STUDY OF BEHAVIOUR OF SINGLE STOREY STEEL FRAMES IN SEISMIC IMPACT, ACCORDING TO ORDINANCE № РД-02-20-2 AND БДС EN 1998-1

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***Abstract**: At present time in Bulgaria two codes are simultaneously in use - our national standards and European standards, which are valid everywhere in the European Union. The package European standards called Eurocodes, meets the latest achievements of science in the field of structural engineering, but for various reasons was not allowed to cancel completely our obsolete national standards. Through several examples in the article bellow I will try to show what is the real consequences of unnecessary delay of the validity of Eurocodes for all building structures.*

***Key words**: standards, steel frames, earthquake, behaviour, pushover analysis*

1. Research

For the purpose of this research two one-storey steel frames are analysed, which are really designed. Their behaviour during the seismic impact is analysed according to the national document Regulation № РД-02-20-2 [2] and European standard БДС EN 1998-1 [1].

The research of the selected frames was done with software package SAP 2000 v.14.2 [3].

1.1. Building with single span and single storey frames in the town of Belovo

The building in which the frame is part, bears loads as follow:

- snow in the region where it was built - s_t = 1,5 kN/m^2;
- dead loads on roof and facades - $g_п$ = 0,412 kN/m^2;
- the loading in seismic impact is shown in Table 1:

Table 1. Particular features of seismic impact

Regulation	Regulation № РД-02-20-2	БДС EN 1998 - 1
Seismic coefficient - k_c	0,27	0,23
Coefficient of behaviour - q	4,0	≤ 4 when DCM
Combination coefficient - ψ_2	0,5	0,3

The frame is constructed by welded steel sections with a geometry shown on Fig. 1. Used steel is S235. The soil under the building belongs to the category „C”.

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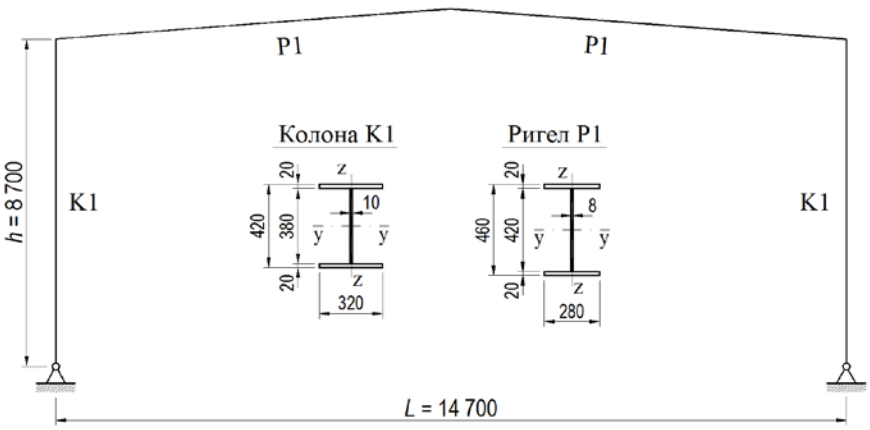

Fig. 1. Geometry and static scheme of typical steel frame, part of building in the town of Belovo.

a) research through response spectrum analysis, according to the Regulation № РД-02-20-2 [2]

When ratio of height of frame column *h* to the height of section *b* is more than 15, firstly accepted coefficient of behaviour *q* = 4 have to be decreased .

(1.1) $\frac{h}{b} = \frac{8700}{420} = 20{,}7 > 15 \rightarrow$ behaviour coefficient $\boldsymbol{q}$ have to be decreased,

where:
h = 8700 mm is the height of the column, see Fig. 1;
b = 420 mm – the height of welded section of the column.

The changed coefficient of behaviour will have the value:

(1.2) $$q_m = \frac{q}{k} = \frac{4}{1{,}286} = 3{,}11$$

The frame elements which section and dimensions are mentioned in the Fig. 1 satisfied all examination in ultimate limit state (ULS).

The calculated through design model elastic horizontal drift, caused by earthquake, has a value Δ_E = 4,29 cm < *h*/200 = 4,35 cm.

Compressed elements of the frame as the columns have to be examined for sensibility for second order effects (p - Δ effects), according to the formulae:

(1.3) $$\theta = \frac{Q.\Delta_E}{F.h.R} = \frac{182{,}756.4{,}29}{24{,}8.870.0{,}3214} = 0{,}115 > 0{,}1,$$

where:
Q = 182,756 kN is total vertical load in columns of frame;
F = 24,8 kN – total shear force in columns of frame;
R = 1/q_m = 0,3214 – modified coefficient of reaction.

