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# Building Cladding using Liner Trays: Experimental and Numerical Approach

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**Abstract**. Liner trays are large channel-type thin-walled steel sections with two narrow flanges, two webs and one wide flange, very frequently used in practice both to resist perpendicular uniformly distributed loading from wind and create a diaphragm effect at the level of buildings cladding. Such cladding systems are normally built using a required number of horizontally laid inter-connected adjacent liner trays plus an external skin of sinusoidal or trapezoidal sheeting installed perpendicularly to their direction (with vertical corrugations). This results in a stiff metal cellular system (as outer wall of the building) having its inner space filled with thermo insulating material. When trying to evaluate the resistance of such elements by experiment, the specific constructional details play a major role and create quite complex problems in establishing a correct experimental procedure. Thus an experimental setup made of three joined liner trays is proposed with adequate detailing to match the real situation of such claddings. The investigation on liner trays was conducted by a joint team belonging to The Romanian Academy (Timisoara Branch), The Politehnica University of Timisoara (CEMSIG Laboratory) and The National Institute for Research and Development (INCD-URBAN-INCERC)–Timisoara Division. Aspects related to the experimental setup, test results (in terms of found collapse modes) experimentally and numerically determined resistances are emphasized. A comparison with code based theoretical results and FE simulation is presented and discussed in the final part.

## 1. Introduction

Liner trays are thin-walled steel sections of large channel-type with two narrow flanges, two webs and one wide flange, very frequently used in practice, to resist perpendicular uniformly distributed wind loading as well as to create a diaphragm effect which acts against horizontal wind/earthquake loading at the level of industrial building cladding. Such systems are normally built using a required number of horizontally laid, inter-connected, adjacent liner trays plus an external skin of sinusoidal or trapezoidal sheeting installed perpendicularly to their direction (with vertical corrugations). This results in a stiff metal cellular system (the outer wall of the building) having its inner space filled with thermal insulating material. The creation of an accurate experimental test setup, trying to model the real behaviour of such complex systems is firmly connected to the loading pattern, especially to the wind load pattern. Due to the randomness of wind direction, sense and intensity, the load on liner tray cross-section may reverse (i.e. pressure/suction), totally changing the response of this structural element [1]. This is caused by the wide flange of the non-symmetric cross-section coming either under compression or under tension and causing different wall-buckling configurations, leading to different effective cross-section patterns [2].

Any cladding system using liner trays installed horizontally, supported by main frame columns, plus the outer skin made of trapezoidal or sinusoidal sheet, has a specific "cellular" structure as presented in *Fig. 1*. In this figure, a typical liner tray cladding is presented, configuration given by a renown supplier acting on the market [3].

The detail presented in figure 1 includes several numbered components of the cladding, i.e.:

a) The thin-walled steel components: (2) horizontal liner tray and (4) vertical trapezoidal sheeting as outer skin;

b) The thermal insulating panel of mineral wool (3);

c) The fastening system of the wall: (5) fastening of the liner tray to steel or concrete sub-structure (various types of screws depending on substructure thickness), (6) fastening of the outer skin / trapezoidal sheet to the liner tray edge, (9) fastening of liner tray (horizontal) longitudinal joint at an interval / pitch less than 1000 mm;

d) Sealing elements as (7) thermal separating strip and (8) self-adhesive sealing strip.

