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THE INFLUENCE OF TRANSVERSE AND LONGITUDINAL STIFFENERS ON STABILITY OF STEEL PLATE GIRDER

Jan Misiak, Sławomir Stachura

University of Ecology and Management
Olszewska 12 Street, 00-792 Warsaw, Poland
tel. +48 825 80 34, fax +48 825 80 31
rektorat@wszie.pl

Abstract

An analysis of flexural work of a plate girder in elastic range has been made in the work taking into account stiffeners of a web as a counteraction to web buckling effect. A path of states of flexural equilibrium has been determined as well, also taking into account the axial compressive force. The analysed plate girder has relatively large span and then the bending moment is a dominant one among internal forces, the normal compressive stresses determine local stability loss and application of the transverse stiffeners does not much affect increase of resistance to local stability loss. On the other hand, use of the longitudinal stiffeners increases the buckling sensitivity coefficient, i.e. results in increase of global buckling resistance. Application of the transverse and longitudinal stiffeners over the whole span of the plate girder causes that its global buckling resistance increases about twice, as the value of the buckling sensitivity coefficient raises from 6.04 to 13.24, while its weight increases not much – by 11%. The transverse stiffeners will have meaning when the tangential stresses from shearing forces that usually occur in the areas of support have the crucial influence on local stability loss. Other cases of occurring significant shearing forces are plate girders under overhead cranes and plate girders of railway bridges that are loaded with large forces concentrated at the places of contact with vehicles' wheels.

Keywords: *static equilibrium, global stability, web local buckling, plate girder stiffeners, finite element method*

1. Introduction

The aim of the work is qualitative and quantitative comparison of the influence of applied longitudinal and transverse stiffeners on local stability of a steel plate girder. Calculations were carried out on the basis of the free supported plate girder with span of 30 m, loaded with combination of dead weight and load of 1.0 kN/m (Fig. 1.1).

A computational model of the plate girder constructed of surface finite elements was used. An upper flange of the plate girder was protected from lateral displacements, which reflected resisting plates that are used in practice, providing for adhesion of a monolithic reinforced concrete slab and protection from lateral buckling.

2. Formulation of the problem

A numerical analysis of state of stable and unstable equilibrium was carried out with use of finite element method (FEM) with shell elements and use of nonlinear geometric relationships. The following nonlinear equations of static equilibrium and stability were solved:

$$[\mathbf{K} + \mathbf{K}_\sigma(\Delta\sigma) + \mathbf{K}_l(\Delta q)]\Delta\mathbf{q} = \Delta\mathbf{P}\,,$$
$$[\mathbf{K} + \alpha_{cr}\{\mathbf{K}_\sigma(\sigma) + \mathbf{K}_l(q)\}]\mathbf{q} = 0\,,$$

where:
K – linear stiffness matrix;

$\mathbf{K}_\sigma$ – geometric stiffness matrix;

$\mathbf{K}_l$ – displacement stiffness matrix.

3. Computations of nonlinear stability of the plate girder

Computations were carried out for the combination of loads $F_{Rd} = 1*1.15 + 2*1.5$ (where 1 was dead weight and 2 was variable load) with use of the nonlinear buckling analysis in Autodesk Robot Structural Analysis Professional program. 3600 surface finite elements and 23162 degrees of freedom were specified in the computational model.

