EXPERIMENTAL AND NUMERICAL ANALYSIS OF COLD-FORMED Z-PURLINS

SLIDING CLIP PURLIN/SHEETING CONNECTION

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Contents of PhD dissertation

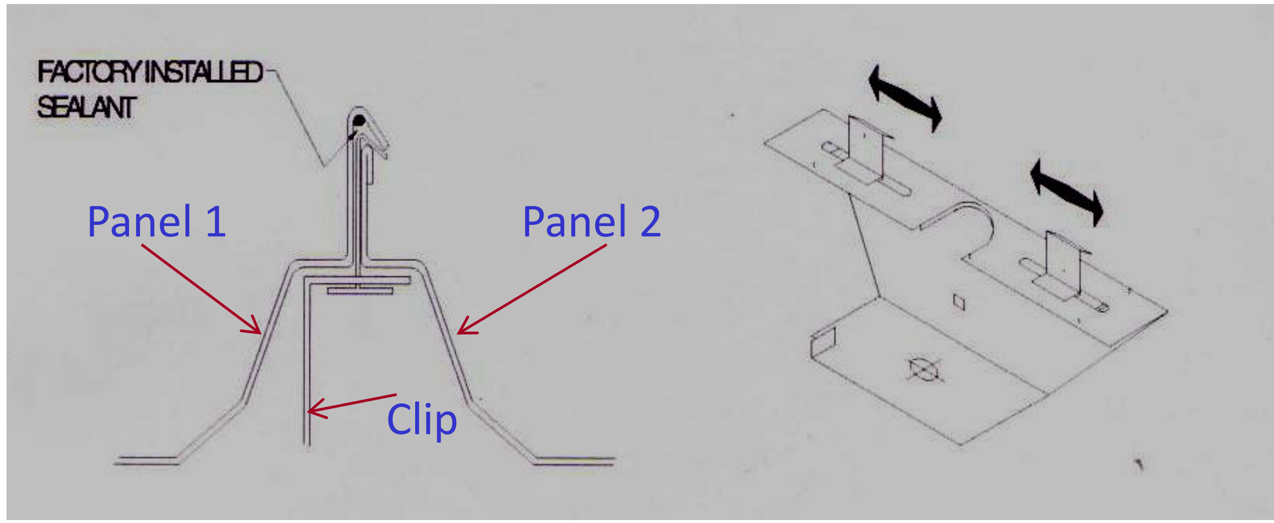
1. Experimental study of purlin/sheeting interaction
2. Effect of sliding clips on purlin/sheeting interaction
3. Full scale load test of purlin/sheeting system
4. Ultimate load test on sheeting
5. Numerical analysis of purlin/sheeting connections

Introduction

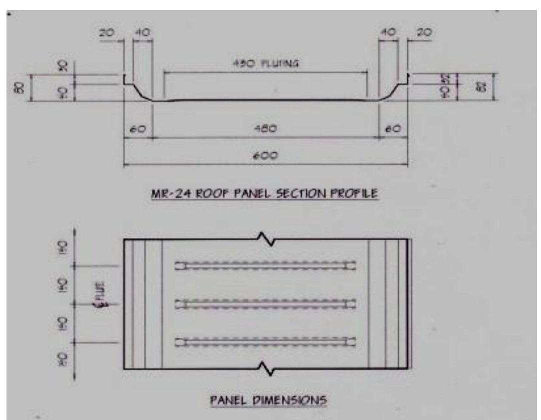
1. Structural arrangement and problem statement
2. Purpose of the research
3. Research strategy
4. Experimental program
5. Experimental results
6. Evaluation of results
7. Conclusions

