection, distribution of internal forces in main bars, stability of main bars, overcritical behaviour of secondary bars) but can also provide negative results. If the results do not come out evidently this is because the hurricane load assumed in design occurs very seldom and pass across the open area. However this can happen otherwise. When the main connections are destroyed and the corrugated sheet does not co-act with skeleton.

One can safely profit from the co-action of corrugated sheet with building skeleton only in the four hinge system of planar members, where the sheet contributes to the geometrical invariability of building but does not interfere with the distribution of planar members internal forces.

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