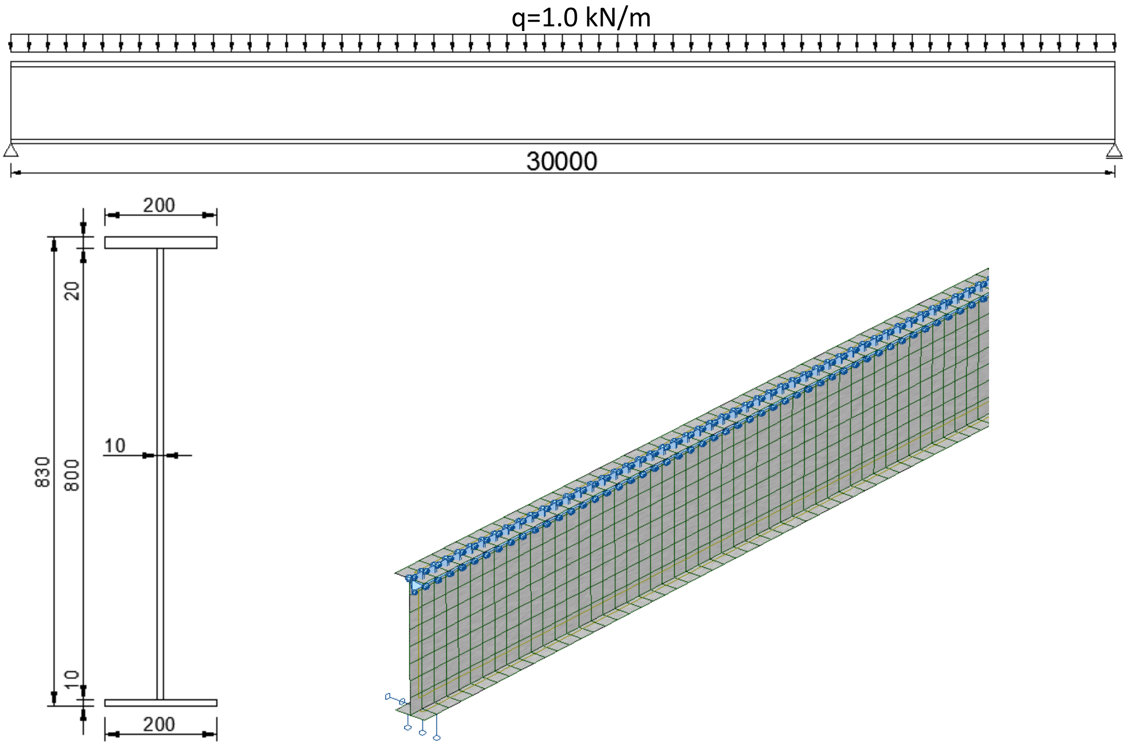

Fig. 1.1. Geometrical dimensions and a fragment of the computational model of the plate girder

The analysis of the plate girder without stiffeners

The plate girder lost local stability of its web and upper flange at its midspan (Fig. 3.1) which is obvious due to maximum bending moment and compressive stresses. A possible counteraction to this stability loss is use of stiffeners.

The buckling sensitivity coefficient α_{cr} for the plate girder is:

$$\alpha_{cr} = \frac{F_{cr}}{F_{Rd}} = 6.04 ,$$

where:

F_{Rd} – comparative load equal to the combination of loads;

F_{cr} – critical load.

The analysis of the plate girder with the stiffeners

The following location combinations of the transverse and longitudinal stiffeners of the plate girder were considered:

- the plate girder with one transverse stiffener,
- the plate girder with three transverse stiffeners,
- the plate girder with three transverse and four longitudinal stiffeners,
- the plate girder with the transverse stiffeners over the whole its span,
- the plate girder with the transverse and longitudinal stiffeners over the whole its span.