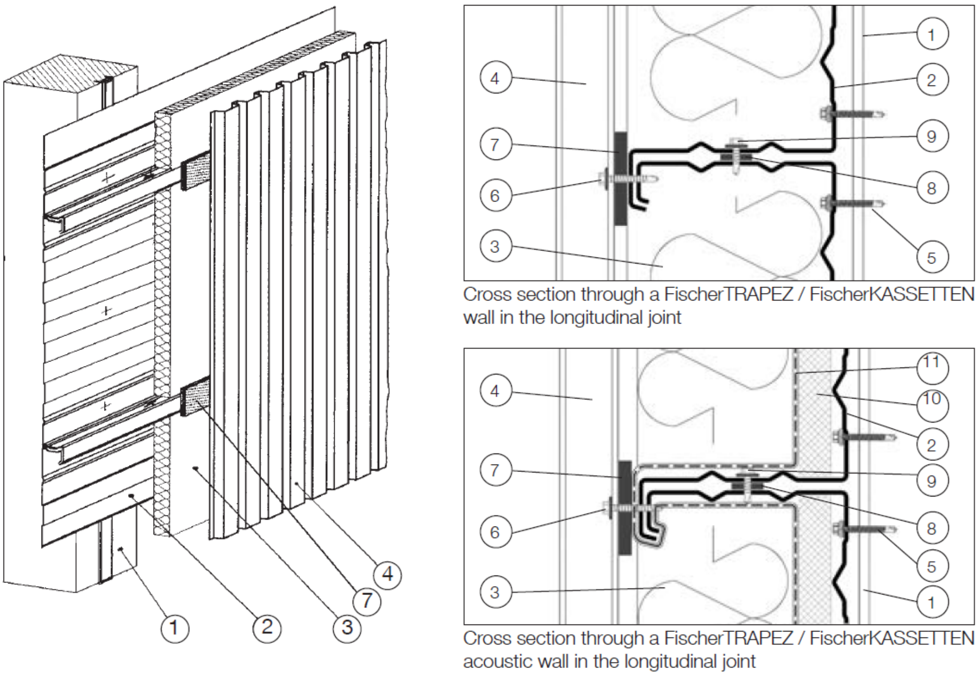


**Figure 1.** Typical liner tray cladding according to [3]

The correct understanding of all constructional details (and especially fastening system) plays a major role in the set-up of an accurate experimental model when testing such elements and observing their collapse modes. Actually, the adjacent liner trays, being overlapped and connected along the longitudinal joint, work together with double thickness webs. Furthermore, the axial stiffness of the trapezoidal sheet spanning across the liner trays narrow flanges (and connected by fasteners to these) is preventing either lateral deflection or torsion or distortion of the cross-section in the case of collapse. Thus, mostly local collapse modes are to be expected, both in practical cases and in the case of the experimental model of the present study (if this one reproduces reality in an accurate way). Therefore, the boundary conditions of the tested specimen need to reproduce as accurate as possible the observed constructional details in order to obtain realistic results in strength testing. A remark needs to be made also: the strong diaphragm effect which actually appears in-plane of such cladding systems (using liner trays) is not the object of present study. Only the perpendicular loads acting on the cladding concern this investigation.

## 2. Experimental investigation performed on single liner tray

The experimental program described in the paper was carried on by using liner tray specimens supplied by a European provider acting on the Romanian market [4]. The cross-section geometry chosen among the available three types of liner trays under analysis is presented in figure 2. Among the wall thickness range offered by the supplier for each type of liner tray (i.e. 0.75 mm, 0.88 mm and 1.00 mm), an average thickness of 0.88 mm was chosen for the tests.

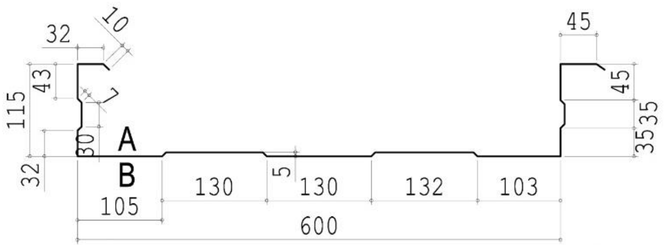


**Figure 2.** Chosen cross-section of liner tray

Considering the dimensional limitation imposed by the available testing rig in the laboratory, a simply supported static scheme with a span of 4.5 m has been adopted for the experimental test setup. Another problem faced by the authors was the experimental modelling of the two different situations of liner tray working under loading: first the external wind pressure on the cladding which is putting the wide flange of the profile in tension and secondly the external wind suction on the cladding which is putting the wide flange of the profile in compression. Obviously, two different setups were required for the two cases. The experimental test setup simulating wind pressure on the cladding is presented in figure 3. As visible in the figure, the specimen support at both ends was built using a timber piece under which a rotating device using steel cylinders was fixed in order to simulate a hinge.

