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EXPERIMENTAL TESTS OF THIN-WALLED STEEL ROOF PROFILES

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Abstract. The main purpose of the performed tests in this paper is the checking of the stiffness characteristics of steel sheets at several load levels.

The testing of the elements was carried out according to EC3, chapter 9, “Testing Procedure”, because the elements are classified as cold-rolled thin-gauge profiles as stated in Romanian Norm NP 012-92 (EC 3 parts 1-3).

The testing procedure consisted of several repeated loading–unloading cycles. Finally, one specimen from each class was loaded until collapsed. The local buckling of the edge ribs caused the collapse of the profiles (in reality this is impossible because the steel sheets are coupled).

The ultimate deflections are limited according to several Norms between *L*/100 and *L*/200. The loading–unloading cycles pointed out the lack of permanent strains for maximum displacements below the *L*/200 limit. Out of this limit the permanent strains appear, *i.e*. the rib folding in the support areas.

The presented study is a part of a large Research Program in the frame of the Faculty of Civil Engineering and Building Services in partnership with INCERC, Iaşi Branch. The tests were carried out in the stand of the Testing Laboratory of the Structural Mechanics Department.

Key words: thin-walled steel profiles; local buckling; quasi-static testing.

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1. Introductions

The main purposes of the research were the study of the behavior under gravitational loads of the following types of NERGAL roof profiles: (a) 0.5 mm, (b) 0.75 mm and (c) 1.00 mm. The strip of sheets is made of DX51DG steel according to the EN 10142 Euro Norm and the EN 10027 parts 1 and 2. According to the EN 10142 this steel is denominated as 1.0226 and the ultimate strength is R_m = 500 N/mm^2.

It was intended to establish the element behavior when this one is subjected to gravitational loads, according to EC3, chap.9, “Testing Procedure”. This was because the elements are classified as cold-rolled thin-gauge profiles as stated in Romanian Norm NP 012-92 (EC 3 parts 1-3). Under these circumstances the elements behave different as the usual rolled profiles due to the fact that local buckling can occur, correlated with the profile shape and the sheet thickness.

The main purpose of the tests is the checking of the stiffness characteristics of the NERGAL steel sheets at several load levels.

2. The Testing Faccilities

A special testing stand was designed in order to carry on the tests of the NERGAL steel sheets. The two KB600-5 profiles of the stand are assembled with four bolts, the span between the supports is of 1,500 mm. The supporting elements of the displacement inductive transducers are attached to the KB profiles. In the Fig. 1 it is presented the testing stand built inside the Laboratory of the Structural Mechanics Department from the Faculty of Civil Engineering and Building Services, Technical University „Gh. Asachi” of Iaşi. The tests were carried out in collaboration with INCERC, Iaşi Branch.

The load transfer is performed according to the EC3 provisions, Ch. 9, “Testing Procedure”, by means of an air mattress that assures the uniform load repartition and the keeping unaltered the stiffness characteristics of the specimen. The direct placement of the ballast on the steel sheet may alter the stiffness characteristics by friction and vault effect.

The displacements were measured in three points, at the midspan and the quarter of span in every space between the ribs. Inductive transducers were used to measure the transverse deflections; their positions are presented in Fig. 2.

The displacements were recorded by means of inductive transducers in the format of analogical electric signal. The loading was performed by ballast with successive layers with 50 N gravel filled sacks.