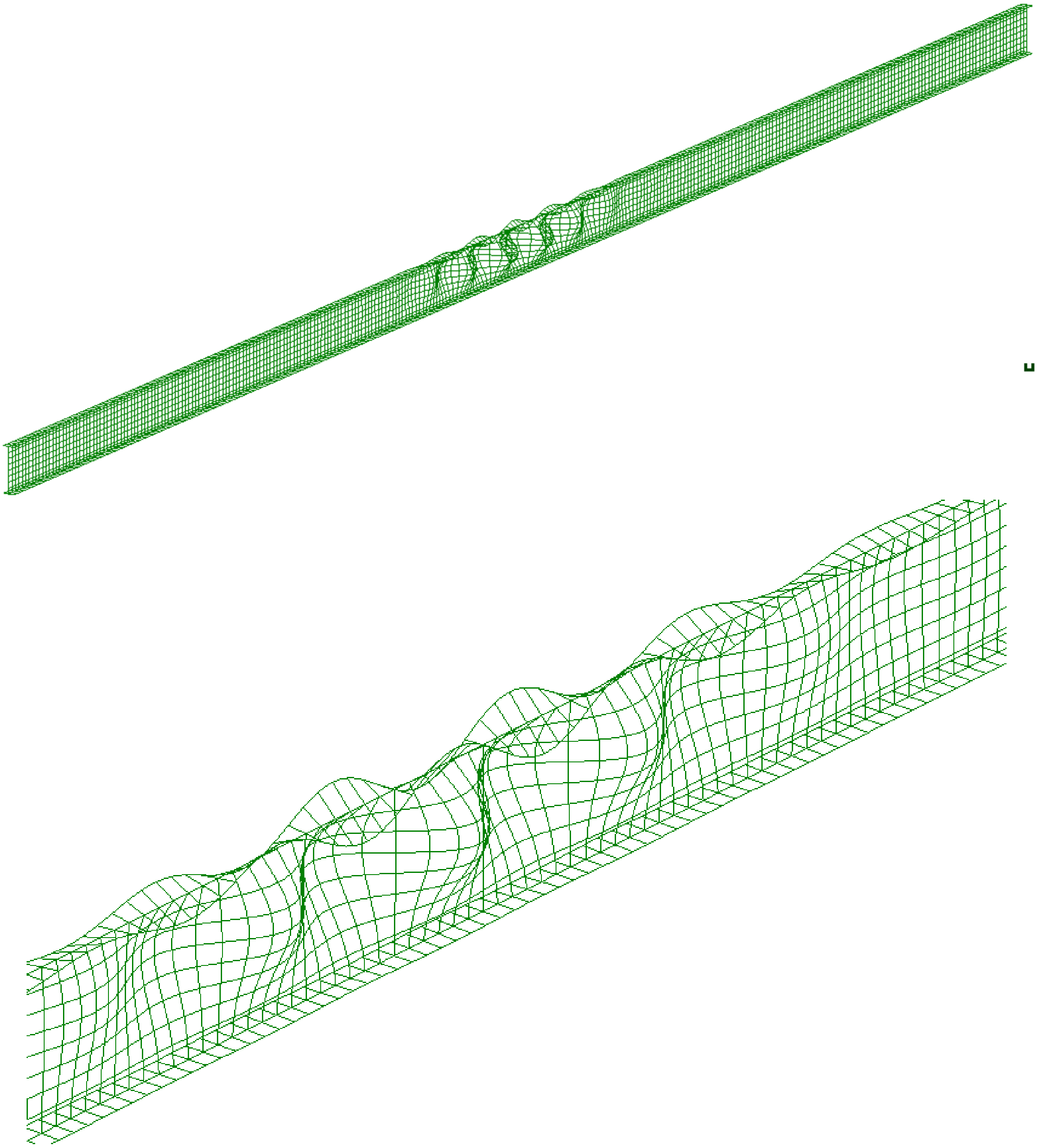

Fig. 3.1. The first form of buckling of the plate girder without stiffeners

The plate girder with one transverse stiffener

The transverse stiffener was applied at midspan of the plate girder (Fig. 3.2) which resulted in the value of the coefficient $\alpha_{cr} = 6.12$. As it is seen, application of the single stiffener increased buckling resistance of the web and the upper flange of the plate girder not much and buckling also occurs at midspan of the plate girder.

