

# Limit State of Trapezoidal Metal Sheets Exposed to Concentrated Load

Kateřina Jurdová

**Abstract**—In most industrial compounds are used trapezoidal metal sheets like a roof decks. These trapezoidal metal sheets are exposed by concentrated loads, usually by service loads arise from installation of air distribution, sanitary distribution, sprinkler system or wiring installation. In objects of public facilities (like shopping centre, tennis hall, etc.) they can be used for hanging advertising posters etc, too. These systems work as “building kit”. These anchoring systems are represented by clamps in shape of “V”.

This paper is occupy with recapitulation of installation systems available in trade with focus on load-bearing capacity specified by producer and on possible methods, how exactly define load bearing capacity of trapezoidal sheet loaded by concentrated load. The load bearing capacity was verified at experimental samples to determine real behavior of trapezoidal metal sheets exposed to concentrated loads.

**Keywords**—Clamps, concentrated load, loading test, trapezoidal metal sheet.

## I. INTRODUCTION

THIS paper is deal with the issue of suspended load by clamps to trapezoidal sheet. The main use of “V” clamps is in hall constructions e.g. shopping centers, sport halls, production or public facilities etc. The construction system of is commonly formed by prefabricated concrete parts, usually by concrete girders supported by constrain columns and lateral bracing. The roof structure is created by trapezoidal metal sheets which are loaded by the other layers of roofing e.g. thermal insulation, water-proofing etc.

These trapezoidal metal sheets are exposed by concentrated loads, usually by service loads arise from installation of air distribution, sanitary distribution, and sprinkler system or wiring installation – see Fig. 1.



Fig. 1 Scheme of system with “V” clamp [6]

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For suspending load could be used clamp in shape “V”. In European market are many producers which offer their own anchoring system for each type of distribution. They also give the values for maximum tension force of suspended load, but they do not say the boundary conditions for using. In common practice the engineers, need to know the true load bearing capacity of trapezoidal metal sheets exposed to concentrated load, but it does not exist any literature or some method how it exactly determine.

There are two approaches to solve this problem. One way is create a numerical model, which is exactly describing real behavior of thread in hole of trapezoidal sheet [8]. Second way is execute an experiment on real specimen of trapezoidal sheet.

On the beginning of this study was done a numerical model with aim to describe a course of stress around the hole in trapezoidal sheet. Model was created as 3D solid by 2D elements (slabs) [1]. After that was created second more complex numerical model by 3D elements (solids). This model was a key to execute first experiment phase of study. The aim was explore a real behavior of trapezoidal sheet loaded by point force through “V” clamp. This contribution is deal with testing of specimens in laboratory and results of this experiment.

## II. AIM OF THE EXPERIMENT

As was write, before executing the tests in laboratory were done first numerical models. For this job was chosen software RFEM by Dlubal.

In numerical models were find out approximate figures of stress [7]. The stress behavior indicate problem with local bearing capacity under the threaded bar. There was became a destructive influence on the hole wall, because of the value of the stress – see Fig. 2.

The values of the stress were several times bigger than tensile strength of the used material (trapezoidal sheet TR 92/275 – see Table I).

TABLE I  
USED TRAPEZOIDAL METAL SHEETS

trapezoidal metal sheet	t (mm)	m (kg/m <sup>2</sup> )	A <sub>eff</sub> (mm <sup>2</sup> /m)	I <sub>eff</sub> (mm <sup>4</sup> /m)	W <sub>eff</sub> (mm <sup>3</sup> /m)
TR 92/275	0.88	10.12	1011.35	1.2E+06	2.3E+04
	1.00	11.49	1168.86	1.4E+06	2.6E+04
	1.25	14.37	1489.44	1.7E+06	3.3E+04

This result was used as base for aim of experiment. It was done a proposal of testing device for pilot test of trapezoidal sheet.

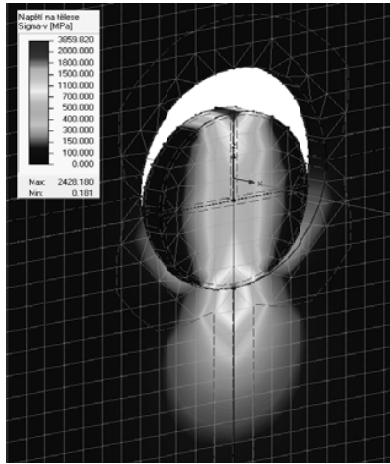


Fig. 2 Stress analysis – 3D model, Dlubal RFEM

#### A. Pilot Laboratory Test

The function of the pilot tests was determining behavior of the trapezoidal without initial tension [2]-[4]. The aim was find out the real behavior of the trapezoidal metal sheet, threaded bars and clams during tensile test—see Fig. 3

