EXPERIMENTAL STUDIES ON WIDE FLANGE TRAPEZOIDAL SHEETING

Mansour Kachichian[*] *– László Dunai*[**] *– László Kaltenbach*[***]

ABSTRACT

In this paper an experimental research study is presented on a new wide flange cold-formed trapezoidal sheeting of Lindab Ltd. The purposes of the tests are (i) to determine the load-bearing characteristics and (ii) to check the relevant design method of Eurocode 3. The experimental program is based on the testing of 40 specimens for moment resistance, moment and crippling resistance and load-bearing capacity. Then the test results are evaluated and the design resistances are determined. This paper presents the experiments and the derived test-based design values.

1. INTRODUCTION

The new, cold-formed LTP38 panel with wide flanges is developed by Lindab Ltd. The speciality of the sheet is that for the wider flange the width-to-thickness (b/t) ratio exceeds the limitations of the Eurocode 3 [1] (b/t > 500) for nominal thickness 0.5 mm. It means that the proposed design rules of the standard cannot be applied for resistance calculations. In the presented research it is aimed to determine the design resistances of the new sheets by test-based design procedure and to check the validity of the Eurocode 3 application rules, under the extreme b/t conditions. The paper has a focus on the experimental study and the derived design resistances.

In the experimental program different supporting arrangements are used to test the sheets with different thicknesses. It is planned and completed to cover the moment resistance in the simply supported span, the moment/reaction force interaction over the support of continuous system and the global load-bearing capacity of three-span system under uniformly distributed load, as follows:

- moment resistance – 22 specimens,
- moment/crippling resistance – 10 specimens,
- load-bearing capacity – 8 specimens.

The specimens are tested under gravity loading until the ultimate loads are reached. The test results are evaluated: the typical ultimate behaviour modes are identified and characterised. From the ultimate loads the design values of the resistances are derived using the test-based design method of Eurocode 3 standard.

The obtained results are directly used for the ultimate limit state checking of the new sheets and – in the next step of the research – for the development of design rules.

[*] Ph.D. Student, BME Dept. of Structural Engineering
[**] Professor, BME Dept. of Structural Engineering
[***] Research Associate, BME Dept. of Structural Engineering

2. EXPERIMENTAL PROGRAM

2.1. Test specimens and arrangements

In the experimental program sheets with three different nominal thicknesses are tested: 0.5, 0.55, 0.6 mm, in three arrangements taking 2, 3 or 4 supports for each sheet thickness, with spans of 1500 and 2000 mm, as shown in Fig. 1. The simply supported arrangement is used for moment resistance, the two-span is for moment/crippling resistance and the three-span-system is for UDL load-bearing capacity determination. The specimens are fixed by self-drilling screws to the supporting cold-formed C-sections having 2 mm thickness and 66 mm flange width. Each of these specimens is tested for positive and negative loading as it is shown in Fig.2. The characteristics of the tested specimens are detailed in Table 1.

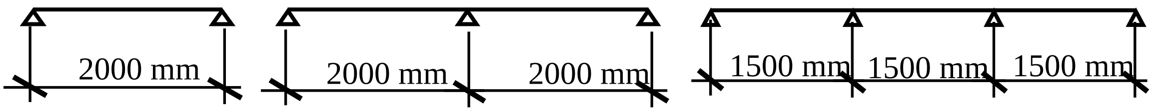


Fig. 1: Test models

Table 1: Characteristics of the tested sheeting

	LTP38/0,5						LTP38/0,55						LTP38/0,6					
Thickness [mm]	0,5						0,55						0,6					
Supported distance [mm]	2000				1500		2000				1500		2000				1500	
Number of Supports	2		3		4		2		3		4		2		3		4	
Number of specimens	4	4	2	2	2	2	3	3	1	1	1	1	4	4	2	2	1	1
Direction of loading	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Number of specimens	40																	