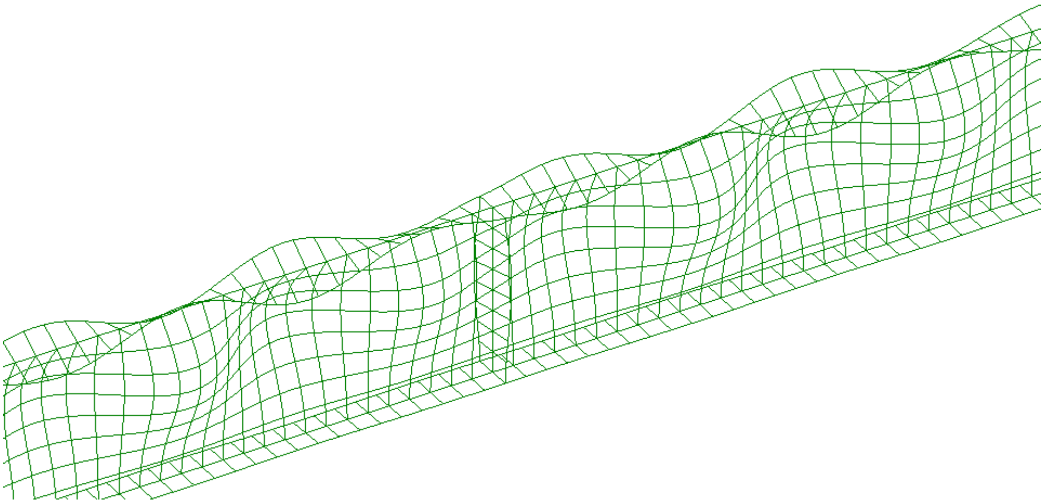

Fig. 3.2. The first form of buckling of the plate girder with one transverse stiffener

The plate girder with three transverse stiffeners

Three stiffeners with spacing of 2 m (Fig. 3.3) were applied and the obtained value of the coefficient α_{cr} was 6.19, which also means that increase of buckling resistance was not high.

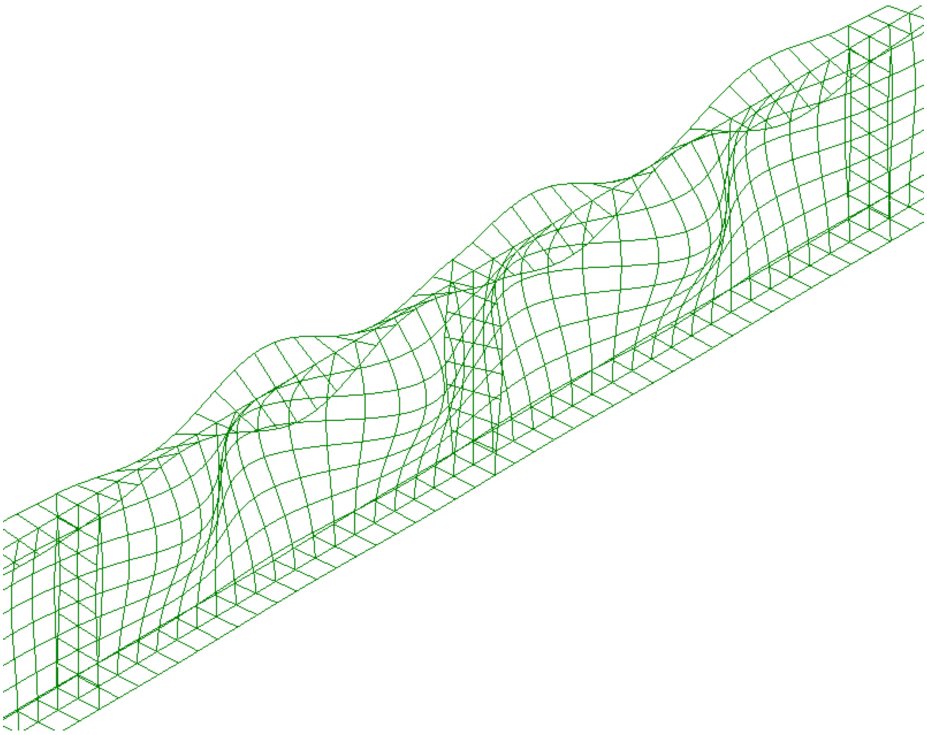

Fig. 3.3. The first form of buckling of the plate girder with three transverse stiffeners

The plate girder with three transverse and four longitudinal stiffeners

Two times two longitudinal stiffeners were applied with such location that the distance from the upper to the lower flange was divided into three equal parts (Fig. 3.4) and the obtained value of the coefficient α_{cr} was 6.32. Application of the longitudinal stiffeners resulted in stiffening the plate girder in the area with the stiffeners and lack of stability loss in this area, but the plate girder lost its stability in the neighbouring area. Therefore, increasing the number of transverse and longitudinal stiffeners is logical.