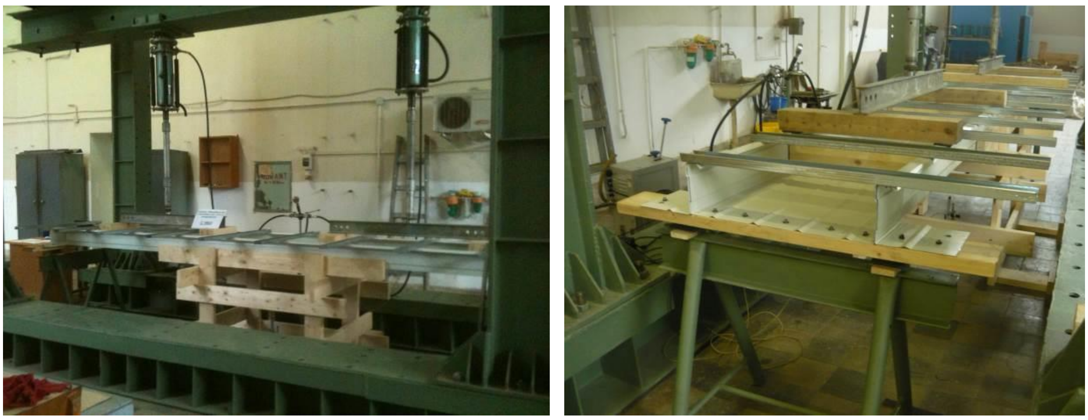

**Figure 3.** Experimental setup for wind pressure

Transversal thin-walled steel profiles connected on the upper edge of the specimen every 350 mm were used to simulate the longitudinal link with adjacent liner trays (existing in reality) and the lateral stiffening role of the outer skin built of the trapezoidal sheet (missing in this arrangement). To complete this effect, timber spacers were installed inside the liner tray cross-section between the vertical webs. Furthermore, a central timber rig (see figure 4) was placed at mid-span, over 50% of the specimen length in order to prevent the lateral-torsional buckling of the liner tray under test loading. Actually, this global collapse mode is not possible in reality, owing to the longitudinal connections of adjacent liner trays and the stiffening by the outer skin as described in figure 1. In order to simulate as close as possible the uniformly distributed wind loading over the specimen surface, a four point concentrated loading was applied, by using two hydraulic jacks. Four transversal timber coupons were used to transmit the load on both liner tray edges, as shown in figure 4.

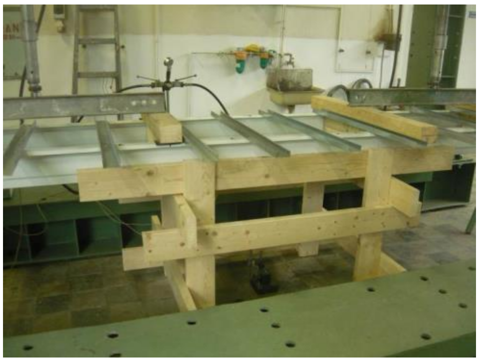

**Figure 4.** Mid span timber rig to prevent lateral-torsional buckling of the specimen

The experimental test setup simulating wind suction on the cladding is presented in figure 5. Since the general experimental arrangement allows only for the application of point loading downwards (via the two available hydraulic jacks) the liner tray was installed in reversed position aiming to put the wide flange in compression.

**Figure 5.** Experimental test setup for wind suction on cladding

**Figure 6.** Smooth transmission of point load via rubber layer

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In order to simulate as close as possible the uniformly distributed wind loading over the specimen surface, a four point concentrated loading was applied here too, provided by the mentioned hydraulic jacks. Four transversal timber coupons were used to transmit the load on the liner tray wide flange. A smoothly distributed transmission of loading on the wide flange (installed upwards in reversed position) was obtained by inserting between the timber coupons and liner tray a rubber layer (figure 6).

## 3. Improved experimental setup of three adjacent liner trays

The conclusions driven when testing single liner tray specimens (requiring a quite complicated experimental arrangement with a whole set of constructional details built to approximate the real response of the cladding) have shown the necessity of a simpler and more realistic experimental arrangement. Thus the idea appeared to use an improved experimental setup built of three adjacent 115x600x0.88 mm liner trays covered with a skin of 15x275x0.5 mm trapezoidal sheet, very similar to the structure of a real cladding (see figure 7).

**Figure 7.** Arrangement using three adjacent interconnected liner tray

Al elements of this arrangement were laterally connected using self-drilling fasteners every 1.0 m as further on described. A similar static scheme to the previous one has been chosen i.e. single span arrangement with a distance L=4.4 m between liner tray supports. The support connection was chosen as fixed at both ends (three fasteners per liner tray), trying to simulate the actual boundary conditions for a real cladding. A support width of 150 mm has been used, simulating the actual contact between liner tray installed horizontally and column. Installing the trapezoidal skin connected with fasteners on the narrow flanges (each second corrugation) has led to a cellular structure, very similar to a real cladding, which did not need all previous supplementary details to provide lateral stabilization (figure 8).