Components

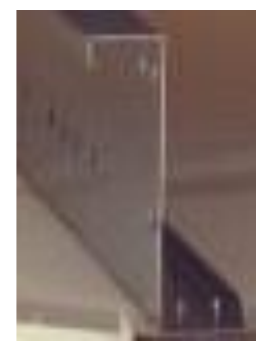
- sliding clip and connection



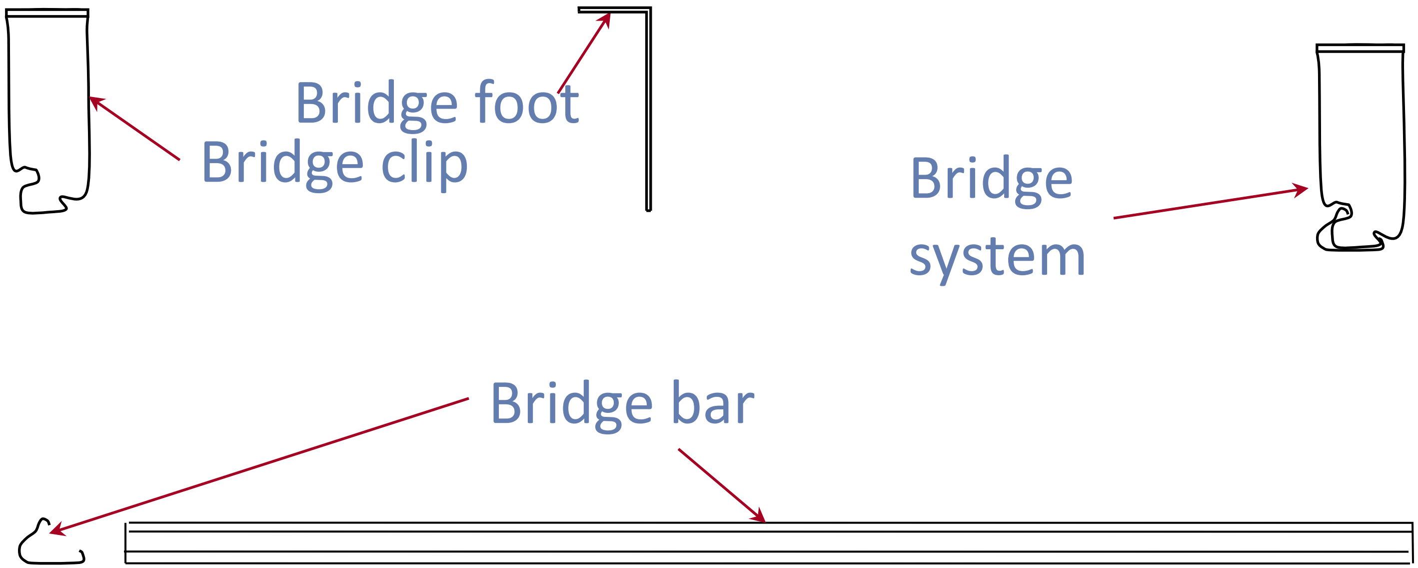
- panel geometry
- material aluminum



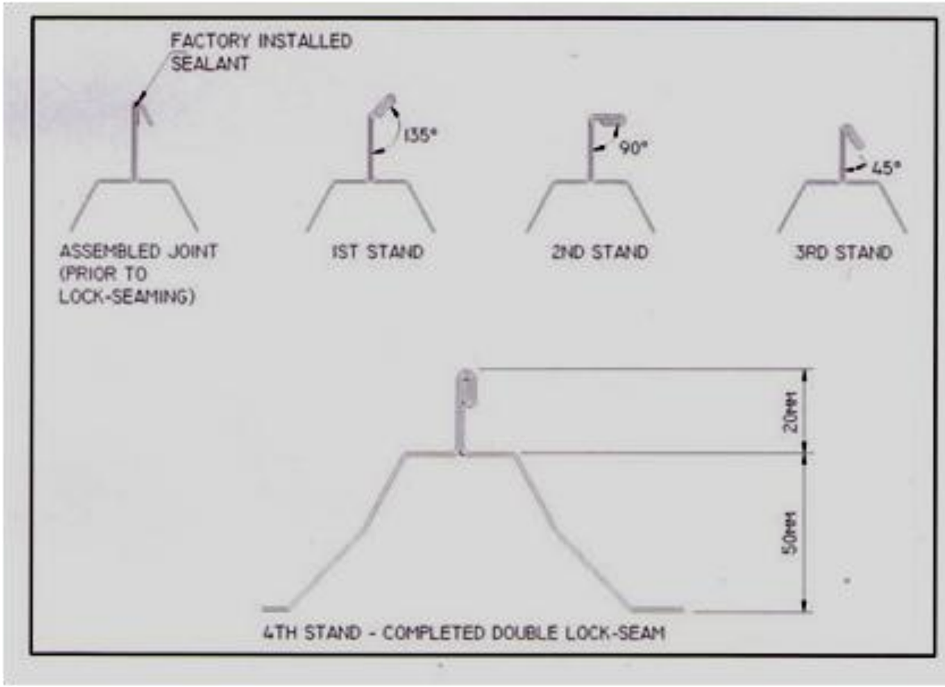
- Z-purlin

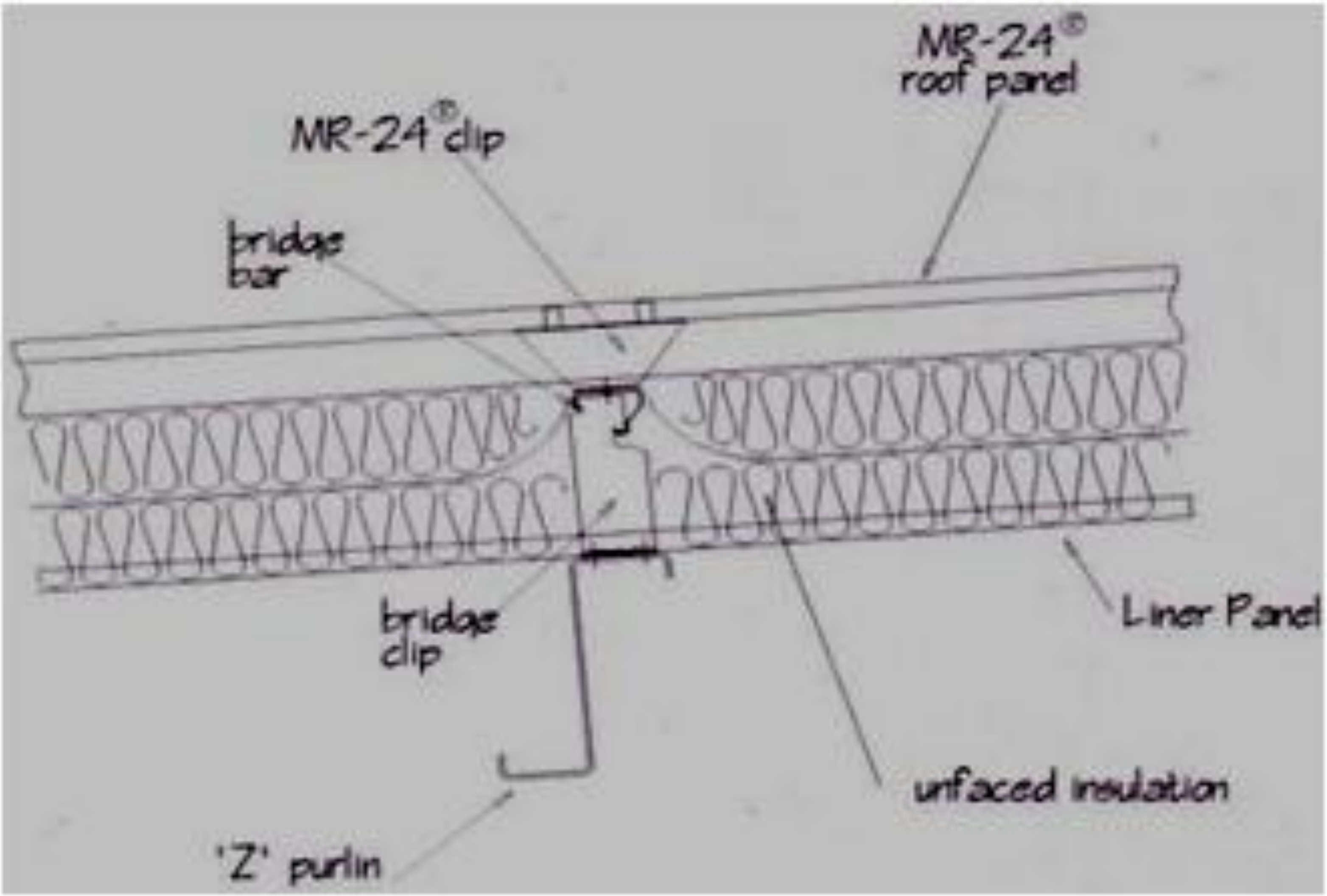


Bridge system



Folding phases of connection




MR-24®
roof panel
MR-24® clip
bridge
bar
bridge
clip
Liner Panel
unfaced insulation
'Z' purlin

Problem statement and aims

thermal expansion or shrinkage ⇨ concentrated stresses at connections ⇨ sliding elements

Sliding elements and bridge system ⇨ Purlin lateral support

lateral support + sliding action of elements have significant effect on the behaviour of the system.

⇩

Define the characteristics of system behaviour.

Determine the characteristics of the used elements and their effect on the lateral stiffness of the system.

Purpose of the experiments

- determine the lateral stiffness of the system
- determine the effect of Z-purlin height
- determine the effect of bridge system
- determine the effect of gravity loads
- determine the effect of lateral load direction

Research strategy

building the test specimens with the supporting, the loading, displacement and measuring systems

