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NUMERICAL ANALYSIS OF A SCALED-DOWN COLD-FORMED STEEL STRUCTURE SUBJECTED TO SEISMIC ACTIONS

BY

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Abstract. The paper presents the numerical evaluation of the structural performance of a scaled-down cold-formed steel CFS profile structure subjected to seismic actions. The main parameter of the investigation was the direction of the applied seismic action, with three directions being considered in the analysis. The obtained results reveal that the structural system is a very stiff one. The peak lateral displacements were recorded at the top of the model, with the maximum value occurring in the Ox direction, the direction in which the structure is more flexible. However, important values were also obtained for the 45° direction. A similar trend was observed for the distribution and magnitude of the axial force.

Keywords: numerical model, scaled-down structure, CFS structures, structural performance, seismic action direction.

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1. Introduction

Cold-formed steel (CFS) sections, that is structural sections manufactured from steel sheets using cold rolling, brake pressing, or folding, have been around for many years. The major structural advantage of CFS members lies in the small thickness of the material leading to an extremely lightweight construction (Macdonald et al., 2008). Compared to the structural elements made of hot-rolled counterparts, CFS members are often more economical and efficient due to their ease and speed of construction as well as greater flexibility in manufacturing (Mojtabaei et al., 2018).

The seismic performance of CFS frame buildings benefits from using a lightweight solution compared with traditional masonry or concrete construction. However, the seismic performance of such structural systems was relatively unknown until the last 20 years. Since then, significant research has been conducted to advance the state of the art (Schafer et al., 2016; Karabulut and Soyoz, 2017; Taranu et al., 2023).

Computer models and numerical simulations are, sometimes, cost-effective ways of assessing the behavior of structures to seismic actions, provided that the used numerical model and loading scenarios are the correct ones (Popa and Mathe, 2011; Leng et al. 2017, Toma et al., 2020). The paper presents some preliminary results on the numerical analysis of a scaled-down cold-formed steel structure subjected to seismic action. The results of the numerical model will be later validated and imposed calibrations will be made using shake table tests.

2. Structural model and loading characteristics

The structural elements were made of a DX51D+Z steel sheet cold-formed into C89/41/12/1 profiles. The elements were connected using 2x Ø4x22 mm self-drilling self-tapping screws. The dimensions of the structural model were 2.3x2.7x2.6 m. The CFS frames were covered using oriented strand boards OSB on the outside and plaster boards on the inside. The scaled-down model mounted on the shake table is shown in Fig. 1.

SAP2000 computer program was used to develop and analyze the structure. The finite element numerical model of the bare CFS frame structure is shown in Fig. 2 together for the selected points for data recording and further analysis. The connections between the individual elements were assumed to be rigid. Only beam-type elements with the real C89/41/12/1 cross-section were used.

The reduced-scale model, illustrated in Fig. 1, had in-plane dimensions of 2700 × 2300 mm, a wall height of 2100mm and a total height (at the ridge) of 2597mm. The model consisted of four panels. The roof consisted of trusses featuring inclined upper chords, as depicted in Fig. 2, orientated transversely. The rigidity of the roof was obtained by employing truss panels positioned atop the longitudinal wall panels and at the center of the transversal wall panels. The

longitudinal wall panels featured openings for windows and doorways. A more detailed description of the model can be found in Taranu et al., 2023.



Fig. 1 – Scaled-down structural model.