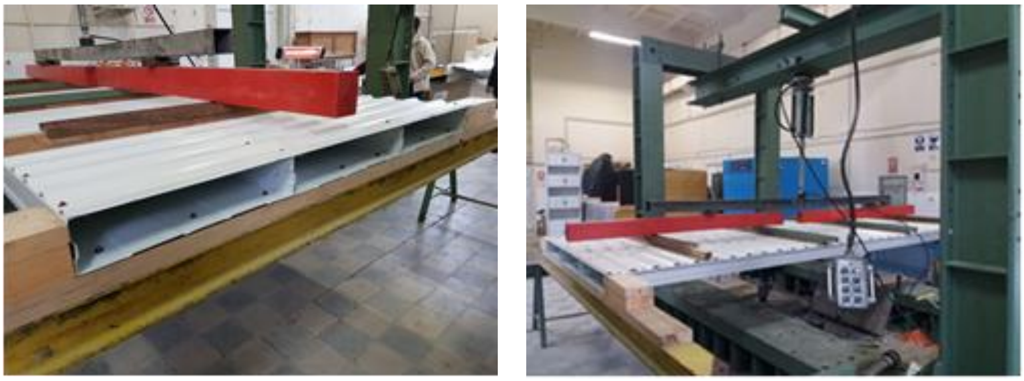

**Figure 8.** Overall image of the experimental setup with outer skin installed

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A single jack system used to apply the four points loading perpendicularly to the cladding has been chosen, after estimating the allowable uniformly distributed load on the cladding. Mid-span deflection meters were installed under each of the three liner trays to control the deflection level.

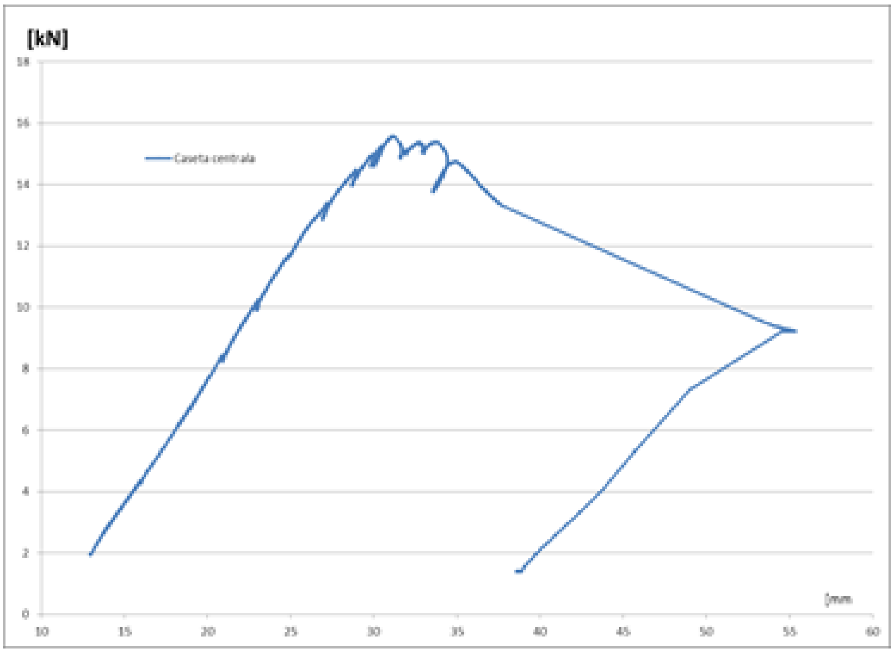


**Figure 9.** Force-deflection plot

During load application and increase in steps of 1kN, the cladding response was monitored, resulting in the force-deflection plot in figure 9. Local buckling zones were observed prior to collapse at the level of liner tray narrow flanges under compression (see figure 10).

**Figure 10.** Local buckling of the narrow flanges in compression

Also, looking at the support area during loading (while getting closer to the collapse phase) a progressive uplift of the wide flange central zones was observed with a pull-out tendency of subsequent fasteners. Observing actual zone location (with shear force effect prevailing in structural response), this was considered as a “shear lag type” effect. A relevant detail in this sense is presented in figure 11.