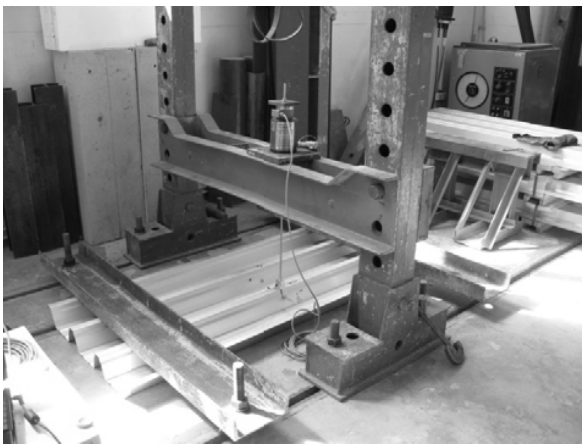


Fig. 3 Test equipment of the tension loading

For pilot testing was used simple loading schema – see Fig. 4.

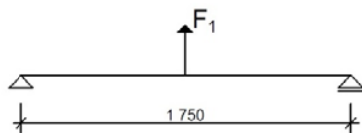


Fig. 4 Loading schema

#### B. Model of True Behavior

After the pilot test was optimized whole test equipment. It was necessary take account of real behavior. So the initial tension was supplemented – see Fig. 5. The aim was find real deformation of the construction system and find out real behavior of the trapezoidal metal sheet, threaded bars and

clams during loading.

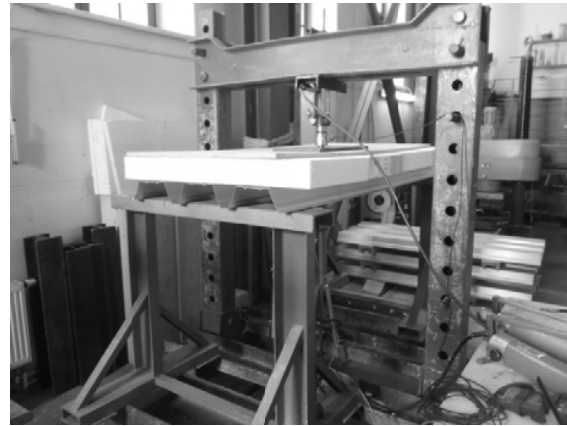


Fig. 5 Test equipment of supplementing initial tension

### III. PROCEDURE

The test equipment was composed from two supports, steel frame, two hydraulic cylinders, two hand hydraulic pumps, measuring instruments, trapezoidal metal sheets Arcellor Mittal, ISOVER polystyrene, plywood, clamps, threaded bars, nuts and washers. For loading initial tension on the top of the system was used pushing hydraulic cylinder KGF. On the bottom of the equipment was used tensile hydraulic cylinder KGF T-series T10-150S.

There were used three specimens of trapezoidal metal sheets with thickness 0.88mm, 1.0mm and 1.25mm. The type of trapezoidal metal sheet was TR 92/275 (by Arcellor Mittal) with S320 steel series. The specimen had following dimensions: 2000mm length, 825mm weight.

The point of testing was found limit states in case that sheet is loaded on 50, 70 and 100% of bearing capacity by dead load situated on upper side of metal sheet together with load hanged on “V” clamp at the bottom wave. By this was simulated real state with external load (e.g. layers of roofing, variable load – snow, air condition equipment etc.) and internal load (load hanged on “V” clamp).

The dead load was created by force which was distributed to area of trapezoidal sheet by layer of polystyrene with thickness 100mm and plywood with thickness 20mm – see Fig. 8.

The initial state started by putting sheet to the supports. The span of sheets was 1.75m and the distance of supports from edge of sheet was 125mm. In next step was assembled polystyrene and plywood on upper side of sheet. For measuring a deflection was installed one indicator at to bottom side of sheet – see Fig. 7. After that was installed the pressure cylinder on the middle of span to upper side of sheet which was served to loading the trapezoidal sheet by dead load on 50, 70 and 100%. That was final step of prepare to first phase of testing. In next step were specimens loaded by simulated dead load on required level (e.g. 50 % in first step). In this moment was end of first phase. The value of deflection was registered.

In second phase were specimens loaded by dead load and by force through punched holes by pliers in bottom wave of sheet.

Anchoring system had an accurate description how to position the clams. A producer Hilti made original punch pliers [5]. This punch plies made a hole in the wall of the trapezoidal sheet from the both sides – see Fig. 6.



