LINEAR BUCKLING ANALYSIS WITH DIFFERENT ABM K-SPAN ARCH PANELS

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Received: 10.03.2012; Revised: 30.04.2012; Accepted: 15.06.2012

Abstract
In this research paper a brief description of the ABM (Automatic Building Machine) technology is given which can be used as a solution for buildings and roofing structures. It is a machine on wheels that makes cold formed arch steel panels in a very short time period. This technology is commonly used by the US army to build temporary buildings and nowadays these panels are becoming more popular in the civilian life. There are two main problems connected with this technology. First is lack of proper theoretical model of the panel, and the second is that all calculations are made according to American design codes, which not always are compatible with European standards. In order to bend ABM panel as an arch, its surfaces were folded. This leads to the cross section losses in axial and bending stiffness but also gives some positive aspects. The walls of the cross-sections are less vulnerable to local buckling. In this paper the following is investigated: how each folding and corrugation improves or worsen the critical load factor in a linear local buckling analysis with the use of Robot [2]. These numerical analyses are made to better understand the corrugation influence on ABM panel.

Streszczenie
Artykuł zwięźle przedstawia technologię ABM (z j. ang. Automatic Building Machine) składającą z się z podwójnie giętych elementów cienkościennych, które są używane jako rozwiązanie dla budynków i przekryć dachowych. Jest to mobilna fabryka, która produkuje w bardzo krótkim czasie zimno gięte panele łukowe. Technologia ta jest z powodzeniem wykorzystywana przez armię USA do budowy tymczasowych budynków, a w dzisiejszych czasach zaczyna być również popularna w budownictwie cywilnym. Z technologia tą związane są dwa podstawowe problemy. Pierwszy, to brak modelu teoretycznego opisującego zachowanie elementu ABM, a drugi to obliczenia są przeprowadzane zgodnie z wytycznymi amerykańskimi, które nie zawsze są kompatybilne z normami obowiązującymi w Europie. Podczas formowania elementu ABM w łuk, powstają na jego powierzchni poprzeczne fałdowania. Fałdowania te prowadzą do strat w podłużnej i giętej sztywności, ale mogą mieć pozytywny wpływ na stateczność lokalną profilu. Artykuł ten przedstawia następujący problem: jak proces głównego gięcia oraz fałdowanie poprzeczne polepsza lub pogarsza wartość współczynnika wyboczeniowego podczas liniowej analizy wyboczeniowej w programie Robot [2]? Te numeryczne analizy są przeprowadzone, aby lepiej zrozumieć wpływ fałdowania na panel ABM.

Keywords: **ABM; K-span; MIC 120; Cold-formed; Steel; Arch, Folding; Geometry, Model.**

1. INTRODUCTION

Due to today's difficult economy, cheap and short time consuming solutions for buildings industry are very desirable. One of the solutions which fulfills the above requirements is the ABM (Automatic Building Machine) technology. It is a mobile factory used to fabricate and construct K-span arch steel buildings based on self-supporting panels made of MIC 120 and MIC 240 profiles. K-span stands for large, self-supporting buildings constructed in this technology. Described in here technology comes from the USA and belongs to M.I.C. Industries Inc.[5]. In Poland there are two firms specializing in this building system. First one, Konsorcjum Hale Stalowe [4] uses MIC 120 profiles (Fig. 1a). Second one, Węglopol Sp z o.o. [7] uses MIC 240 profiles (Fig. 1b). In this paper only MIC 120 profiles are considered.

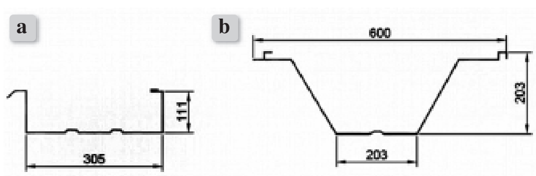

Figure 1.
MIC 120 and MIC 240 cross-sections

According to Walentyński R., Cybulski R., and Kozieł K.[6], ABM system is based on the American Design Codes. This gives a series of limitations of the use this system in Europe due to different loading considerations. Also, there is no proper theoretical panel model and surface folding created during the bending of the panels into arch is not well understood. European standards [3] recommend treating ABM panel's cross-section as class 4. So it means that folded surfaces are not taken into calculation process. It is not totally correct especially that folding gives some resistance to local buckling.