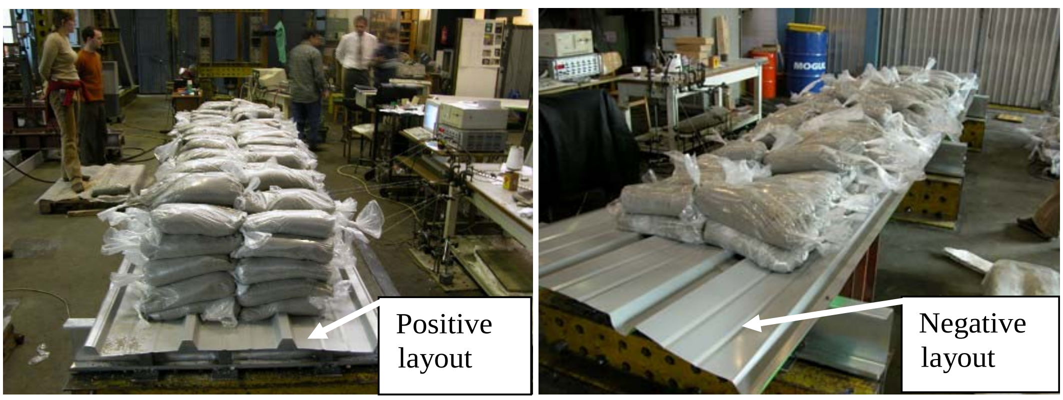


Fig 2: Test and loading arrangements

2.2. Loading and measuring systems

The sheets are tested under gravity loading using sand bags having 0.05 kN self weight, as it is shown in Fig. 2. The load is applied by two types of sequences: the first loading case is applied on the one- and two-span sheets, taking small load increments starting from the midspan in case of simply supported and from the middle support in case of three supported sheets. The increment of the load is repeated toward the outer ends, as it is shown in Fig. 3. For load-bearing tests UDL increments are applied on the sheet, as it can be seen in Fig. 4.

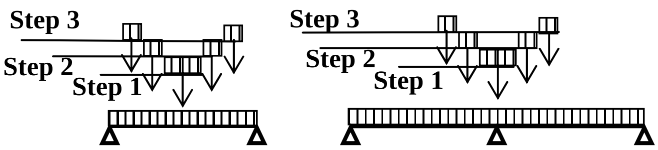


Fig. 3: Load steps in case of 2 and 3 supported sheet

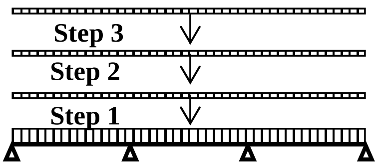


Fig. 4: Load steps in case of 4 supported sheet

The number of the load units and their position on the sheets are documented after each load step. The displacements generated by these loads are measured and stored by computer manually in four positions in case of simply supported sheets and in 6 positions in case of three and four supported sheets, as it is shown in Fig. 5.

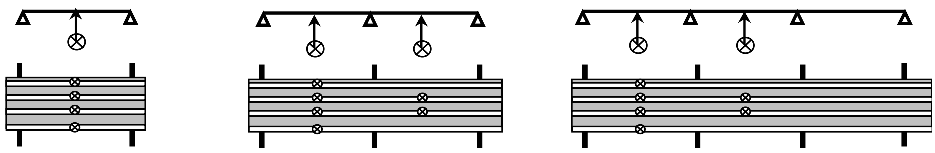


Fig. 5: Measuring system in case of 2, 3 and 4 supported sheeting

The displacements are measured by transducers, through a pulley system, fixed to the lower layer of the sheets, close to the webs.

The loads and the corresponding displacements are measured and documented; on this basis the serviceability load level can be checked and the ultimate behaviour can be studied.

2.3. Testing procedure

Depending on the supporting system of specimens the load started with the prescribed sequence, after completing the specimen and installing the measuring system. The load starts with the prescribed way until the nonlinearity of behaviour is noticed, then the sand bags are placed carefully to the prescribed positions. The displacements are measured several times during the nonlinear steps, within the waiting period (app. ten minutes) under the same load, to check the effect of plastic flow. Then the loading is continued until final failure of sheet. The last measured and documented values are considered to be the ultimate loads. The measuring devices are saved by a supporting structure against the deterioration during the collapse.

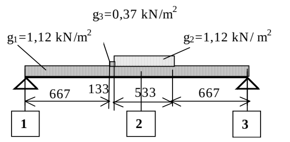
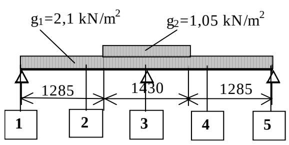
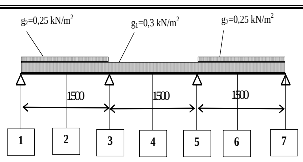
3. EXPERIMENTAL RESULTS

3.1. Ultimate load

The specimens are loaded as mentioned before and the displacements are measured after each load step, until the first sign of failure, then the last measure of displacement is performed. The last measured load and the corresponding displacements characterize the experimental ultimate behaviour.

On the bases of the obtained experimental ultimate loads the relevant internal and reaction forces are calculated to characterize the moment and moment/crippling resistances (note that the internal and reaction forces are calculated by linear analysis; more accurate nonlinear analysis is required to be done during the advanced design method development). In Table 2 three illustrating examples are presented: it shows the applied loads, the corresponding displacements and the calculated reaction forces and bending moments obtained from the experimental ultimate load.