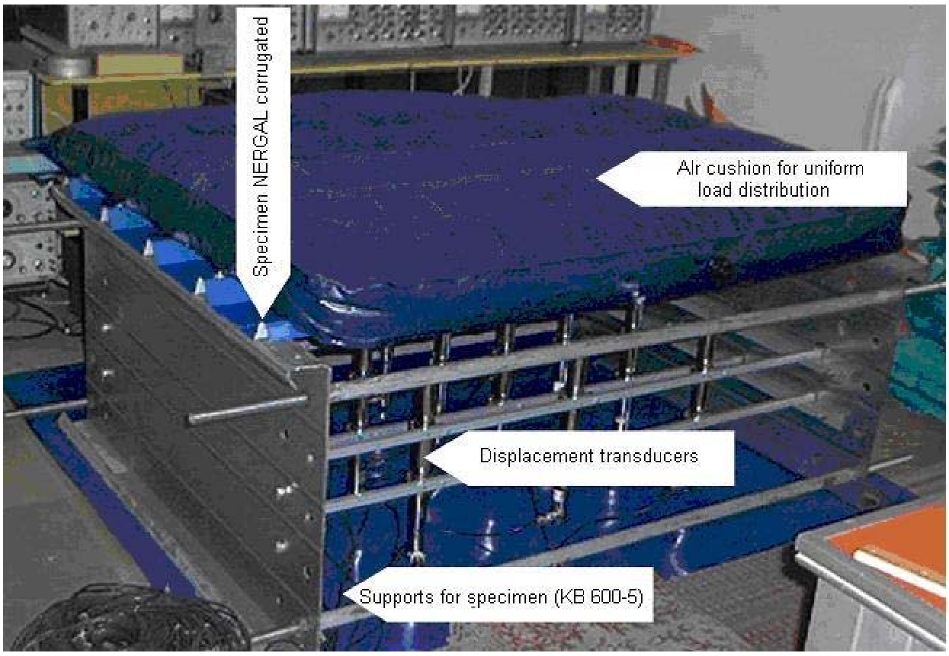


Fig. 1 – View of the testing stand.

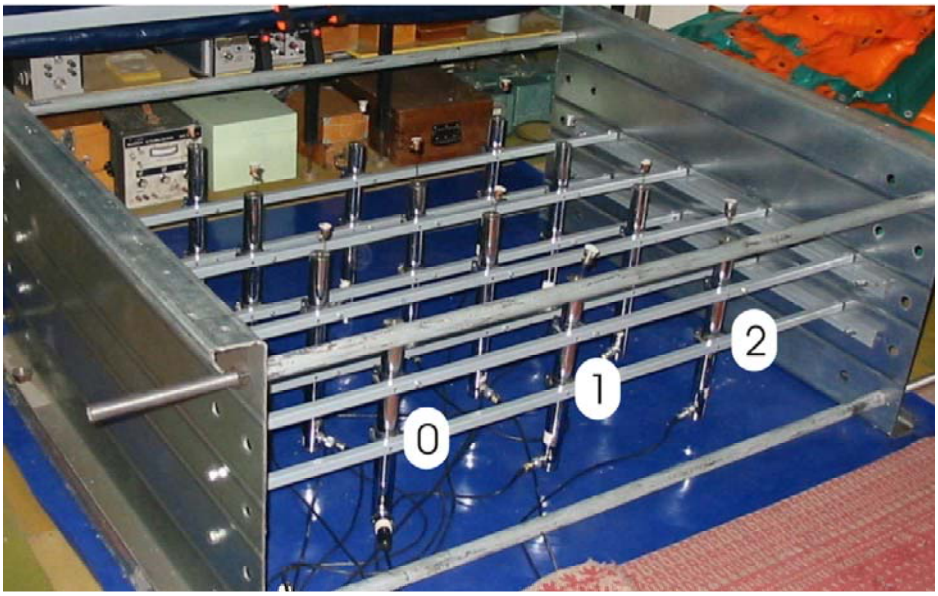


Fig. 2 – The testing stand with the inductive transducers.

In the case of the 0.75 and 1 mm NERGAL steel sheets the air mattress couldn't be used because the load capacity was lower then the loading level corresponding to collapse. In this case it was performed the direct ballasting with sacks only on the sheet ribs.

3. The Testing Procedure

The testing procedure consisted of two steps as follows:

(i) The ballasting was performed in loading–unloading cycles for checking the stiffness characteristics.

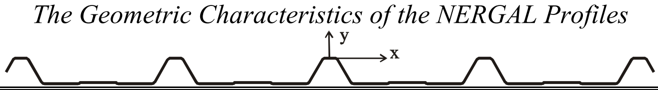
(ii) The ballasting was performed up to a level corresponding to the specimen's collapse by local buckling.

In the Table 1 there are presented the theoretical values of the geometrical characteristics and the tested sections, in order to be compared to the experimental stiffness characteristics of the NERGAL profiles.