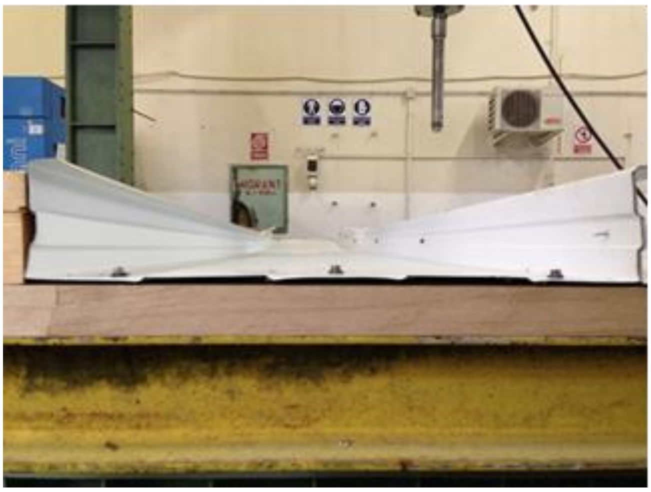

**Figure 11.** Uplift of wide flange central area

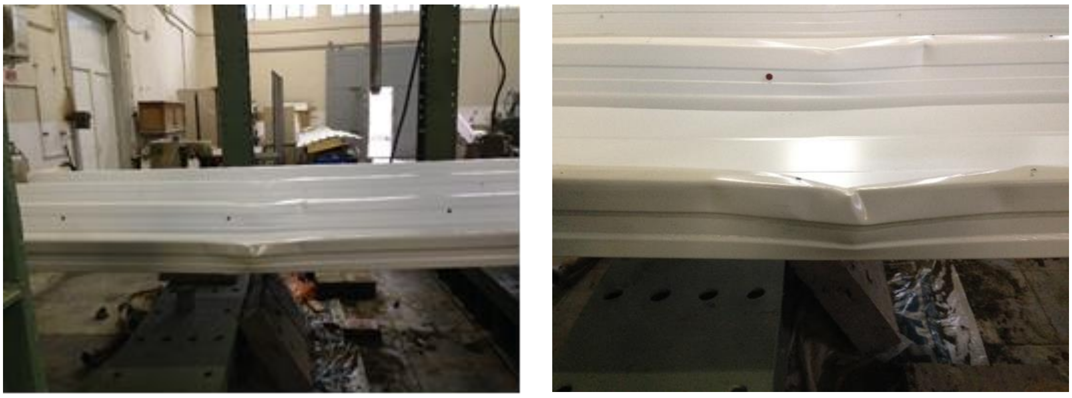

**Figure 12.** Failure mechanism of the tested setup

The final collapse of the tested structure (also of local nature) was observed at the level of the compression web zone of liner tray and connected narrow flange. A web crippling–type pattern appeared under one of the transversal beams used to apply the jack load, propagating transversally and causing the final failure (see figure 12)

## 4. Numerical simulation of triple liner tray setup

Numerical simulations were performed, in similar conditions described for a single liner tray, using FE software ABAQUS 6.7 [5], in order to calibrate and validate the models and facilitate the necessary parametric analyses that are to follow. The system geometry and materials, the fastener distribution and the loading system, accurately reproduce the employed setup. The average net thickness of 0.81 mm was chosen for all cross-sections. SHELL elements of S4R type, with 4 nodes, reduced integration, 6 DOF per node were used for modelling the cold-formed steel linear tray sections. Analyses were performed for both types of wind loading, pressure and suction. The dynamic explicit solver was used for better computational time cost and an easier convergence of the non-linear matrix. The material used in the study was input accordingly to the real material behavior curve reported by testing specimens of steel S280.