F – U relationships

Lateral stiffnesses

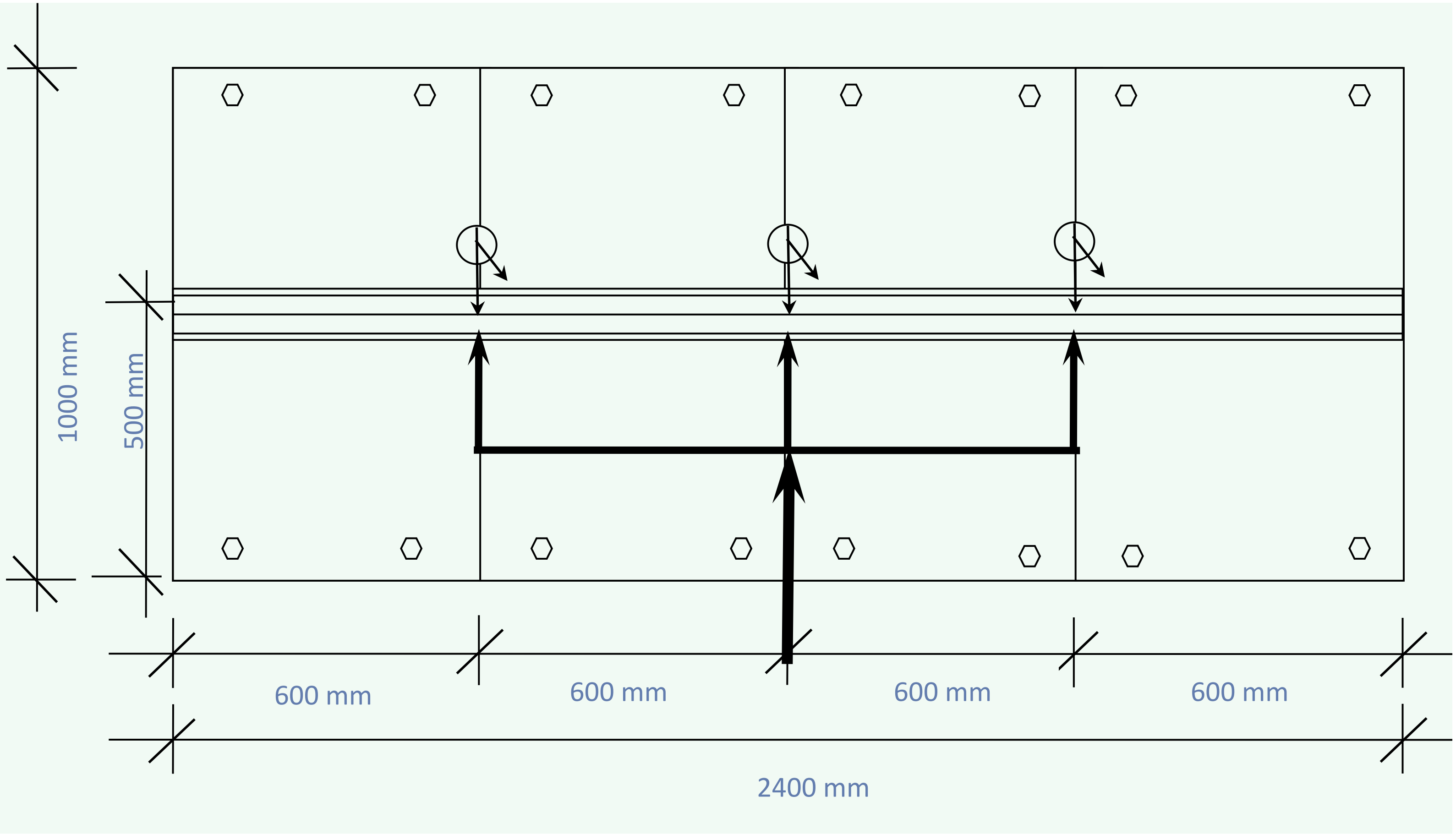
Effect of system parameters

Experimental program

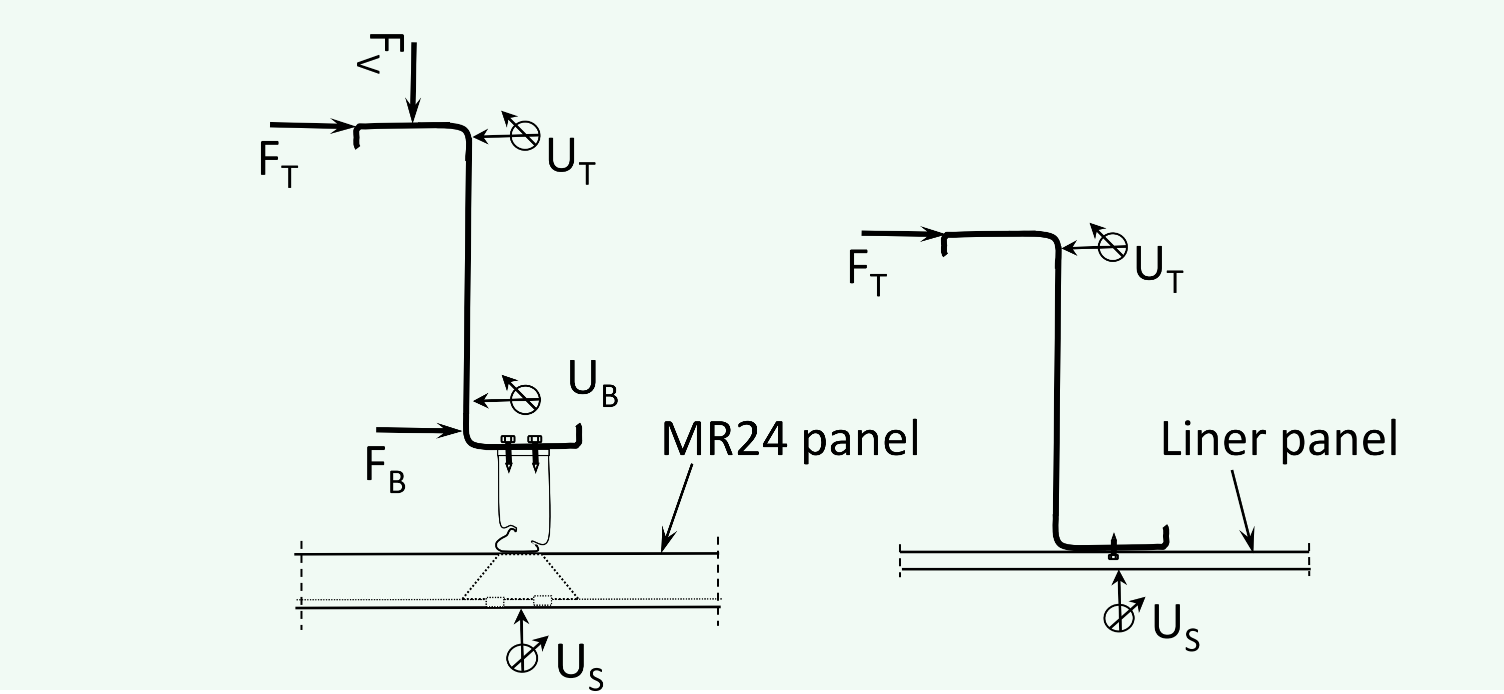
- Test specimens
- Test arrangement
- Loading and measuring system
- Test procedure