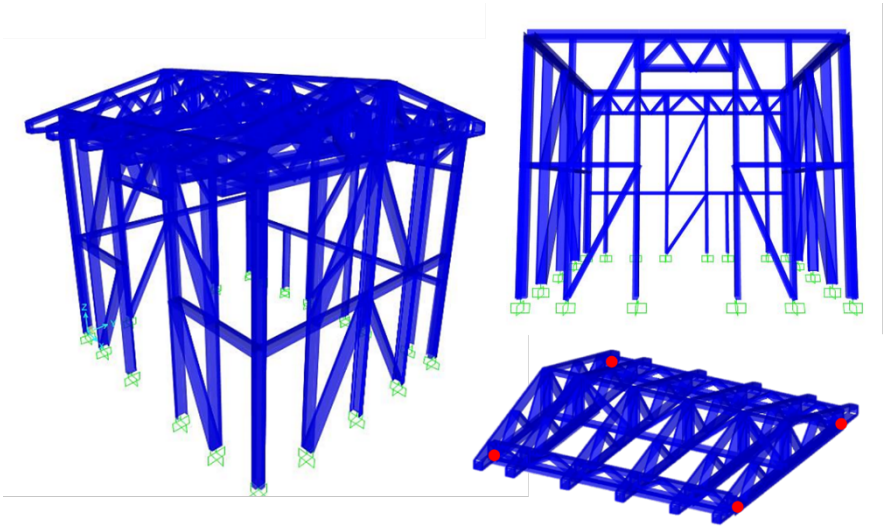


Fig. 2 – CFS model in SAP2000.

For this stage of the research only the dead load was considered to act on the structure. The structure was subjected to seismic action, in three different directions: Ox direction, Oy direction and at a 45° angle direction. The selected seismic recording for this study case was the one registered for the 4th March 1977 Vrancea earthquake, presented in Fig. 3, having a Peak Ground

Acceleration (PGA) of 194.93cm/s^2 at 6.14sec for the North-South NS component.

A Time-History Analysis was conducted using the Direct Integration method for each of the three directions mentioned above.

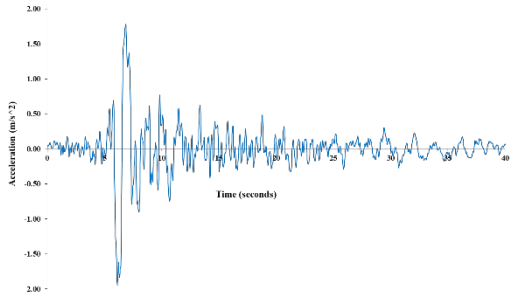


Fig. 3 – Vrancea 1977 earthquake (NS component).

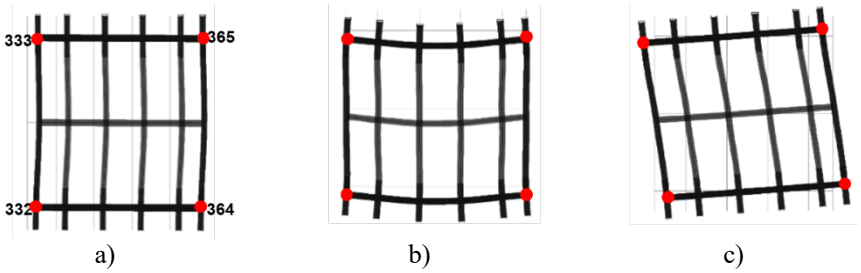
3. Results and discussion

The fundamental period of the CFS frame structure, resulting from the modal analysis, was only 0.038066sec, the structure being very stiff. This high stiffness was due to the multiple bracings used in the CFS frames. The modal analysis results for the first three modes were presented in Table 1. In Fig. 4, the deformed shape of the structure associated with each mode of vibration is illustrated.

Table 1

Dynamic characteristics of the CFS frame structure

Mode no.	Period [sec]	Frequency [sec^{-1}]	Circular frequency [rad/sec]	Eigenvalue [rad^2/sec^2]
1	0.03806	26.2705	165.062	27245.606
2	0.02879	34.7322	218.228	47623.857
3	0.02277	43.9183	275.947	76146.814



a) b) c)

Fig. 4 – Deformed shape corresponding to the: a) 1st mode of vibration; b) 2nd mode of vibration; c) 3rd mode of vibration.

The difference in stiffness of the CFS frames could also be observed by analyzing the response of the structure to the seismic action. For this purpose, the displacements at the top level were compared, on all three considered directions for the seismic action. Table 2 presents the displacement values of four nodes found at the top of the structure, pointed out in Fig. 4, the maximum values for each seismic action being emphasized. The results of the displacements for the case when the seismic action acted on a 45° angle are presented for both directions, i.e. Ox and Oy.