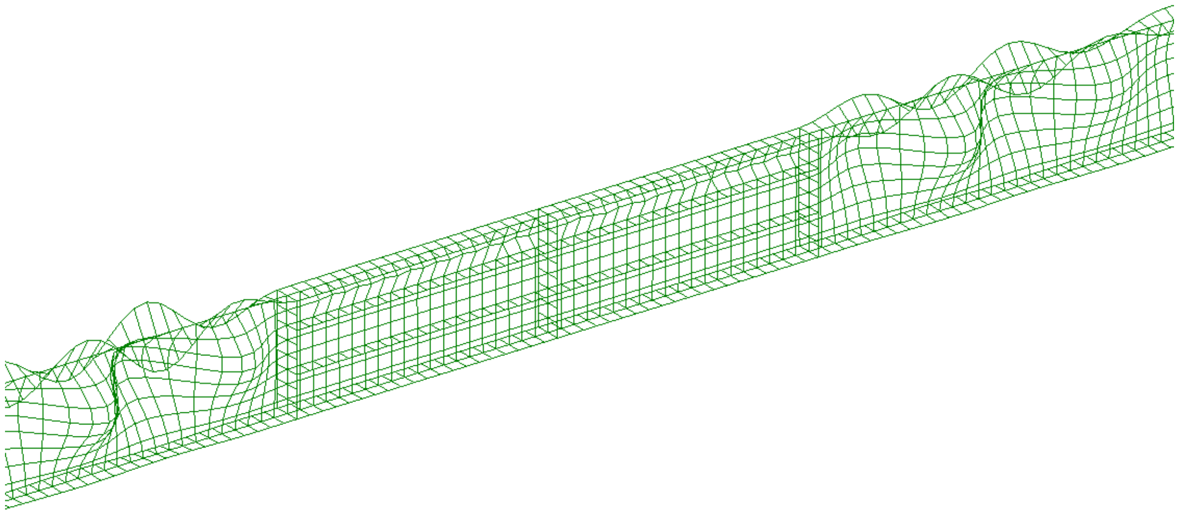

Fig. 3.4. The first form of buckling of the plate girder with three transverse and four longitudinal stiffeners

The plate girder fully stiffened with the transverse stiffeners

Only the transverse stiffeners were applied over the whole length of the plate girder with spacing of 1m (Fig. 3.5) and the obtained value of the coefficient α_{cr} was 6.46. An expected effect in the form of significant increase of resistance of the plate girder to local stability loss was not obtained.

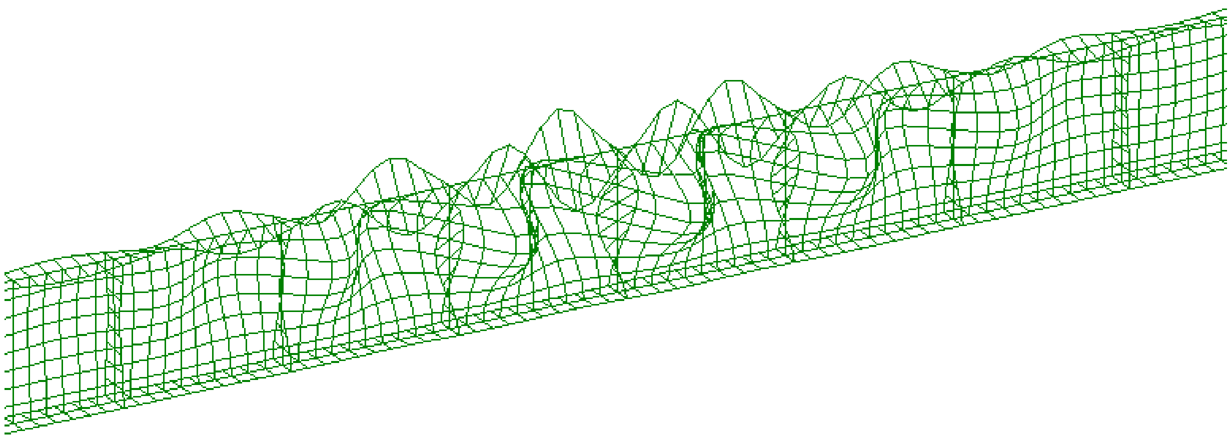

Fig. 3.5. The first form of buckling of the plate girder with the transverse stiffeners over the whole its length

The plate girder fully stiffened with the transverse and longitudinal stiffeners

Both the transverse and the longitudinal stiffeners were applied over the whole length of the plate girder (Fig. 3.6) and the obtained value of the coefficient α_{cr} was 13.25. It may be stated that it was a significant increase of buckling resistance of the plate girder in comparison to the previous results. The deformation shows that in this case, the web was not buckled; it was sufficiently protected from stability loss, while the upper flange was buckled.