Table 2: Internal and reaction forces

<table>
<tr><td rowspan="2">Test</td><td rowspan="2">Ultimate load</td><td colspan="2">Deflections</td><td colspan="9">Internal and reaction forces at ultimate load level</td></tr>
<tr><td>Max UDL [mm]</td><td>Ultimate load [mm]</td><td colspan="4">Reaction forces [kN/m]</td><td colspan="5">Bending moment [kNm/m]</td></tr>
<tr><td rowspan="2">T1</td><td rowspan="2">
</td><td rowspan="2">10.1</td><td rowspan="2">13.95</td><td colspan="2">R1</td><td colspan="2">R3</td><td colspan="5">M2</td></tr>
<tr><td colspan="2">1.43</td><td colspan="2">1.43</td><td colspan="5">0.8</td></tr>
<tr><td rowspan="2">T23</td><td rowspan="2">
</td><td rowspan="2">13.95</td><td rowspan="2">16.05</td><td>R1</td><td colspan="2">R3</td><td>R5</td><td colspan="2">M2</td><td>M3</td><td colspan="2">M4</td></tr>
<tr><td>1.619</td><td colspan="2">6.664</td><td>1.619</td><td colspan="2">0.619</td><td>-1.231</td><td colspan="2">0.619</td></tr>
<tr><td rowspan="2">T37</td><td rowspan="2">
</td><td rowspan="2">13.8</td><td rowspan="2">15.7</td><td>R1</td><td>R3</td><td>R5</td><td>R7</td><td>M2</td><td>M3</td><td>M4</td><td>M5</td><td>M6</td></tr>
<tr><td>1.969</td><td>5.156</td><td>5.156</td><td>1.969</td><td>0.593</td><td>-0.703</td><td>0.141</td><td>-0.703</td><td>0.593</td></tr>
</table>

3.2. Failure modes

In the experimental ultimate behaviour the typical local plate buckling stability phenomena are observed. Depending on the studied arrangement four different types of failure modes are obtained as follows:

- Buckling of the smaller upper flange in case of 2 supported sheets in positive layout, as shown in Fig. 6/a, b.
- Buckling of the wider upper flange in case of 2 supported sheets, negative layout, as shown in Fig. 7/a, b.

- Combined buckling and crippling of lower wider flange and web over support (Fig. 8/a) and buckling of upper flange in the span (Fig. 8/b) in case of 3 and 4 supported sheets, positive layout.
- Combined buckling and crippling of lower smaller flange and web over support (Fig. 9/a) and buckling of the upper wider flange in the span (Fig. 9/b) in case of 3 and 4 supported sheets negative layout.

Fig. 6: Simply supported sheet failure – positive layout

Fig. 7: Simply supported sheet failure – negative layout

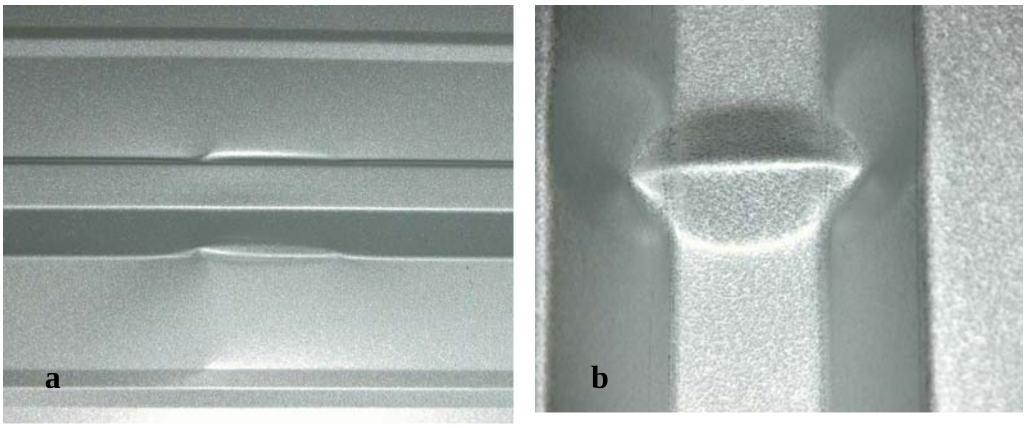


Fig. 8: Three or four supported sheet failure – positive layout

Fig. 9: Three or four supported sheet failure – negative layout

4. ANALYSES OF RESULTS

4.1. Calculation of test-based design resistance

From the test results the design resistances are derived by the method recommended in the Eurocode 3, 1.3.