Obviously when design of the frame are being done according to the Regulation № РД-02-20-2, p-Δ the effects have to be considered.

b) research through response spectrum analysis, according to БДС EN 1998 - 1 [1]

Assumed coefficient of behaviour q = 1,5.

The frame elements satisfied all examination in ultimate limit state (ULS).

The calculated through research model elastic horizontal drift, caused by earthquake, has a value Δ_E = 8,87 cm.

Considering the assumed coefficient of the behaviour q = 1,5 , real horizontal drift d_r will be:

(1.4) $$d_r = \Delta_E . q = 8{,}87.1{,}5 = 13{,}3\text{cm}$$

The horizontal drift of a frame caused by earthquake is limited up to:

(1.5) $$d_r.\nu \le 0{,}0075.h \rightarrow \begin{cases} d_r.\nu = 13{,}305.0{,}4 = 5{,}3\text{cm} \\ 0{,}0075.h = 0{,}075.870 = 6{,}525\text{cm} \end{cases} \rightarrow \text{requirement is done.}$$

Necessity of reporting the p - Δ effects:

(1.6) $$\theta = \frac{Q.d_r}{F.h} = \frac{180{,}97.13{,}305}{52{,}23.870} = 0{,}053 < 0{,}1,$$

where:
Q = 180,97 kN is a total vertical load in columns of frame;
F = 52,23 kN – total shear force in the columns.

When analysis of a frame is done according to БДС EN 1998 - 1 it is not necessary p-Δ effects to be considered.

c) research through non-linear static method of analysis (pushover analysis)

When the non-linear static method for analysis is used, steel frame is calculated two times – with the conditions of loading according to the Regulation № РД-02-20-2 and standard БДС EN 1998 - 1. In the Table. 2 are shown calculated results.

Table 2. Conditions of loading and results from the pushover analysis

Regulation, describing conditions of loading	Regulation № РД-02-20-2	БДС EN 1998 - 1
Coefficient of behaviour - q	1	1
horizontal drift, elastically - Δ_E	12,7 cm	13,3 cm
- plastic hinge when Δ_E is reached	no	no
- shear force when Δ_E is reached	76,72 kN	80,57 kN
Horizontal movement for formation of 1st plastic hinge - Δ_{pl}	22,74 cm	22,78 cm
- shear force when Δ_{pl} is reached	137,06 kN	137,98 kN

Obviously to obtain plastic hinge in the frame, a horizontal drift Δ_{pl} have to be many times bigger than the movement Δ_E when q = 1. In other words, plastic hinge in the frame will not be formed during the earthquake. The frame will work in a elastic state.

1.2. Building with two span one storey frame, situated in the town of Kavarna.

The building in which the frame is part, bears loads as follow:
- snow in the region where it was built - s_t = 0,88 kN/m^2;
- dead load on the roof - $g_п$ = 5,193 kN/m^2;
- the loading during the seismic impact is shown Table. 3:

Table 3. Particularities of loading during the Earthquake

Regulation	Regulation № РД-02-20-2	БДС EN 1998 - 1
Seismic coefficient - k_c	0,27	0,32
Coefficient of behaviour - q	4,0	$\leq$ 4 when DCM
Coefficient of combination - ψ_2	0,5	0,3

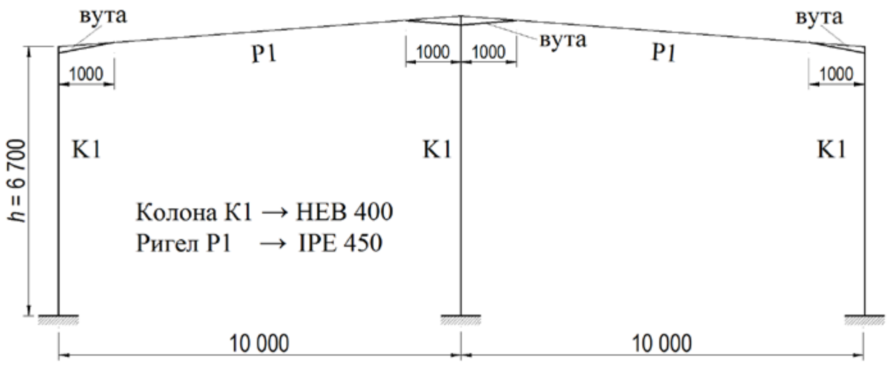

Fig. 2. Geometry and static scheme of typical steel frame, part of the building in the town of Kavarna

For this building is it typical that the roof is green. On the roof are put 60 cm soil on which the grass is planted.