The length of the specimen is of 1,600 mm and the span between the supports (bolted connections were used) is of 1,500 mm.

Table 1

The Geometric Characteristics of the NERGAL Profiles



Pos. No.	Thickness mm	Area cm^2	Weight kg/m^2	Position of centroid		Moment of inerția cm^4
				X_G cm	Y_G cm	
1	0.40	4.327	3.397	–0.291	–0.146	0.126
2	0.45	4.868	3.821	–0.291	–0.148	0.142
3	**0.50**	**5.409**	**4.246**	**–0.291**	**–0.151**	**0.158**
4	0.60	6.491	5.095	–0.291	–0.156	0.191
5	**0.75**	**8.114**	**6.369**	**–0.291**	**–0.163**	**0.240**
6	**1.00**	**10.818**	**8.492**	**–0.291**	**–0.176**	**0.324**
7	1.25	13.523	10.616	–0.291	–0.188	0.411

4.The 0.5 mm Profile Test

The tests for all three specimens were carried out in increasing loading–unloading cycles. The maximum loading level for every cycle was of 100, 150 and 200 daN/m^2.

The force *vs.* displacement relationship for all the three specimens is sinuous, the steel sheet acting relatively unstable. For example, in the Fig. 3 there is presented the average displacement of the *T*1, *T*4, *T*7 and *T*10 transducers, mounted at the midspan of the E2-0.50 specimen.

The displacements measured at midspan are greater in average by 30% up to 40% than the computed values. These increases are explained by the sheet deformation in the support areas. For this reaons, the stiffness characteristic is determined by taking into account the relative displacement at the middle and quarter of span.

By analysing the results one notice the fact that stiffness differs as a function of the loading level, *i.e.* it decreases as the load increases. Thus, in the case of the 100 daN/m^2 loading step the stiffness reduction is only 10.2% while in case of the 200 daN/m^2 loading step the reduction reaches 22.75%. The explanation of this phenomenon is given by the sheet folding when subjected to load. Folding diminishes the rib height, thus the stiffness characteristic is significantly decreased (the moment of inertia).

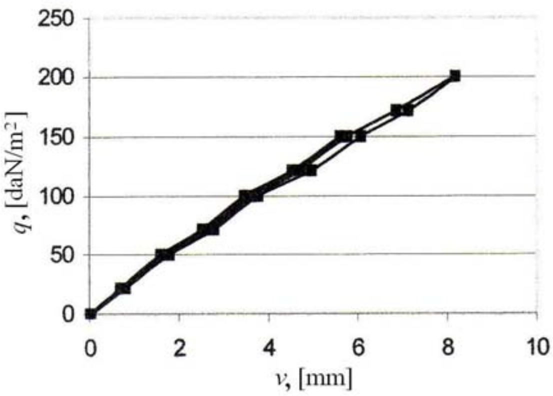


Fig. 3 – The measured displacement at the midspan of the E2-05 specimen.

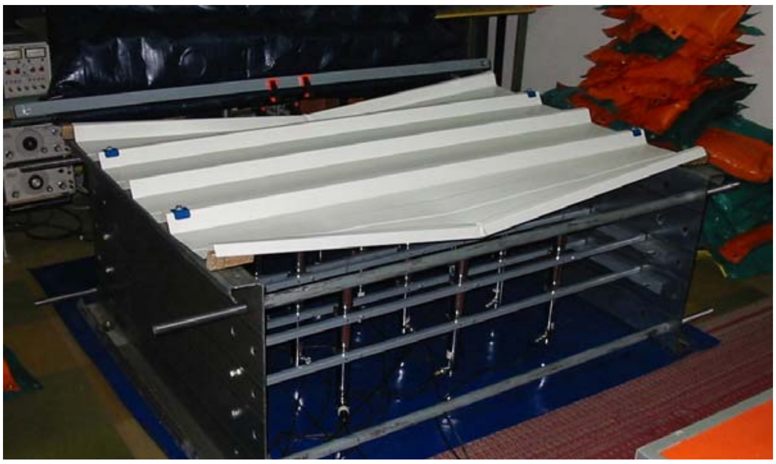


Fig. 4 – The collapse of the E3-050 specimen (buckling).