Test specimen

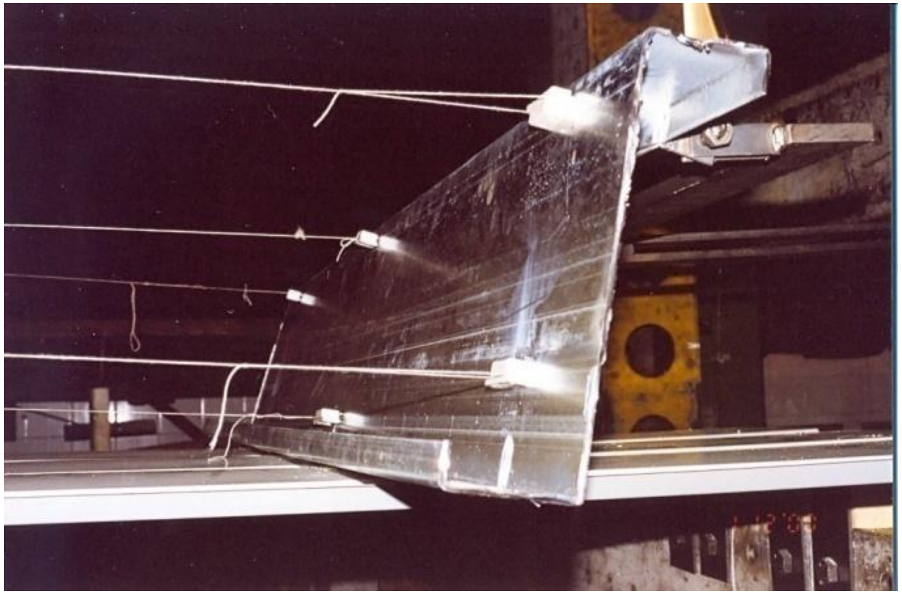
Test arrangement



Loading and measuring systems



Loading and measuring systems

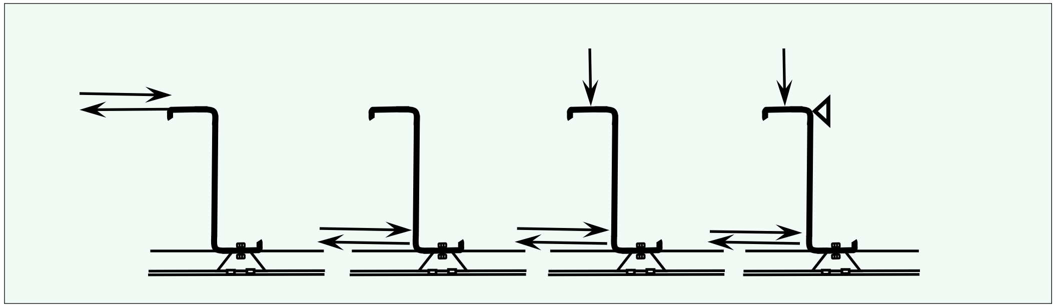


Applied loads

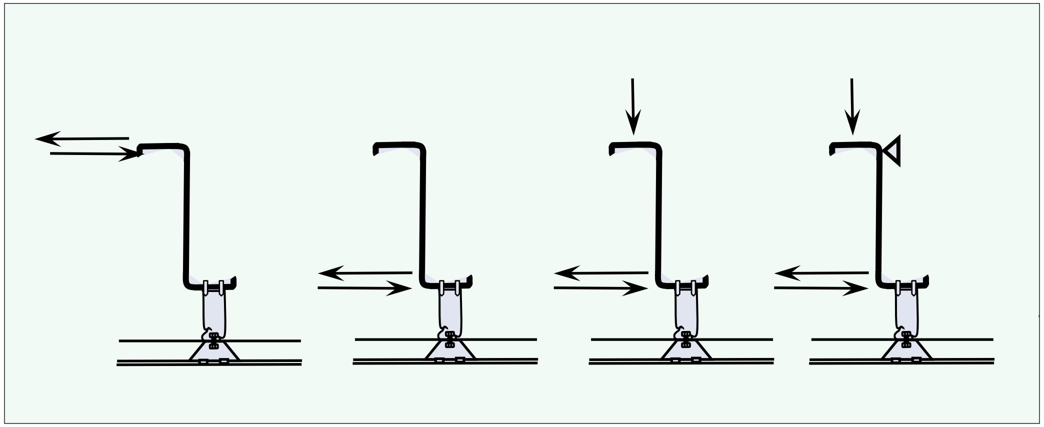
- Mechanically generated lateral load acting at three load points on the top of the upper flange .
- Mechanically generated lateral load acting at three load points at the lower flange level.
- Vertical load with adjustable intensity acting as distributed load at the top of the upper flange to simulate the gravity loads.

Specimen groups

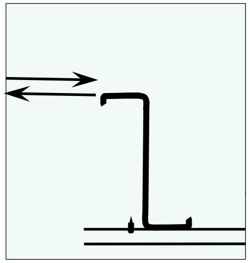
Group 1



Group 2



Group 3



Specimen

components of specimens	specimen code	sheeting panels	sliding clip	heat insulation	bridge system	purlin t=1.5 [mm]
group 1	MR24#1B	MR24	used	used	–	Z–250
	MR24#1A	MR24	used	used	–	Z–200
group 2	MR24#2B	MR24	used	used	used	Z–250
	MR24#2A	MR24	used	used	used	Z–200
group 3	MR24#3B	liner	–	–	–	Z–250
	MR24#3A	liner	–	–	–	Z–200

Specimen

components of specimens	specimen code	sheeting panels	sliding clip	heat insulation	bridge system	purlin t=1.5 [mm]
group 1	MR24#1B	MR24	used	used	–	Z–250
	MR24#1A	MR24	used	used	–	Z–200
group 2	MR24#2B	[illegible]	[illegible]	[illegible]	used	Z–250
	MR24#2A	[illegible]	[illegible]	[illegible]	used	Z–200
group 3	MR24#3B	liner	–	–	–	Z–250
	MR24#3A	liner	–	–	–	Z–200

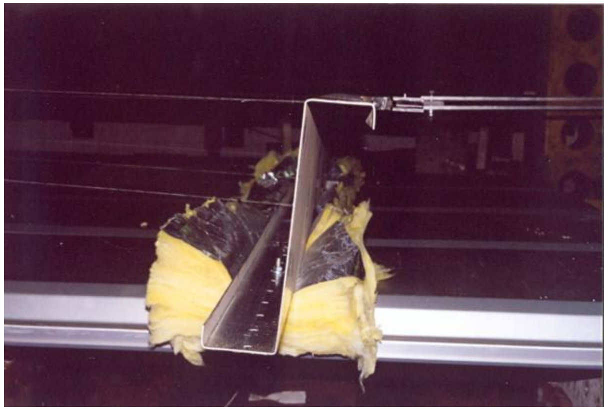
182 specimens
min. 4 ×

Testing procedure

lateral loads are applied mechanically.

force magnitude is measured by load cell.