A displacement of 100 mm was applied in one loading point along the entire span of the tray (according to the experiment). Four loading props were used to distribute the load uniformly by modelling 4 rigid cubical rigid bodies, positioned evenly across the trays (following experimental

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distribution), and one longer rigid body was placed perpendicular on these supports. The displacement was input in the centre of gravity of this latter rigid body. The 4 supporting bodies and the perpendicular one were connected through a tie surface-to-surface connection and were given no rotation degrees of freedom, and only allowed to move on the load applying axis Y. The trays were partitioned according to the load applying points prescribed in the experiment and connected together by wire features, with assigned connection sections type beam, which simulate the effect of an actual bolt. The wires were placed at a 1000 mm distance for the inner walls of the tray, and at 275 mm distance for the upper flanges. The end supports were modelled as shell rigid bodies of 150 mm wide, which were given zero degrees of freedom (restrained). As stated in the experiment, the walls of the end supports of the lateral trays were assigned a boundary condition of no lateral displacement. The end support conditions were considered pinned, by connecting them with wire features type beam to the rigid supports. The trays were then connected with the same wire features type beam section to the trapezoidal sheet as stated in the experiment. This sheet acts as a way to distribute the pressure evenly on the trays. The sheet was of shell type with 0.45 mm thickness and was given an elastic behaviour of material (S280).

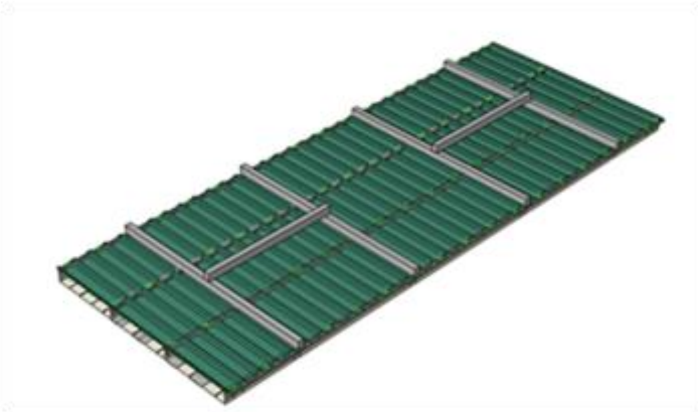

**Figure 13.** FEM simulation of the experimental arrangement (wind pressure

Similar constraints, boundary conditions, elements, material and loadings were used to model both compression and suction wind loading scenarios for all three sections. The numerical model, in the compression case scenario, is exemplified in figure 13. The failure mode found by simulation for the numerical model is showing a similar pattern to the experimental one (figure 14).

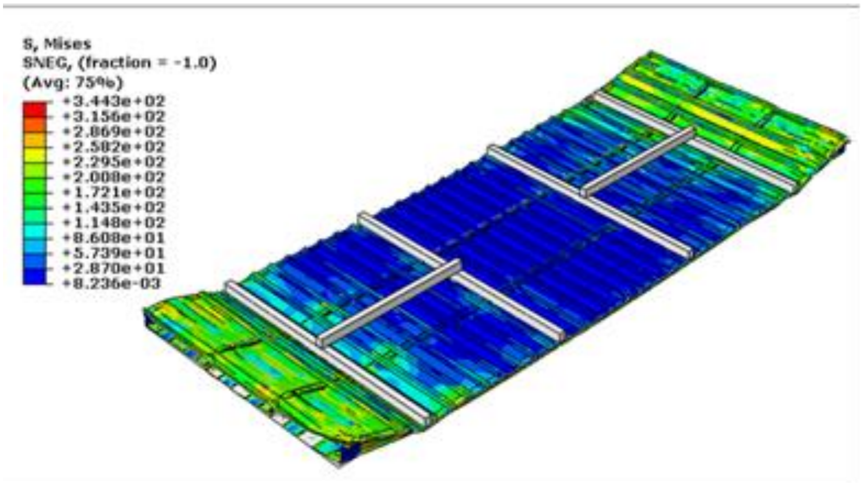


**Figure 14.** Failure mode of the numerical model

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Some further collapse details for this numerical model are presented in figure 15 by "uncovering" the liner trays through skin removal.