The E3-050 specimen was loaded up to the occurrence of the local buckling phenomenon. The collapse occurred suddenly at a loading level of 270 daN/m^2. The buckling was local and occurred simultaneously at the midspan of the two edge ribs. In the Fig. 4 it is presented the collapse of the specimen.

5. The 0.75 mm Profile Test

In the same way that in case of the NERGAL 0.5 mm profile the tests for all three 0.75 mm specimens were carried out in increasing loading–unloading cycles. The maximum loading level for every cycle was: 100, 150, 200, 250, 300, 350 and 400 daN/m^2.

For all kinds of specimens the loading–unloading cycles were carried out in order to obtain the residual strains. The obtained results prove that no residual strains occur at low levels of loads, the residual effects being nothing else but re-arrangements in the support areas (these elements are very sensitive). At high levels of loading the residual effects may be caused by the change of the profile cross-section.

In the Fig. 5 there is presented the load *vs.* average displacement relationship (transducers *T*1, *T*4, *T*7 and *T*10, mounted at the midspan) during a loading–unloading cycle up to 100 daN/m^2. One can notice a linear shape of this variation, straighter that in case of 0.5 mm profiles. Some non-linearities are caused by the different stiffness of the edge ribs.

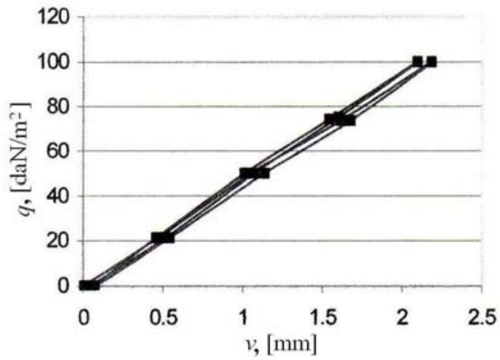


Fig. 5 – The behavior of E1-075 specimen during two consecutive cycles.

After reloading of the specimen for next cycle one notice a path almost identical to the last curve, may be finded thus meaning the residual deflections were consumed after the first loading cycle.

By analysing the stiffness characteristics on the basis of the recorded deflections at midspans there are noticed differences up to 20...30% when compared to the theoretical values. Under these circumstances it is noticed a better behavior of the 0.75 mm NERGAL sheet than the 0.5 mm profile. Even though, the stiffness characteristics were also obtained from relative deflections, to avoid distortions.

In the same way like 0.5 mm NERGAL sheet, the 0.75 mm profile provides stiffness depending on the loading step. In the Fig. 6 it is presented this correspondence after processing the results from the three specimens.

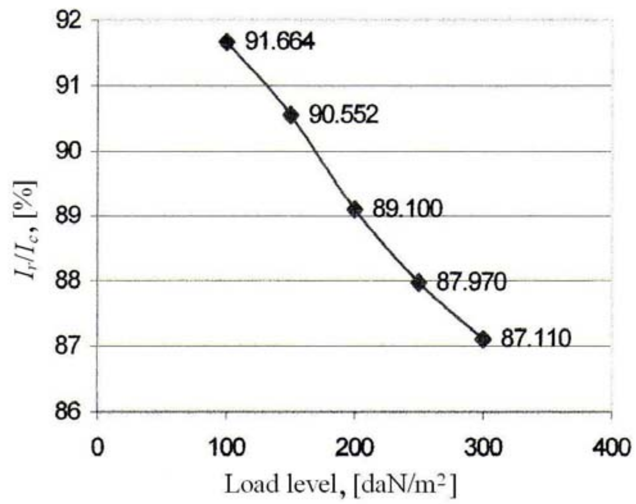


Fig. 6 – The dependence of stiffness characteristic *vs.* load level (0.75 mm steel sheet).

Thus, at the 100 daN/m^2 loading step, the stiffness decay is only of 8.336%, at the 200 daN/m^2 loading step it attains 10.90% and when the 300 daN/mp step is applied, the reduction is of 12.89%.