lateral and vertical deformations are measured by inductive transducers

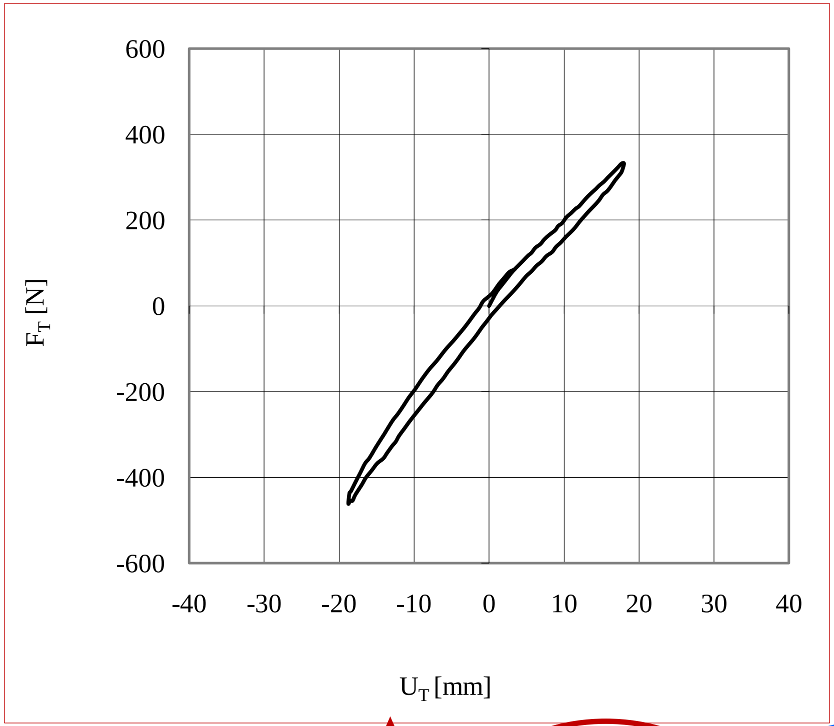


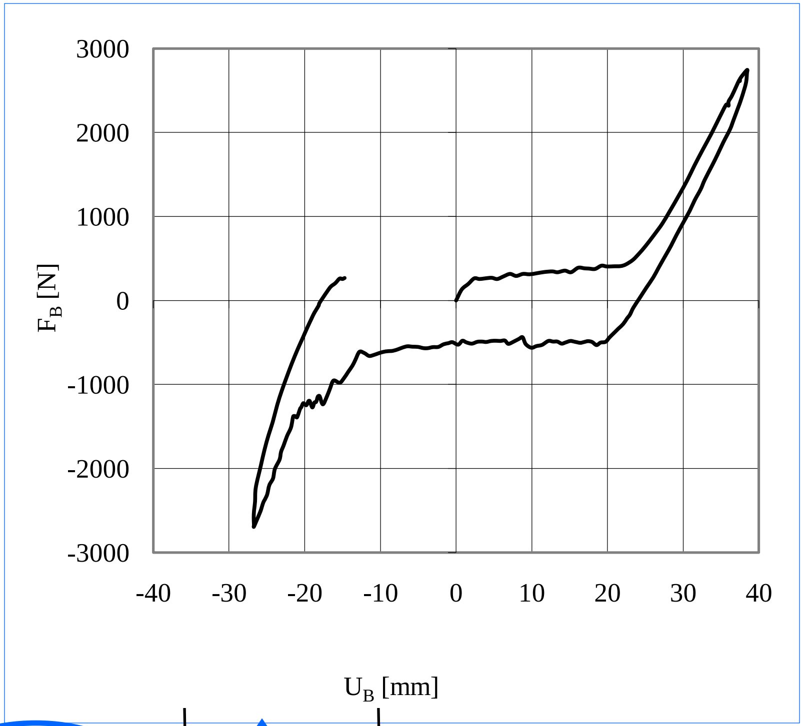
$F_T \Rightarrow U_T$

$F_B \Rightarrow U_B$

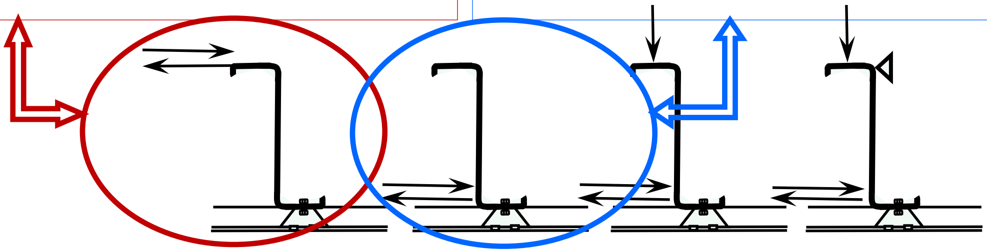
$F_B + F_V \Rightarrow U_B$

Experimental results 1

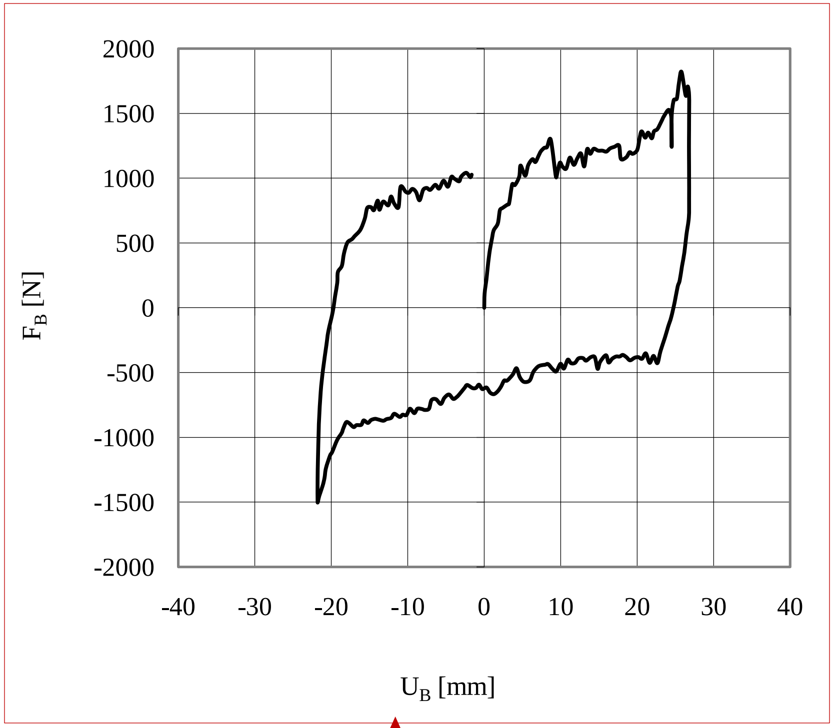


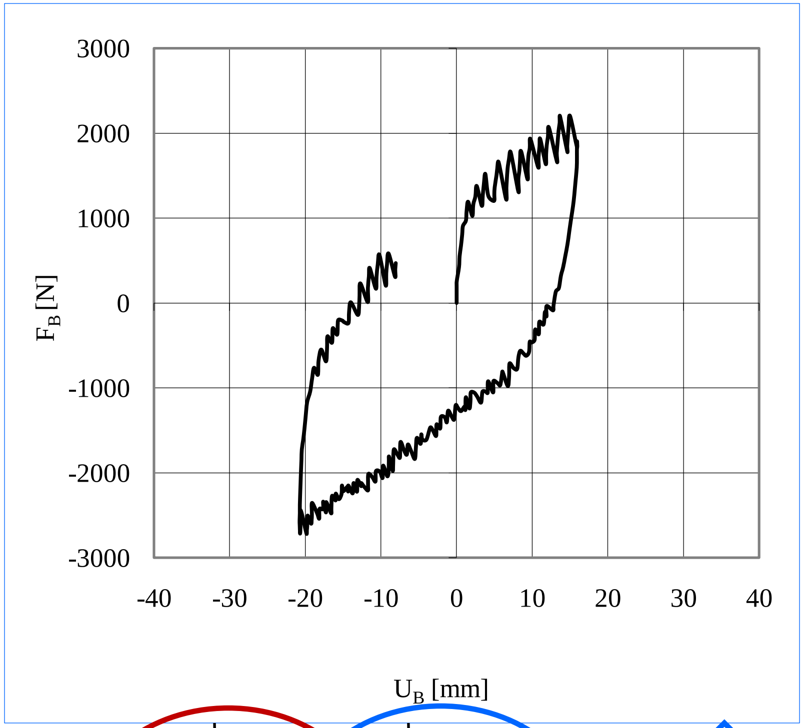


Group 1

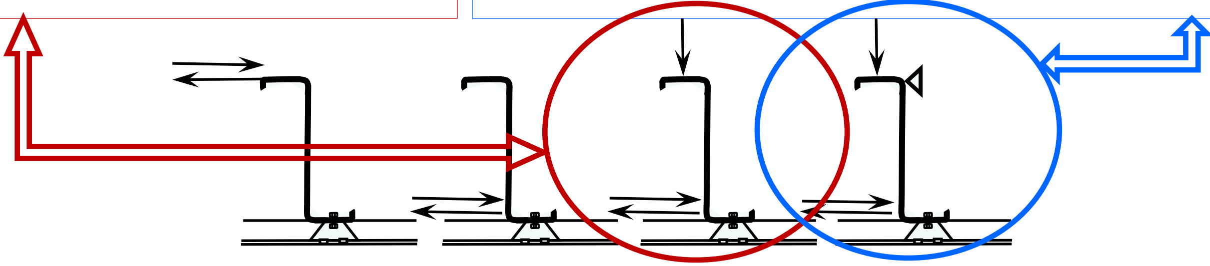


Experimental results 2

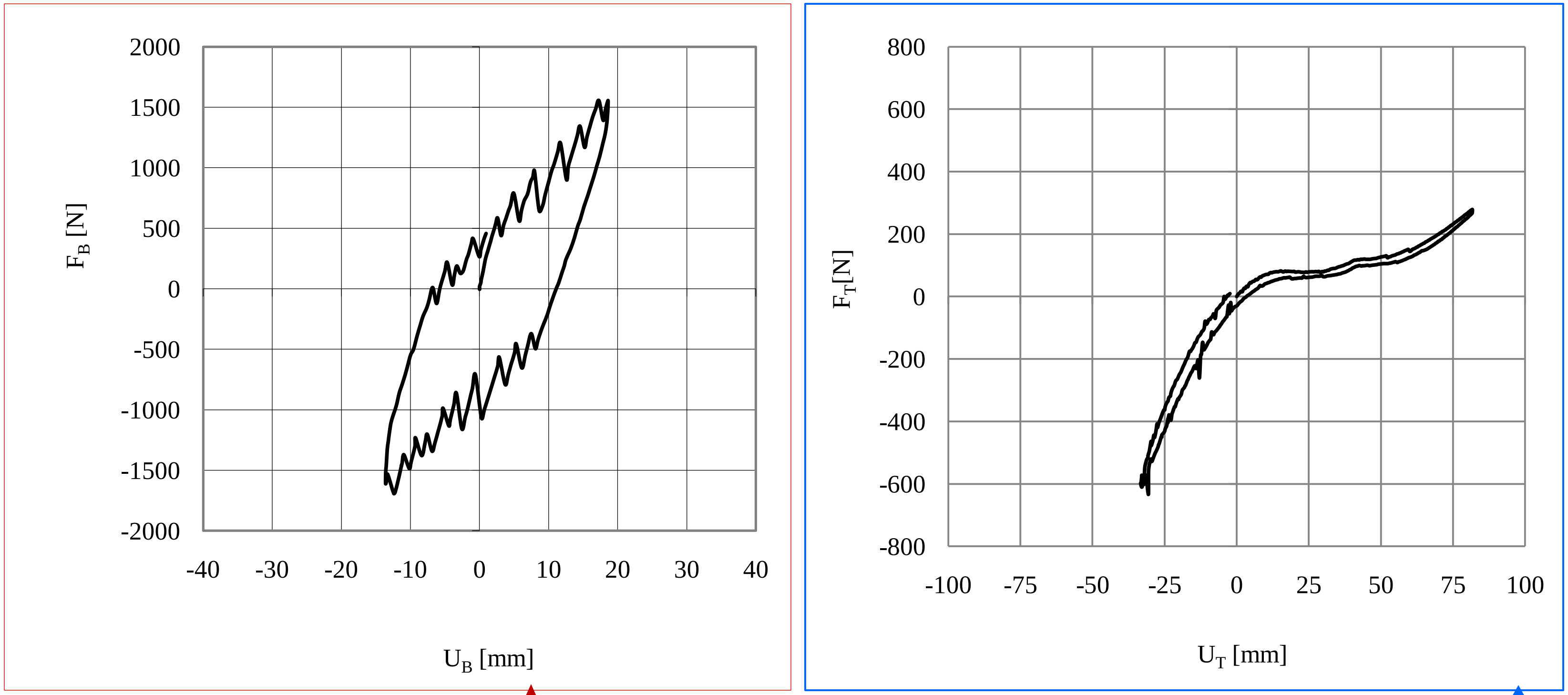


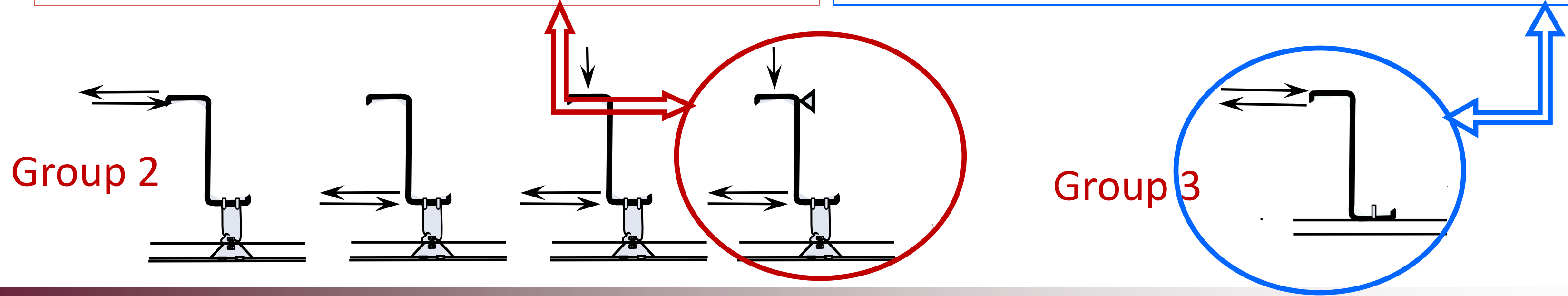


Group 1



Experimental results 3

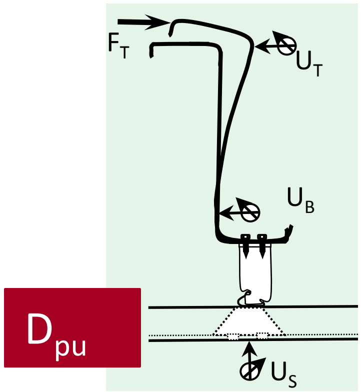


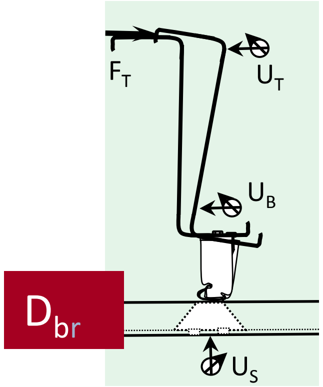