Fig. 6 Punch plies and hole for position threaded bar

After that is necessary placed threaded bar (particularly M8–4.8.) through the holes and complete whole anchoring system according producer's manual. At the bottom of the “V” clamp is welded assembling nut for threaded bar M10. The bar M10 was connected to steel joint of hydraulic tensile cylinder KGF T-series T10-150S which was anchored – see Fig. 7.



Fig. 7 Anchoring system with “V” clamp and tensile hydraulic cylinder

The measuring indicators were installed after assembled of clamp system to the wave. Indicators had start point at the bottom edge of added nut screwed to bar of clamp.

Each specimen was gone through same testing procedure with two phases. There were 9 specimens, exactly three trapezoidal sheets with thickness 0.88mm, three sheets with thickness 1.00mm and three sheets with thickness 1.25mm. First specimen of the plate with same thickness was tested in first phase with 50% of initial load bearing capacity, second specimen was tested with 70% of initial load bearing capacity and third specimen was tested with 100% of initial load

bearing capacity.

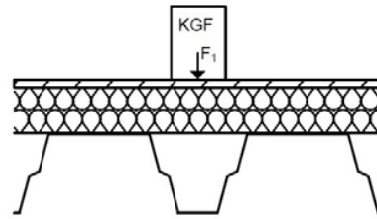


Fig. 8 Loading schema – phase 1

In the middle of the span were placed measuring instruments at the bottom of the wave – see Fig. 9.

The test was performed by measuring an initial deformation from each part of load bearing capacity and for each type of sheet thickness.



Fig. 9 Measuring instrument on the bottom of the wave sheet

Second phase was loading an anchoring system – “V” clamp, by tensile hydraulic cylinder T10-150S. Loading schema – see Fig. 10. Loading of clamp was slow through the hydraulic tensile cylinder. The end of testing in second phase was come when the trapezoidal sheet reach the local buckling – see Fig. 12.

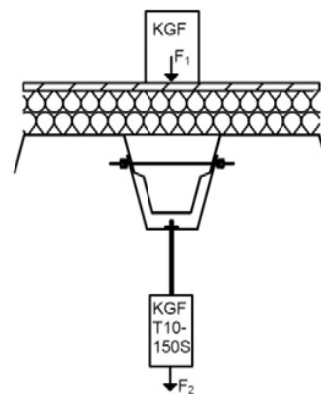


Fig. 10 Loading schema – phase 2

## IV. MEASURED VALUES

The aim of the testing specimen was find a first and second limit state of behavior trapezoidal metal sheet.

The criterion for second limit (serviceability state) state was maximal deflection equal to span/200. The calculation of limit deflection  $u_{lim}$  is 8.75mm.

At the end of first phase was obtained values of deflection for each specimen. These values are marked by  $u_3$ . In second phase was obtained values of deflection by force in clamp. Those values are marked by  $u_2$ . The second limit state arisen when the summation of deflection  $u_3$  and  $u_{dov}$  reach value equal to  $u_{lim}$ . The appropriate force to  $u_{dov}$  is marked by  $F_2$ . Value of this force accorded to maximal load which could be hanged on clamp. The marking  $u_{dov}$  means maximal deflection by hanged load which satisfied to second limit state. This was made for each type of thickness sheet – see Table II.

TABLE II  
DEFLECTIONS AND APPROPRIATE FORCES FOR EACH THICKNESS OF METAL SHEETS

trapezoidal metal sheet thickness 0.88 mm			
L = 1750 mm	$u_{lim} = L/200 =$	8.75	mm
	$u_3 =$	3.10	mm
50% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	5.65	mm
	appropriate force $F_2 =$	4.69	kN
	$u_3 =$	3.80	mm
70% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	4.96	mm
	appropriate force $F_2 =$	4.24	kN
	$u_3 =$	5.17	mm
100% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	3.58	mm
	appropriate force $F_2 =$	3.56	kN
trapezoidal metal sheet thickness 1.00 mm			
L = 1750 mm	$u_{lim} = L/200 =$	8.75	mm
	$u_3 =$	2.81	mm
50% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	5.94	mm
	appropriate force $F_2 =$	5.94	kN
	$u_3 =$	3.82	mm
70% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	4.93	mm
	appropriate force $F_2 =$	4.97	kN
	$u_3 =$	5.61	mm
100% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	3.14	mm
	appropriate force $F_2 =$	3.31	kN
trapezoidal metal sheet thickness 1.25 mm			
L = 1750 mm	$u_{lim} = L/200 =$	8.75	mm
	$u_3 =$	3.31	mm
50% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	5.44	mm
	appropriate force $F_2 =$	7.16	kN
	$u_3 =$	5.07	mm
70% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	3.68	mm
	appropriate force $F_2 =$	4.78	kN
	$u_3 =$	7.31	mm
100% of load bearing capacity	$u_{dov} = u_{lim} - u_3$	1.44	mm
	appropriate force $F_2 =$	2.10	kN

Dependence of force  $F_2$  and deflection  $u_2$  for trapezoidal sheet with thickness 0.88 – see Fig. 11 (a)). For trapezoidal sheet with thickness 1.0 mm –see Fig. 11 (b)) and for 1.25mm –see Fig. 11 (c)).