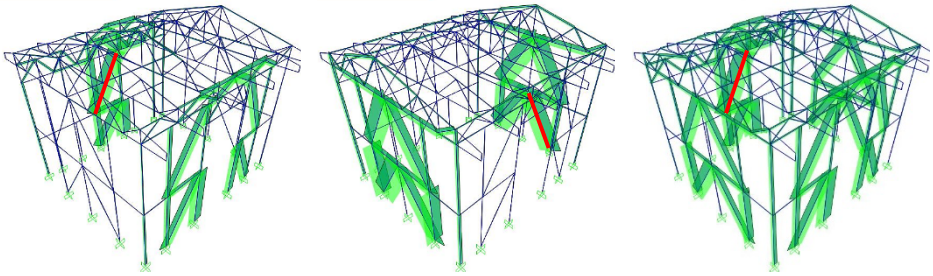
Table 2

Maximum displacements of the CFS frame structure due to seismic action

Node	Displacement [$\times 10^{-2}$ mm]			
	Vrancea '77 - Ox direction	Vrancea '77 - Oy direction	Vrancea '77 - 45° direction	
	Ox	Oy	Ox	Oy
332	6.69	3.31	4.75	**2.47**
333	**7.61**	3.32	**5.36**	2.43
364	6.69	3.41	4.7	2.3
365	7.43	**3.42**	5.28	2.35

The displacement results revealed that the CFS frames found in the Ox direction were the less rigid ones, with a maximum displacement of 0.0761 mm when subjecting it to seismic action. The smaller stiffness was due mainly to the greater openings for the door and window. The CFS frames found on the Oy direction of the structure are stiffer, with a displacement of only 0.0342mm being obtained. For the case when the seismic action acted on a 45° angle direction, significant values were also obtained, compared to the other two cases, as presented in Table 2.

The results concerning the axial force revealed that the structural elements were more loaded when the seismic action acted on the Ox direction, the most loaded element being one bracing, emphasized in Fig. 5a. The maximum axial force for this case reached 634.74N. For the seismic action in the Oy direction, the maximum value for the axial force was 387.9N, associated with the bracing emphasized in Fig. 5b. For the 45° direction of the seismic action, higher values were obtained than in the previous case, the maximum value being 449.71N. In this last case, it was observed in Fig. 5c that the energy dissipates in both directions, leading to important values of the axial force in all the bracings of the structure.



N_{max}=634.74N a) N_{max}=387.90N b) N_{max}=449.71N c)

Fig. 5 – Axial forces due to Vrancea 1977 seismic action on: a) Ox direction; b) Oy direction; c) 45° direction.

The tensile stress for the most loaded elements, for each direction of the applied seismic action was:

$$\sigma_{x,\,Ox}=1.912\,\frac{N}{mm^2} \qquad \sigma_{x,\,Oy}=1.168\,\frac{N}{mm^2} \qquad \sigma_{x,45}=1.355\,\frac{N}{mm^2}$$

Considering the minimum yield stress of the material of f_y=344.74N/mm^2, it resulted that all the elements will remain in the elastic domain, the value of the obtained tensile stress being much smaller than the yield limit.

4. Conclusions

Based on the obtained results using numerical simulations it can be concluded that the structural system based on CFS frames is a stiff one due to the presence of diagonal elements that stiffen the structure. The peak lateral displacements are larger in the direction of the existing openings (windows and doors) and smaller in the perpendicular direction to the openings. Axial forces have significant values in the elements bordering the door and window openings and exhibit larger values when the seismic action is applied in the Ox direction of the model.

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ANALIZA NUMERICĂ A UNEI STRUCTURI DIN OȚEL LAMINAT LA RECE SUPUSĂ ACȚIUNILOR SEISMICE

Articolul prezintă evaluarea numerică a performanței structurale a unei structuri realizată din profile metalice laminate la rece, la scară redusă, ce este supusă acțiunilor seismice. Parametrul principal al cercetării este direcția de aplicare a acțiunii seismice, fiind considerate trei direcții în cadrul analizei. Rezultatele obținute sunt caracteristice unei structuri foarte rigide. Valori maxime ale deplasărilor laterale au fost înregistrate la nivelul superior al structurii, maximul fiind atins în cazul aplicării acțiunii seismice pe direcția Ox, direcție pe care structura este mai flexibilă. Totuși, valori semnificative au fost obținute și pe direcția de 45°. De asemenea, o tendință similară a fost observată și în cazul distribuției magnitudinii forței axiale.