The frame is build from steel hot-rolled sections with the geometry as is shown on the Fig. 2. The steel which is used is a steel S235. The soil under the building is category „C".

a) research through response spectrum analysis, according to the Regulation № РД-02-20-2 [2]

Firstly is accepted coefficient of behaviour q = 4, but here again the ratio of height of frame's column h to the height of section b is more than 15.

(1.7) $\frac{h}{b}=\frac{6700}{400}=16{,}75>15 \rightarrow$ coefficient of the behaviour $\boldsymbol{q}$ must be decreased,

The changed coefficient of behaviour will have the value:

$$q_m=\frac{q}{k}=\frac{4}{1{,}088}=3{,}676 \qquad (1.8)$$

The frame elements which section and dimensions are mentioned in the Fig. 2 satisfied all examination in ultimate limit state (ULS).

The calculated through research model elastic horizontal drift, caused by earthquake, has a value Δ_E = 1,43 cm < h/200 = 3,35 cm.

Compressed elements of the frame as the columns have to be examined for sensibility for second order effects (p - Δ effects), according to the formulae:

$$\theta=\frac{Q.\Delta_E}{F.h.R}=\frac{570{,}09.1{,}43}{112{,}42.670.0{,}272}=0{,}0398<0{,}1, \qquad (1.9)$$

During the frame analysis according to the Regulation № РД-02-20-2 is not necessary to account p-Δ effects.

b) research through response spectrum analysis, according to БДС EN 1998 - 1 [1]

Assumed coefficient of the behaviour during the Earthquake q = 1,5.

Neither of frame elements does not satisfy the examination of ultimate limited state.

The calculated through research model elastic horizontal drift, caused by earthquake, has a value equal Δ_E = 4,63 cm.

Considering the assumed coefficient of the behaviour q = 1,5 , real horizontal drift d_r will be:

(1.10) $d_r = \Delta_E . q = 4{,}63 . 1{,}5 = 6{,}94\text{cm}$

The horizontal drift of frame caused by earthquake is limited to:

(1.11) $d_r . \nu \leq 0{,}0075 . h \rightarrow \begin{cases} d_r . \nu = 6{,}94 . 0{,}4 = 2{,}78\text{cm} \\ 0{,}0075 . h = 0{,}075 . 670 = 5{,}02\text{cm} \end{cases} \rightarrow$ requirement is done.

Necessity to account p - Δ effects:

(1.12) $\theta = \frac{Q . d_r}{F . h} = \frac{556{,}01 . 6{,}94}{367{,}18 . 670} = 0{,}015 < 0{,}1 ,$

When analysis of a frame is done according to БДС EN 1998 - 1 it is not necessary p-Δ effects to be accounted.

c) research through non-linear static method of analysis (pushover analysis)

When the non-linear static method for analysis is used, steel frame is calculated two times – with the conditions of loading according to the Regulation № РД-02-20-2 and standard БДС EN 1998 - 1. In the Table. 4 are shown calculated results.

Tabble 4. Conditions of loading and results from the pushover analysis

Regulation descraibing Loading conditions	Regulation № РД-02-20-2	БДС EN 1998 - 1
Coefficient of behaviour - q	1	1
horizontal drift, elastically - Δ_E	5,21 cm	6,93 cm
- plastic hinge when Δ_E is reached	non	Yes in the columns
- shear force when Δ_E is reached	413,54 kN	570,89 kN
Horizontal movement for formation of 1st plastic hinge - Δ_{pl}	6,58 cm	6,58 cm
- shear force when Δ_{pl} is reached	555,55 kN	556,2 kN

In order to create plastic hinge in frame, loaded according to the Regulation № РД-02-20-2, the horizontal drift Δ_{pl} have to be bigger of movement Δ_E when q = 1.

When the coefficient of behaviour q = 1,5 and loading conditions are according to БДС EN 1998 - 1, the horizontal drift of top of the frame Δ_E = 4,63 cm. To obtain 1st plastic hinge , the behaviour coefficient have to be $q \leq 1{,}08$.

Conclusions

The above-mentioned examples clearly shows that the real coefficient of behaviour q of single storey steel frames during earthquake is smaller than determined by Regulation № РД-02-20-2 [2] and БДС EN 1998-1:2005 [1]. And while the second standard allows the possibility to decrease the value of the coefficient q, in the 1st one the value is fixed and is equal to q = 4.

The unreasonably large values of the q in Regulations № РД-02-20-2 can cause the following:

- resulting internal forces in elements of the frame due to earthquake are falsely low;

- the horizontal shear forces in anchors, respectively in foundation, are many times lower than the real one.

The author could recommend analysis of one storey steel frames for seismic impact to be performed with a value of coefficient of behaviour $q \leq 2$, which is the value of the system „Inverted pendulum", see БДС EN 1998-1:2005 [1].

LITERATURE

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