The folding effect that leads to the reduction of the moment of inertia is less significant that in case of 0.50 mm steel sheet. Moreover, during a significant increase of the load it is not observed an important stiffness decrease, as it was expected, thus the shape of the graph from Fig. 6 is approximately linear.

At last the E3-075 specimen was ballasted in order to obtain the ultimate load. Thus it was attained a 500 daN/m^2 load, when the first signals of damage occurred, *i.e.* noises that forecast the stability loss. In order to avoid the damage of the equipment, the experiment was interrupted because the specimen loading was very large.

The maximum average displacement recorded at this loading level was of 11.391 mm. The load applied directly changes dramatically the specimen behavior, *i.e.* the loading–unloading relationship. Thus, in the Fig. 7 it is presented the situation of the last two loading steps of the E3-075 specimen, first with air mattress, and the second without. In the first loading step without air bed one notice a stiffness increase, after that the slope becomes similar to the situation when the load is transmitted though the airbed.

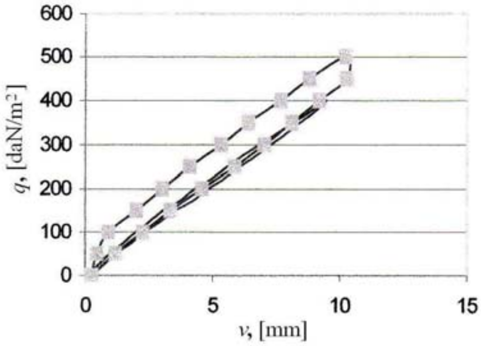


Fig. 7 – The behavior of the E3-075 specimen (with/without airbed).

6. The 1.0 mm Profile test

The tests of the 1.0 mm NERGAL profile were carried out in the same way like the previous two profiles, *i.e.* the loading and measurements. The behavior of these specimens looks more stable than those of 0.5 and 0.75 mm.

The shape of the *F vs*. Δ relationship is almost linear, the sinuosity is due to the averaging, the measured stiffness characteristic is computed from the relative deflections at *L*/2 and *L*/4 and for the first two cycles it represents 95.186% from the theoretical value.

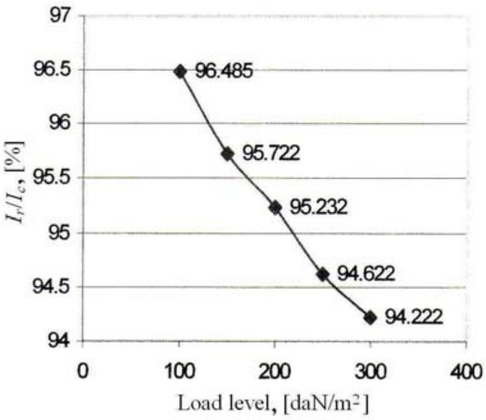


Fig. 8 – The stiffness characteristic *vs*. load level dependence (1 mm thickness sheet).

In the case of the 1 mm NERGAL profile the folding effect that leads to the reduction of the moment of inertia is less significant than in the other cases (Fig. 8).

Finally, the E3-1 specimen was ballasted in order to find out the ultimate load. The first signs of collapse were similar to those of the 0.75 mm sheet, *i.e.* specific noises. The maximum loading level was of 700 daN/m^2, which corresponds to a maximum mean deflection at the midspan of 11.049 mm.

In the case of this test it was noticed the lack of the stiffness difference caused by the direct placement of the load, thus meaning that for bigger thickness the stiffness increase due to the loading fashion (independent poliplan sacks) is insignificant.

The Fig. 9 presents the force *vs*. deflection dependence in case of the E3-1 specimen at the last test with the airbed and with direct placement of load over the sheet.

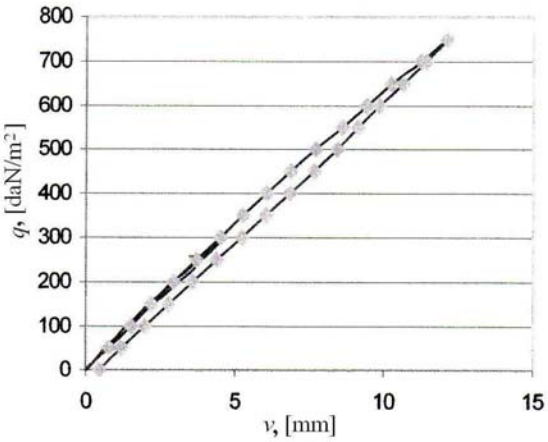


Fig. 9 – The behavior of the E3-1 specimen (with / without airbed).