According to the standard first the observed test results should be adjusted by the actual geometrical and material characteristics according to Eq. (1):

$$R_{adj,i}=R_{obs,i}/\mu_R \tag{1}$$

where:
$R_{adj,i}$ is the adjusted test result for test number i,
$R_{obs,i}$ is the observed test result for test number i,
μ_R is the function of the observed and nominal values of the yielding strength and core thickness of tested specimen, given by the Eurocode 3, 1.3 for panel test design.

Once the adjusted values are available, the characteristic values can be determined by Eq. (2):

$$R_k = R_m +/- ks \tag{2}$$

where:

R_k is the characteristic value of the test result determined on the bases of at least 4 tests. The determination of values with fewer tests should be taken as it is detailed in Eurocode 3, 1.3 methods for panel test design,

R_m is the mean values of the adjusted test results,

k is the appropriate coefficient,

s is the standard deviation.

On the bases of the characteristic values the test-based design values can be determined by Eq. (3):

$$R_d = \frac{R_k}{\gamma_M \gamma_{sys}} \tag{3}$$

where:

γ_M is the partial factor for resistance,

γ_{sys} is the partial factor for difference in behaviour under test and service conditions.

4.2. Evaluation of results

According to these steps the characteristic and design values of moments resistances, the moment/crippling resistances and load-bearing capacities are derived; the results are collected in Table 3.

Table 3: Test-based design resistances

		LTP38 t=0.5 mm positive	LTP38 t=0.5 mm negative	LTP38 t=0.6 mm positive	LTP38 t=0.6 mm negative	LTP38 t=0.55 mm positive	LTP38 t=0.55 mm negative
Moment resistance	M_R [kNm/m]	0.532	0.455	0.836	0.784	0.7	0.733
Moment-reaction force resistance	M_R [kNm/m]	-0.72	-0.66	-1.02	-0.71	-0.97	-0.9
	R_R [kN/m]	3.92	3.08	5.26	3.56	5.14	4.48
Load bearing capacity	g_R [kN/m^2]	2.157	1.801	2.895	2.573	3.414	3.414

It can be seen from Table 3, that the moment resistance is smaller for simply supported beam in midspan than it is over the support for three supported sheets, acting together with reaction force; it is due to the re-arrangement of the moments caused by the nonlinear behaviour. This is why the coupling moment and reaction force effect can be studied by advanced nonlinear analysis.

The last row of the table shows, that the load bearing capacity of sheets supported by 4 supports is smaller for sheets with nominal thickness 0.6 mm, than for sheets with nominal thickness 0.55 mm. It is because of the bigger observed core thickness of the LTP38/0.55 sheets.

It can be seen as well that the resistance values of the sheeting with the positive layout is higher than it is for sheets with negative layout; the comparison is shown in Table 4.

Table 4: Positive/negative resistance ratios of the sheets

		LTP38/ t=0.5 mm	LTP38/ t=0.6 mm	LTP38/ t=0.55 mm
		+/-	+/-	+/-
Moment resistance	M_R [%]	1.17	1.07	0.95
M_R Moment-reaction force resistance	M_R [%]	1.09	1.43	1.07
	R_R [%]	1.27	1.47	1.14
Load bearing capacity	g_R [%]	1.19	1.12	1.00

5. CONCLUSIONS

In this paper the newly developed wide flange LTP38 sheets are examined by experimental tests, then the obtained results are evaluated to find the test-based design resistances and to create a technical background for the development of static design method for these sheets. On the bases of the completed research the following conclusions are drawn:

- In the moment resistance tests the obtained ultimate values are in contradiction with the previously expected calculated values, essentially in case of thinner sheets. This observation proves that the design limit for the b/t ratio (500) of the Eurocode 3, 1.3 should be kept.
- In case of three supported sheets the moment and reaction force interaction shows the tendency of higher bending moment resistance over the support, compared to bending moment in the field in case of pure cases. It shows the effect of the nonlinearity in the internal force distribution and calls the attention on the application of advanced nonlinear analysis.
- The experimental load bearing capacities of the typical structure arrangements (with 1.5 m support spacing) indicates that even the smallest thickness 0.5 mm sheets can be used under typical loading circumstances.
- The test-based design resistances can be applied to derive design tables and as background for the development of improved design method.

ACKNOWLEDGEMENT

The authors wish to acknowledge the support of the OTKA T035147 project and the Lindab Butler Ltd.

REFERENCES

[1] ENV 1993-1-3, Eurocode 3, Design of Steel Structures, Part 1.3: Cold Formed Thin-Gauge Members and Sheeting, 1996.

[2] Dunai L. - Ádány S. - Kachichian M. - Kaltenbach L. - Kálló M.: *Experimental testing of LTP38 panels*, Research Report, BME, Budapest 2003.