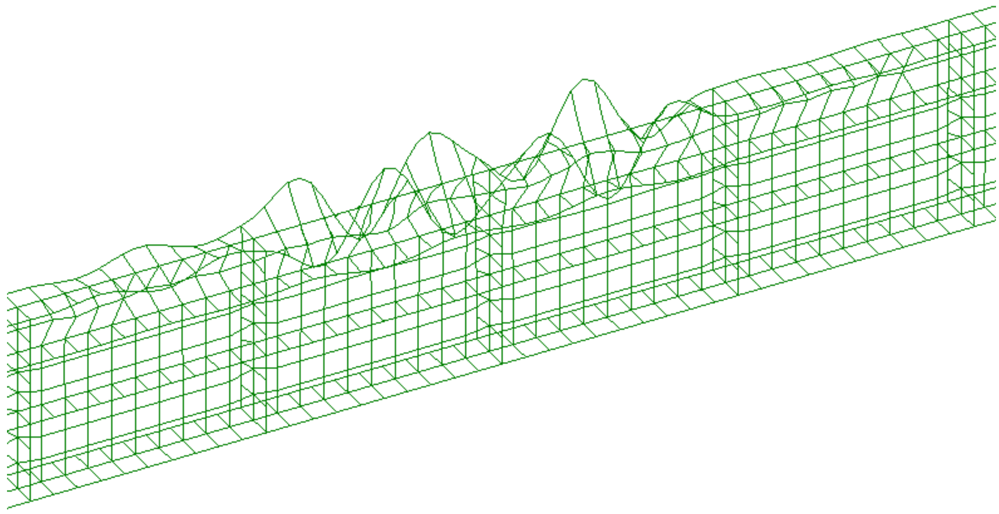

Fig. 3.6. The first form of buckling of the plate girder with the transverse and longitudinal stiffeners over the whole its length

Tab. 3.1. Comparison of the obtained results of the nonlinear stability analysis of the plate girder

Case	α_{cr}
The plate girder without stiffeners	6.04
The plate girder with one transverse stiffener	6.12
The plate girder with three transverse stiffeners	6.19
The plate girder with three transverse and four longitudinal stiffeners	6.32
The plate girder with the transverse stiffeners over the whole its span	6.46
The plate girder with the transverse and longitudinal stiffeners over the whole its span	13.24

4. Computation of nonlinear static equilibrium

From the stability analysis that was carried out it does not follow that transition to a destruction state of the plate girder will result from buckling effect. Such flexural work of the plate girder is possible that causes plastic stresses and formation of plastic hinges and thus the plate girder transits from a structure to a mechanism. Therefore, the analysis of states of static equilibrium should be carried out by solving incremental equations of equilibrium:

$$\left[K_L - K(\Delta\sigma) - K(\Delta q)\right]\Delta q = \Delta R \, .$$

The plate girder without stiffeners

A path of states of equilibrium (Fig. 4.1) was determined by calculations. For the load of p=4.6 kN/m plastic stresses of 235 MPa occurred in the plate girder and the critical load was 9.05 kN/m. Then, carrying possibilities of the plate girder would be exhausted by limit state of carrying capacity.

Buckling sensitivity of the plate girder was studied as well by determining the path of states of equilibrium with presence of axial compressive load, taking on the constant load of p=4 kN/m. The results of calculations are presented in Tab. 4.2 and in Fig. 4.2.