7. Conclusions

The present paper deals with the results of the experimental analysis of the 0.50, 0.75 and 1.00 mm NERGAL profiles when subjected to gravitational loads. The purpose of the tests was the checking of stiffness characteristics for the NERGAL sheets at several loading steps.

The NERGAL profile is made of DX51DG steel sheet according to the EN 10142 and EN 10027 parts 1 and 2 (Euro Norms), the steel is denominated as 1.0226 according to EN10142; the ultimate strength is R_m = 500 N/mm^2.

The testing of the elements was carried out according to EC3, chap.9, “Testing Procedure”, because the elements are classified as cold-rolled thin-gauge profiles as stated in Romanian Norm NP 012-92 (EC 3 parts 1-3). The tests were performed on a special stand. The loading was performed by ballasting with 50 N sacks, distributed over an air mattress that provides the uniform load distribution and doesn't affect the stiffness characteristics of the specimen.

The deflections were measured at every three points at midspan and quarter span, on every space between the ribs, thus using 12 measurement points.

The testing procedure consisted of several repeated loading–unloading cycles. Finally, one specimen from each class was loaded until collapsed.

The loading–unloading cycles pointed out the lack of permanent strains for maximum displacements below the $L/200$ limit. Out of this limit the permanent strains appear, *i.e*. the rib folding in the support areas.

The local buckling of the edge ribs caused the collapse of the NERGAL profiles (in reality this is impossible because the steel sheets are coupled). As a consequence, the assembly technique of the steel sheet edges becomes very important.

The stiffness reduction of the NERGAL tested profiles in case of a limited displacement ($L/200$): for the 0.50 mm profiles reaches about 20%; for the 0.75 mm profiles it reaches about 10% and for the 1.00 mm profiles it reaches about 5%.

One may notice that the ultimate deflections are limited according to several Norms between $L/100$ and $L/200$.

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STUDII EXPERIMENTALE ASUPRA ELEMETELOR DE ACOPERIŞ REALIZATE DIN PROFILE METALICE CU PEREŢI SUBŢIRI

(Rezumat)

Obiectivul principal al studiilor experimentale a fost acela de a verifica acele caracteristici de rigiditate ale foilor de tablă cutată utilizate pentru panourile de acoperiş la diferite niveluri de încărcare.

Testarea elementelor a fost efectuată în conformitate cu prevederile EC3, cap. 9, "Proceduri de testare", deoarece elementele se încadrează în clasa de profile metalice cu pereţi subţiri formate la rece, aşa cum este prevăzut în Normativul românesc NP 012-92 (corespunzător EC3 cap. 1-3).

Procedura de testare a constat în mai multe cicluri de încărcare – descărcare. In final, câte o epruvetă din fiecare categorie a fost încercată până la cedare. Mecanismul de cedare al fâşiilor de tablă cutată s-a realizat prin pierderea locală a stabilităţii aripilor marginale (în realitate acest mod de cedare nu este posibil deoarece fâşiile de tablă sunt cuplate de-a lungul cutelor marginale).

Deplasările ultime sunt limitate de diferite norme la valori cuprinse între $L/100$ şi $L/200$. Ciclurile de încărcare – descărcare au subliniat absenţa deformaţiilor permanente pentru deplasări maxime sub limita de $L/200$. Peste această limită deformaţiile permanente apar sub forma deformaţiilor în cutele marginale în zonele de reazem.

Aceste studii au făcut parte dintr-un program de cercetare mai amplu din cadrul Facultăţii de Construcţii şi Instalaţii din Iaşi în parteneriat cu INCERC, filiala Iaşi. Testele au avut loc în cadrul Laboratorului de Incercări al Departamentului de Mecanica Structurilor.