Deformation components

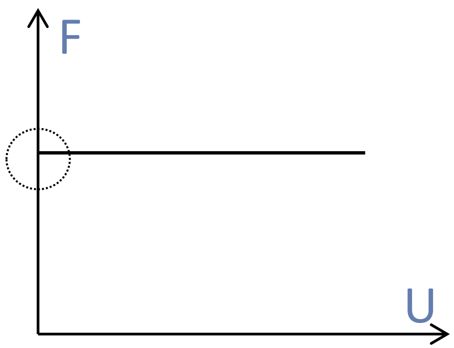
- D_{sh} – MR24 sheeting deformation
- D_{cl} – clip deformation
- D_{br} – bridge deformation
- D_{pu} – purlin deformation

In the tests the effects of D_{sh} and D_{cl} are not significant.

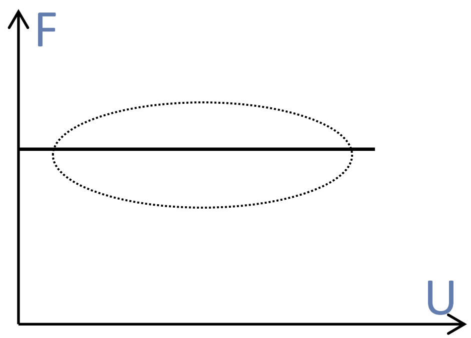




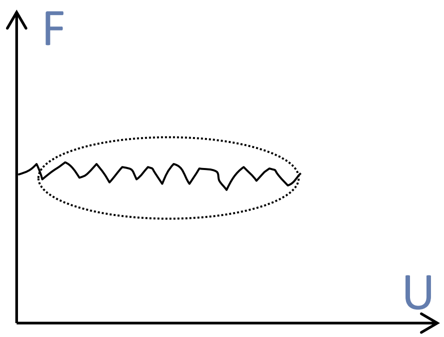
Deformations and sliding types



S_{in} – initial slip after the load introduction.

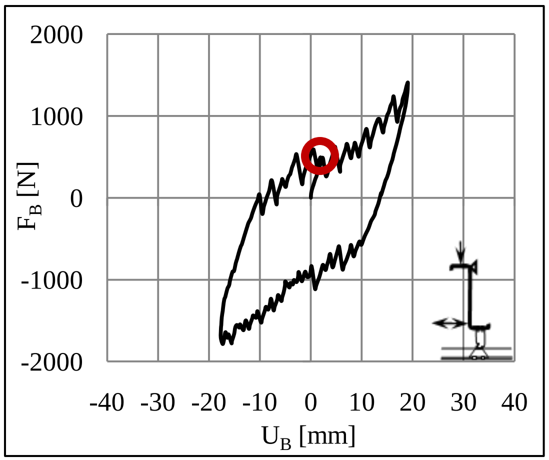


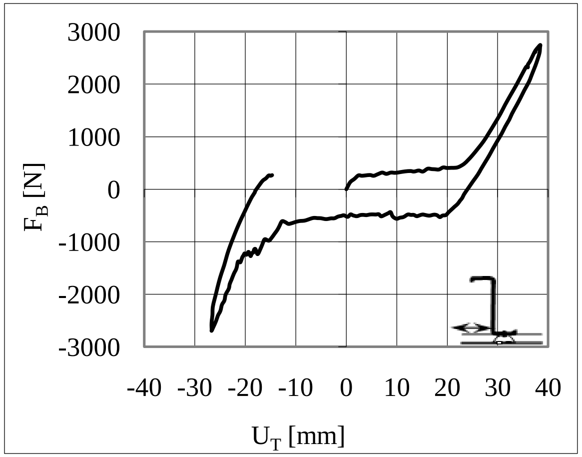
S_{sm} – „smooth” slip after the first slip happened.

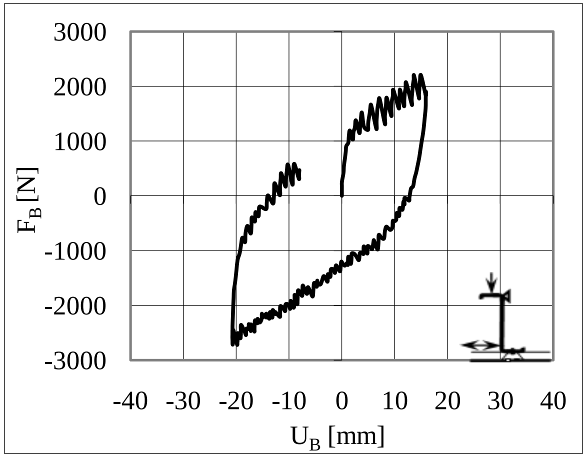


S_{cs} – „continuous” stick–slip after the first slip happened.