Tab. 4.1. The results of P-delta calculations

Load p [kN/m]	uz [cm]
0	4.542
0.5	7.292
1	10.042
1.5	12.779
2	15.526
2.5	18.272
3	21.081
3.5	23.764
4	26.51
4.5	29.257
4.6	29.806

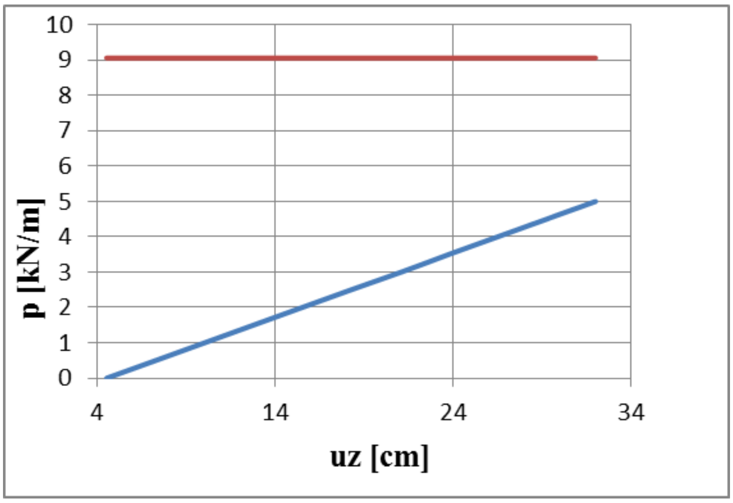

Fig. 4.1. The path of states of equilibrium for the plate girder without stiffener

Tab. 4.2. The results of P-delta calculations

Load N [kN/m]	uz [cm]
0	26.577
1	26.59
5	26.642
15	26.774
35	27.042
75	27.589
105	28.012
250	30.212
500	34.728
550	35.763

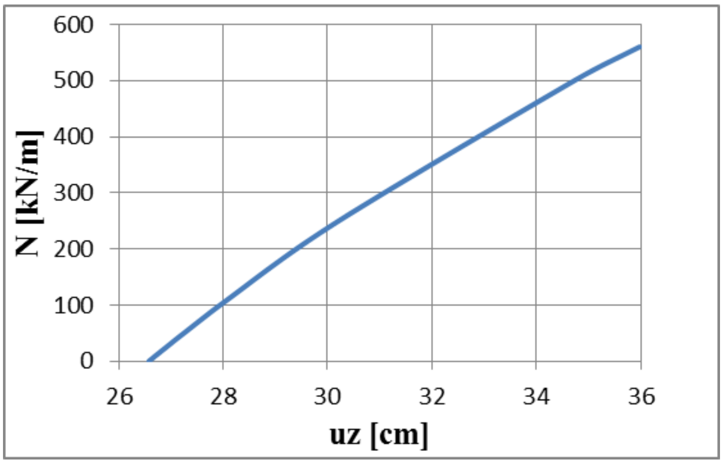

Fig. 4.2. The path of states of equilibrium for the plate girder without stiffener

In this case, possibilities of the plate girder are exhausted as a result of stability loss in elastic range and stresses are even lower than plastic stresses and are $\sigma = 230.4$ MPa. Significant displacements will occur in direction perpendicular to the plane of the plate girder.

The plate girder with the transverse and longitudinal stiffeners

The results obtained for the plate girder stiffened in this way are presented in Tab. 4.3 and the path of states of equilibrium is shown in Fig. 4.3. For the load of about p=4.6 kN/m plastic stresses of 235 MPa also occurred in the stiffened plate girder and the critical load was 19.86 kN/m. Therefore, limit state of carrying capacity would be reached earlier through formation of the plastic hinge.

Tab. 4.3. The results of P-delta calculations

Load p [kN/m]	uz [cm]
0	5.443
0.5	8.066
1	10.89
1.5	13.314
2	15.94
2,5	18.567
3	21.196
3.5	23.825
4	26.456
4.5	29.088
4.6	29.626