First limit state was obtain when the displacement (deformation) of threaded bar reach value 0.1mm. Bigger value of displacement (deformation) are distorted because

occurred to enlarge of pressure area for bar by deforming of punched hole in sheet. Appropriate force to approximation value of deformation 0.1 is marked by  $F_2$ . Values are arranged in tables – see Table III.

TABLE III  
DEFORMATION WHEN THE FIRST LIMIT STATE BECAME

trap. sheet thickness 0,88 mm	difference of deformation $\Delta u$	appropriate force $F_2$ (kN)
50 % bearing capacity ( $F_1$ )	0.091	0.300
70 % bearing capacity ( $F_1$ )	0.098	0.288
100 % bearing capacity ( $F_1$ )	0.081	0.066
trap. sheet thickness 1,0 mm	difference of deformation $\Delta u$	appropriate force $F_2$ (kN)
50 % bearing capacity ( $F_1$ )	0.111	0.645
70 % bearing capacity ( $F_1$ )	0.122	0.303
100 % bearing capacity ( $F_1$ )	0.134	0.252

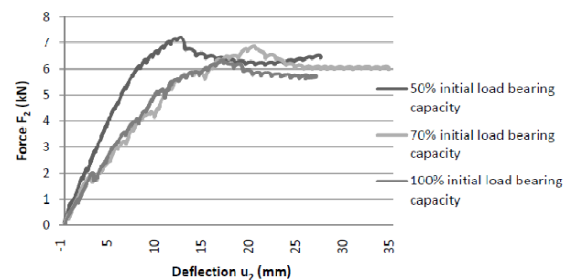


Fig. 11 (a) Trapezoidal sheet thickness 0.88 mm – deflection  $u_2$  depending on force  $F_2$

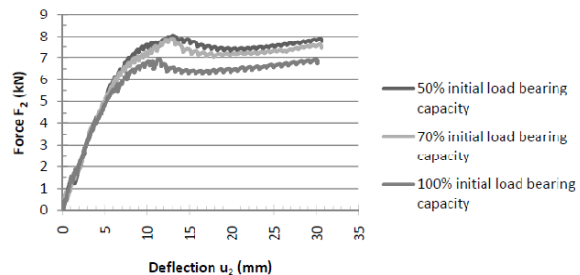


Fig. 11 (b) Trapezoidal sheet thickness 1.00 mm – deflection  $u_2$  depending on force  $F_2$

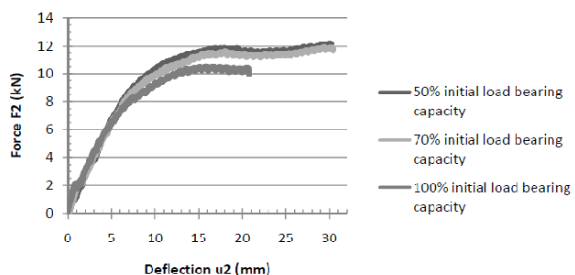


Fig. 11 (c) Trapezoidal sheet thickness 1.25 mm – deflection  $u_2$  depending on force  $F_2$

## V. RESULTS

The aim of the testing specimen was find the first and second limit state of trapezoidal metal sheet exposed by local

force (load) by clamp. First limit state depended on deformation-threaded bar bearing resistance. Maximal values of force which could be hanged on clamp are in Table III. Values of deflection are shown in Table II. Threaded bars bearing resistance-deformation had effect on difference between values of  $F_2$  for first limit state a second limit state. If the criterion of displacement would be bigger than 0.1 mm then the value of force  $F_2$  will be bigger. Increasing criterion is defended by conclusion of tests because enlarge of pressure area for bar by deforming of punched hole in sheet distorted measured values.



Fig. 12 End of testing of second phase (local buckling)

## VI. CONCLUSION

Specify the limit state for trapezoidal sheets exposed by local load is very difficult. This contribution only outline the theme of clamps anchored in to wave of trapezoidal sheet. The results of this paper are necessary to understand as partial results which couldn't be generalized. This study will be continued by evaluation of measured values which will be source for creating the new numerical models focused on threaded bar bearing resistance.

## ACKNOWLEDGMENT

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