Deformations and sliding types







S_{in} – initial slip after the load introduction.

S_{sm} – „smooth” slip after the first slip happened.

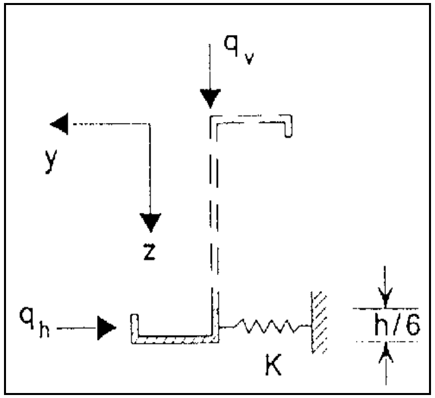
S_{cs} – „continuous” stick–slip after the first slip happened.

Analysis of experimental results

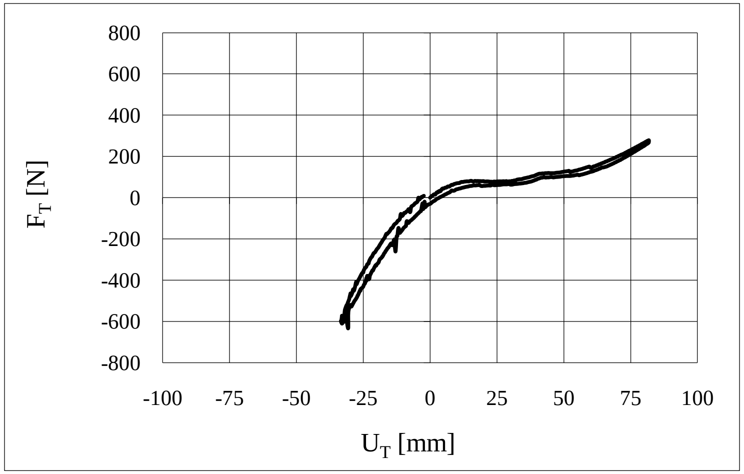
F_T-U_T ⟹ K

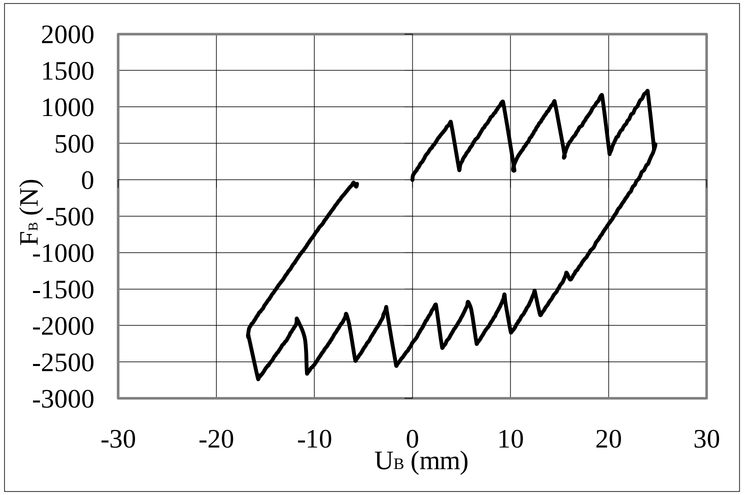
F_B-U_B ⟹ K

$$\frac{1}{K} = \frac{\delta}{F}$$



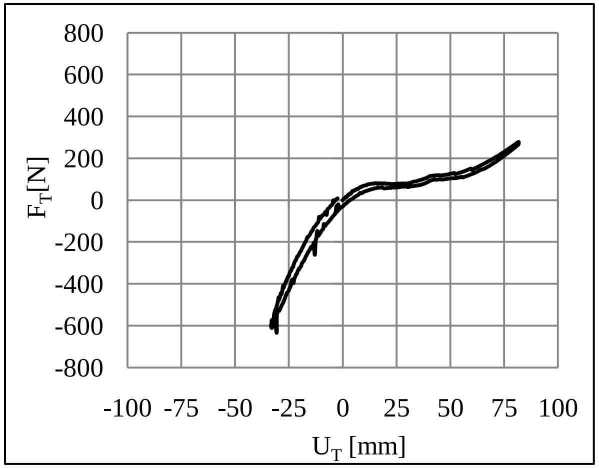
due to the nature of the F–U relationships, two models are developed to calculate the lateral stiffness values

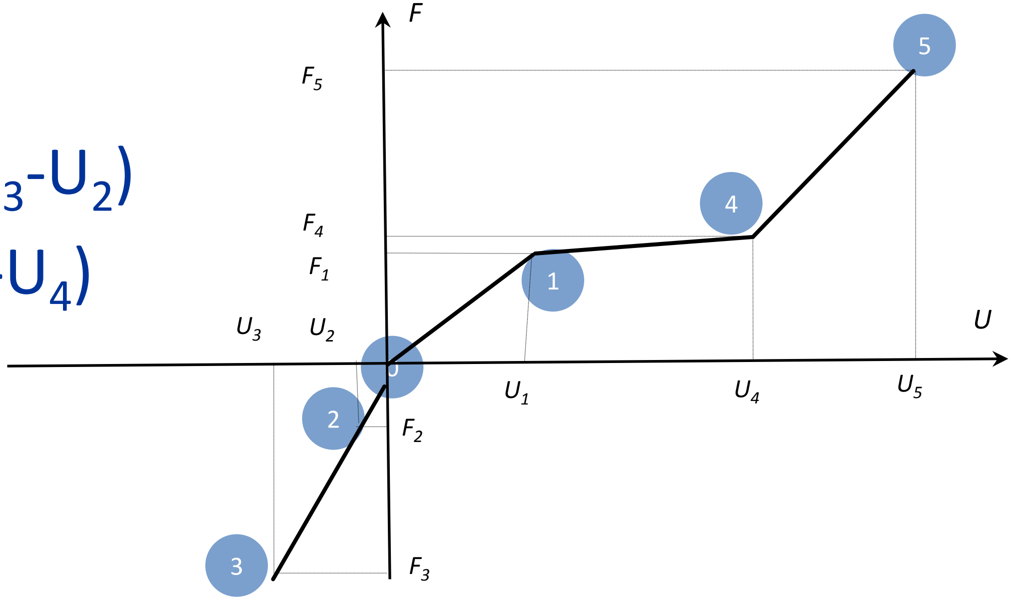




Model #1

- displacements without sliding
  - $K_1=(F_1/L)/U_1$
  - $K_4=(F_4/L)/U_4$
  - $K_{1(-)}=(F_3-F_2)/L)/(U_3-U_2)$
  - $K_3=(F_5-F_4)/L)/(U_5-U_4)$

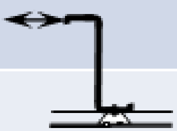
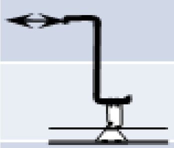
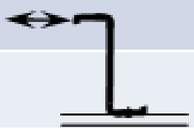




characteristics of Model #1

Model #1 lateral stiffness

average stiffness of the tested specimens

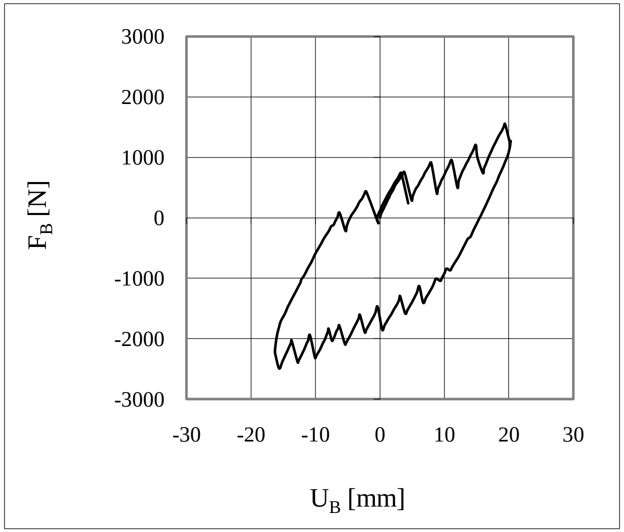
	specimen	purlin	$K_4 \times 100$ [N/mm^2]	$K_{1(-)} \times 100$ [N/mm^2]	$K_3 \times 100$ [N/mm^2]
	MR24#1A	Z200	0.83	0.85	
	MR24#1B	Z250	0.74	0.842	
	MR24#2A	Z200	0.143	0.143	
	MR24#2B	Z250	0.061	0.124	
	MR24#3A	Z200	0.352	1.478	0.389
	MR24#3B	Z250	0.176	0.635	0.294