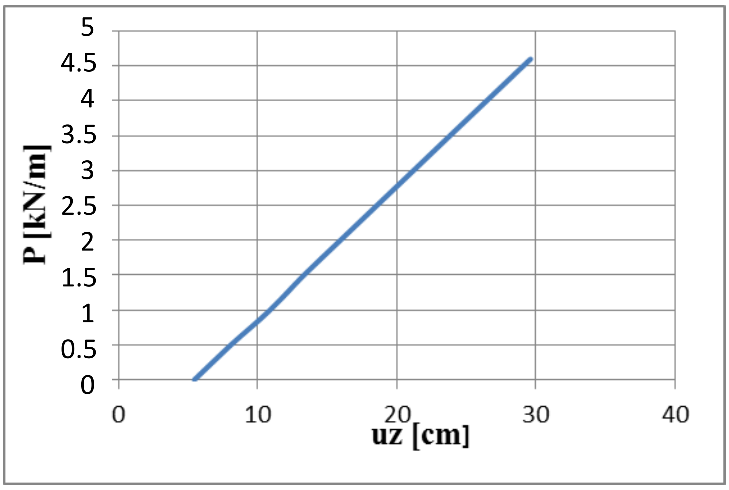

Fig. 4.3. The path of states of equilibrium for the stiffened plate girder

Also buckling sensitivity of the stiffened plate girder was studied by determining the path of states of equilibrium with presence of axial compressive load, as in the case of the plate girder without stiffeners. The results of calculations are presented in Tab. 4.4 and in Fig. 4.4.

Tab. 4.4. The results of P-delta calculations

Load N [kN/m]	uz [cm]
0	26.456
1	26.468
5	26.515
50	27.053
100	27.712
250	29.688
500	33.663
550	34.569
560	34.764

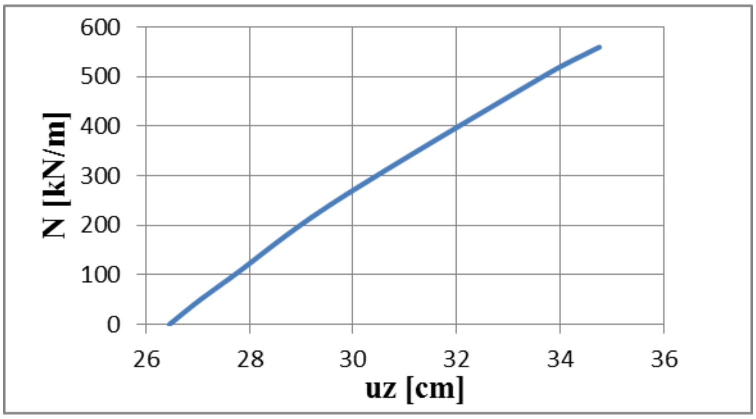

Fig. 4.4. The path of states of equilibrium for the stiffened plate girder

In this case, possibilities of the stiffened plate girder would be exhausted as a result of reaching plastic stresses by maximum stress.

5. Summary

The plate girder that has been analysed has relatively large span and then the bending moment is a dominant one among internal forces, the normal compressive stresses determine local stability loss and application of the transverse stiffeners does not much affect increase of resistance to local stability loss.

The transverse stiffeners will have meaning when tangential stresses from shearing forces that usually occur in the areas of support have a crucial influence on local stability loss. Other cases of occurring significant shearing forces are plate girders under overhead cranes and plate girders of railway bridges that are loaded with large forces concentrated at places of contact with vehicles' wheels.

Application of the longitudinal stiffeners results in increase of the coefficient α_{cr}, i.e. results in increase of buckling resistance.

References

[1] Brzoska, Z., *Statyka i stateczność konstrukcji prętowych i cienkościennych*, PWN, Warszawa 1965.
[2] ECCS Technical Committee 8 – *Stability, Rules for Member in EN1993-1-1,Background documentation and design guidelines*, Nr 119, 2006.
[3] ECCS Technical Committee, *Design of Steel Structures, Part 1-1: General rules and rules for buildings*, 2010.
[4] PN-EN 1993-1-5 *Eurokod. 3 Projektowanie konstrukcji stalowych, część 1-5: Blachownice*,
[5] Waszczyszyn, Z., Chichoń, Cz., Radwańska, M., *Metoda elementów skończonych w stateczności konstrukcji*, Arkady, Warszawa 1990.
[6] Autodesk Robot Structural Analysis Professional 2013, licencja dla WSEiZ.