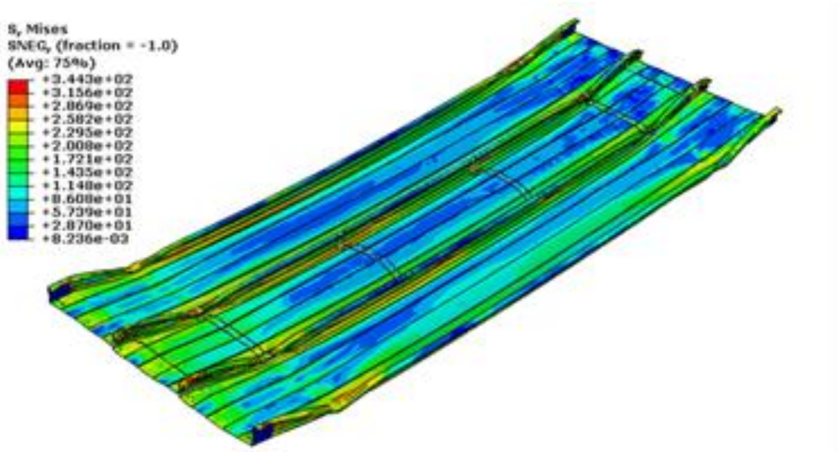


**Figure 15.** Collapsed pattern of the three liner tray arrangement ("uncovered")

The local buckling zones of the numerical model look similar (as position and actual pattern) to the experimental results. When comparing the experimental versus numerical force -deflection plot, a good correlation is also exhibited (figure 16).

In figure 16 the blue plot marked with crosses represents the numerical force-deflection graphic, evolving very closely to the experimental one until the failure moment. As in the real situation (observed during the experiment) the narrow flanges and the liner tray web failure has occurred on the transversal lines located under the rigid beam used to apply the jack force. Also as observed in the experimental phase, the failure was of local type (i.e. web crippling) however propagating to all four vertical webs on the same transversal line.

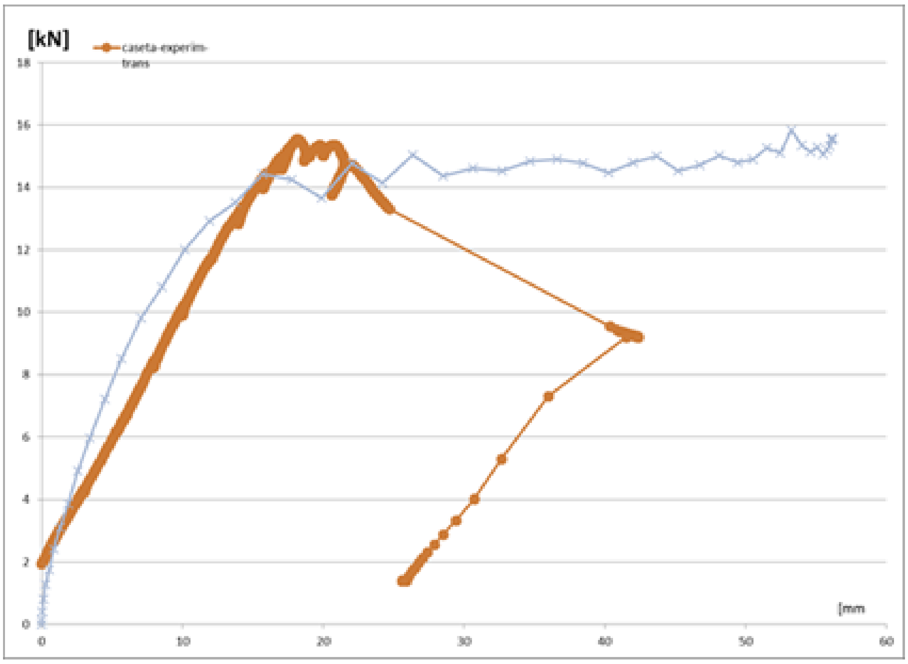


**Figure 16.** Comparison between force-deflection plots (experimental versus numerical)

## 5. Conclusions

An experimental investigation is presented in the paper, focusing on liner tray strength under wind load acting on building cladding. A simple assessment of wind pressure/suction change along the building perimeter (depending on wind direction and sense) is clearly showing the dual situation of each liner tray work/response: under pressure or under suction [1]. Therefore each liner tray in the cladding needs to be designed [2] considering both situations. The typical constructional detail of a liner tray cladding [6] was considered by the authors when building the experimental arrangement to simulate liner tray work under wind load. On the same purpose, an assembly of three adjacent was actually tested in the laboratory. Some important elements of the considered detail, especially the fastening details, play a paramount role in defining and creating correct boundary conditions in the frame of the experimental setup in order to simulate real conditions with sufficient accuracy. Test results are described, observing the location and nature of collapse zones. A comparison between experimentally determined values and values resulting from ABAQUS numerical simulation performed on the same setup is presented, showing a good result correlation and thus confirming the numerical model.

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