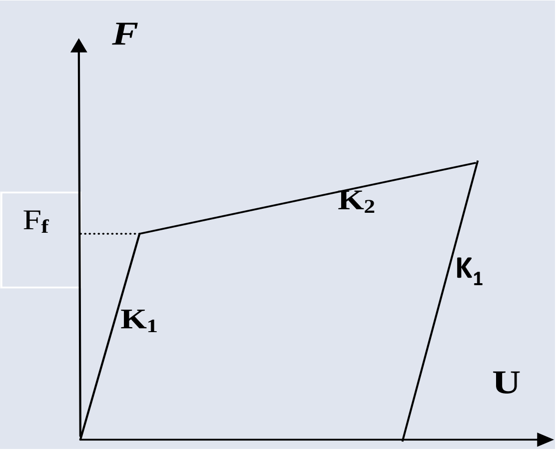
Model #2

K_1 average elastic lateral stiffness of the system

K_2 friction/sliding stiffness of the system including nonlinear behaviours and sliding effects

F_f average initialling friction/sliding load at which sliding behaviours occurs





characteristics of Model #2

Parameters of Model #2

$K_1=(k_{11}+ k_{12} +k_{13})/3$

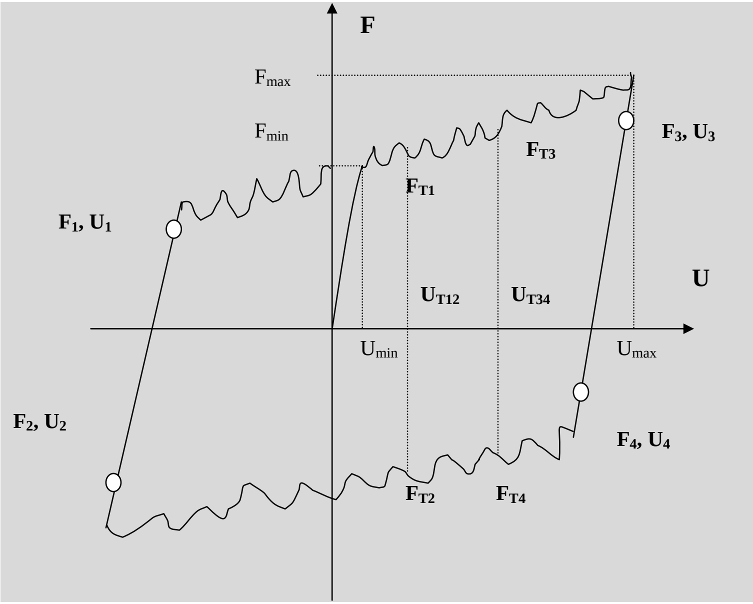
$K_{11}=(F_{min}/L)/U_{min}$

$K_{12}=(F_3-F_4)/L)/(U_3-U_4)$

$K_{13} =(F_1-F_2)/L)/(U_1-U_2)$

$K_2=(F_{max}-F_{min})/L)/(U_{max}-U_{min})$

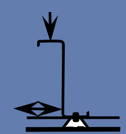
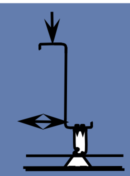
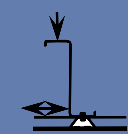
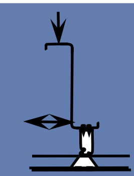
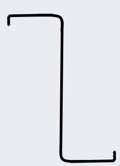
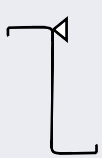
$F_f =((F_{T1}-F_{T2})+(F_{T3}-F_{T4}))/4$



Model # 2 parameters

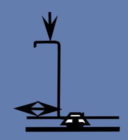
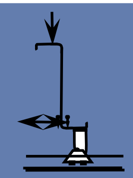
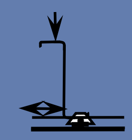
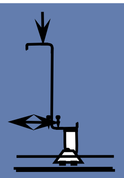
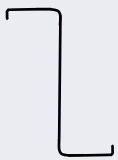
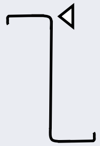
Model #2

initial stiffness K_1 ×100 [N/mm^2]

upper flange condition	F_V [N]				
		Z–200	Z–200	Z–250	Z–250
	0	0.164	0.009	0.1	0.005
	662	0.247	0.003	0.067	0.011
	1709	0.275	0.004	0.176	0.022
	2308	0.329	–	0.162	–
	662	0.269	0.08	0.226	0.064
	1709	0.263	0.09	0.187	0.07
	2308	0.306	0.085	0.196	0.077
	2907	0.311	0.085	0.38	0.079

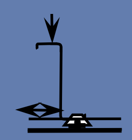
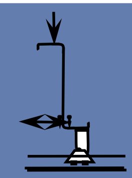
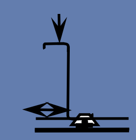
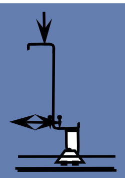
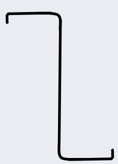
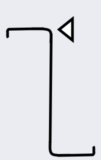
Model #2

friction sliding stiffness K_2 ×100 [N/mm^2]

upper flange condition	F_V [N]				
		Z–200	Z–200	Z–250	Z–250
	0	0.003	0.0014	0.0025	–
	662	0.01	0.0003	0.0028	0.0058
	1709	0.014	0.0013	0.0115	0.0128
	2308	0.018	–	0.0094	–
	662	0.054	0.0219	0.0353	0.0103
	1709	0.044	0.0169	0.0346	0.003
	2308	0.051	0.0145	0.0406	0.0135
	2907	0.058	0.0147	0.034	0.0073

Model #2

friction sliding force $2F_f$ [N]

upper flange condition	F_V [N]				
		Z–200	Z–200	Z–250	Z–250
	0	1072	–	859	–
	662	1430	169	458	–
	1709	1812	–	1573	–
	2308	1978	–	1900	–
	662	2140	1314	1298	1580
	1709	2083	2121	1693	2128
	2308	2141	2524	1888	2459
	2907	2713	3011	2080	3044

Evaluation of results

- lateral load at top flange
- lateral load at bottom flange

Lateral load at top flange

- purlin height effect on specimen stiffness:

  Z-250/ Z-200 ⟹ 40-90 %

- bridge system effect on specimen stiffness:

  with bridge/without bridge ⟹ 10-15 %

- direction of load effect on specimen stiffness:

  Positive/negative load ⟹ 25–100 %

Lateral load at bottom flange

- the effect of high bridge system is significant on the lateral stiffness K_1 ⟹ 1-40 %

  K_2 ⟹ 5-50 %

  F_f ⟹ 60-100 %
- gravity load has significant effect as well

  ⟹ 5-100 %
- purlin height and restrain of the purlin upper flange have smaller effect compared to the previous two parameters ⟹ 30-90 %

Conclusions

1. I designed a test procedure to test cladding systems with sliding and bridge elements; I completed tests on 182 specimens.
2. I analyzed the test results on the basis of F-U relationships for specimens and determined the typical behaviour modes.
3. On the basis of the test results I developed two models to characterize the observed behaviour.
4. The models are used for stability design of purlins:

   (i) lateral stiffness values are built in the design method of purlins.

   (ii) the insufficient structural arrangements are determined.

Thank you