Currently this problem is being analyzed in the Department of Civil Engineering of The Silesian University of Technology by Prof. Ryszard Walentyński, PhD student Robert Cybulski, and PhD student Krzysztof Kozieł, who have published several research papers analyzing this system.

2. TECHNICAL SPECIFICATIONS

The technical specifications of the ABM arch panel cross section 120 are maximum thickness of 1.0 mm, characteristic yield strength of steel is 320 MPa, modulus of elasticity of 210 GPa, Poisson ratio of 0.30, and shear modulus of 81 GPa.

3. GEOMETRICAL SPECIFICATIONS

The general cross section geometry, consists of 2 flanges (one flange in each side), and a convex web. At the top of each flange there are two horizontal flat lips. At the top part of the left flange, the horizontal part is at the right side. In this flange both top parts have 10 mm of length, but differ in their thickness, one has 1 mm and the other 2 mm of thickness. The same occurs in the top part of the right flange, with the only difference, that the second element with 2 mm of thick and 15 mm long. Fig. 2, shows a detail drawing of the cross section dimensions.

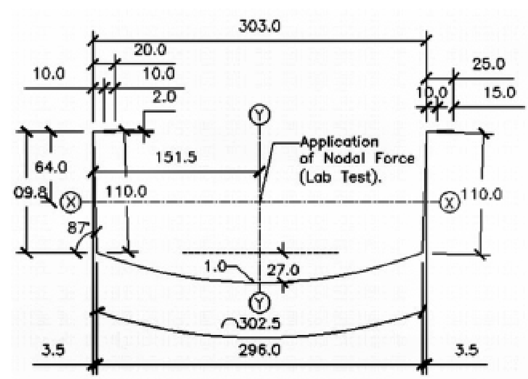

Figure 2.
Detail drawing of cross section

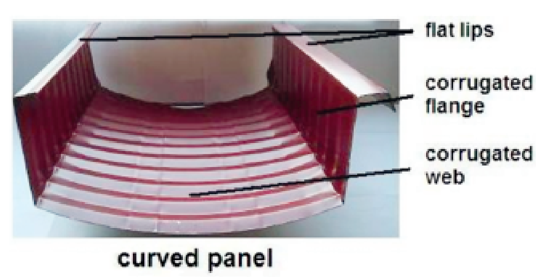

Figure 3.
Geometry of cross section

There are three types of corrugations to be distinguished and these are (Fig. 3):

a. Main Corrugation: it is the curvature or arc formed in between supports, this arch has a height from the midpoint of the arc to the level of supports equal to 4mm and the arc is formed with a sector of a circle with an angle equal to 2.865°.

b. Secondary Corrugation: these are the sinusoidal waves formed in the corrugated flange and corrugated web. The web corrugations have amplitude of 1.2mm from the center to the crest and a wavelength of 30.0 mm from crest to crest. The side corrugations at the flanges have an amplitude of 1.5mm from the center to the crest and a wavelength of 34.0 mm from crest to crest.

In both cases half of a sphere is considered of 7.5 and 8.5 mm in the bottom and side corrugation respectively, localized at each end of the web and side corrugations.

c. Tertiary Corrugation: these are two waves that are perpendicular to the secondary corrugations and go along the length of the panel. The length of this corrugation is 30.0 mm and amplitude of 1.0 mm up from the web, (Fig. 4).

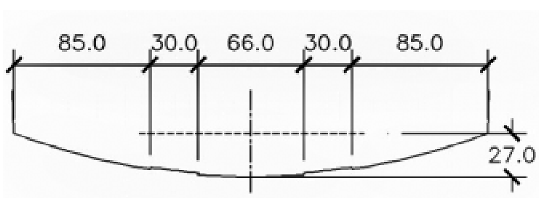

Figure 4.
Tertiary corrugation

4. NUMERICAL MODEL DESIGN

All models were analyzed with the use of Robot [2]. Model A will have a Zero Gaussian curvature, will have the same cross section geometry, and is a smooth, horizontal, planar model, (Fig. 5).

The second model, Model B, consists of the cross section as Model A and includes the main corrugation. As a result we obtain a curved panel with a Negative Gaussian curvature, (Fig. 6).

In the third model (Model C), the Negative Gaussian

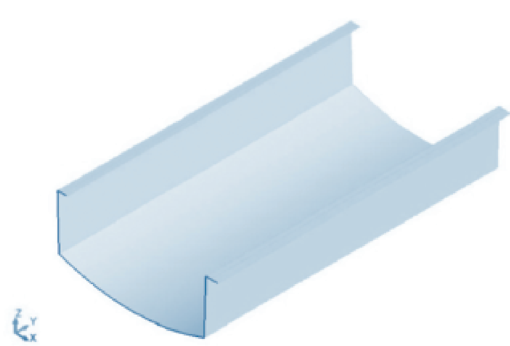

Figure 5.
Model A

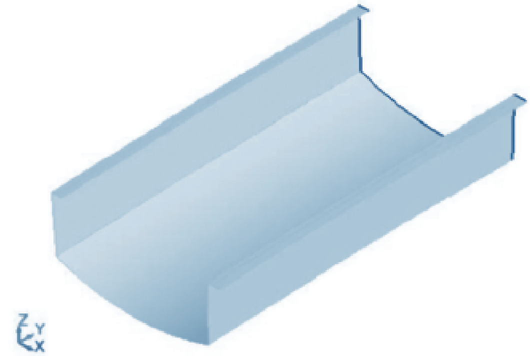

Figure 6.
Model B

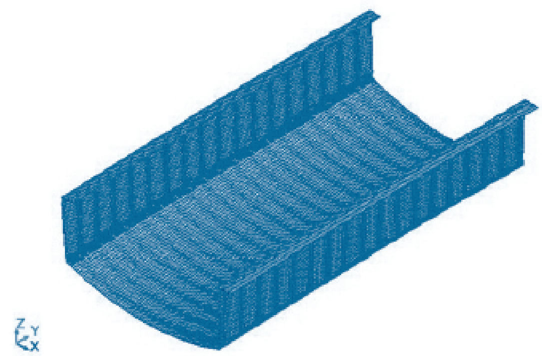

Figure 7.
Model C

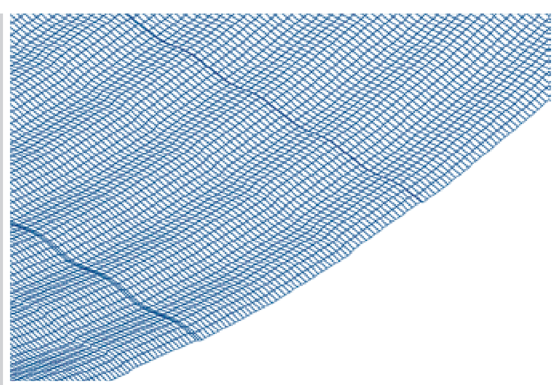

Figure 8.
Model D

curvature and the secondary corrugation were incorporated. Due to the complex geometry of this panel, the geometry was done completely by means of AutoCAD [1], (Fig. 7).

The fourth model, Model D, was incorporated the Negative Gaussian curvature, the secondary corrugation, and tertiary corrugation. Due to the complex geometry of this panel, the geometry was done completely by means of AutoCAD, (Fig. 8).

Several models were also developed to have better understanding of the geometry influence of the cross section and the 3 corrugations that were already mentioned above. They were developed in the same way as Model C and D. In Table 1 the different combinations and changes that were implemented in each model are collected to compare the result of buckling critical load.

Table 1.
Model characteristics

Model	Cross section	Main Corr.	2nd Corr.	3rd Corr.
E	Fig. 2	0	YES	-
F	Fig. 2	0	-	YES
G	Fig. 9	0	-	-
H	Fig. 9	Neg.	-	-
I	Fig. 10	0	-	-
J	Fig. 10	Neg.	-	-
K	Fig. 2	0	-	-
L	Fig. 2	Neg.	-	YES
M	Fig. 11	0	-	-
N	Fig. 11	Neg.	-	-

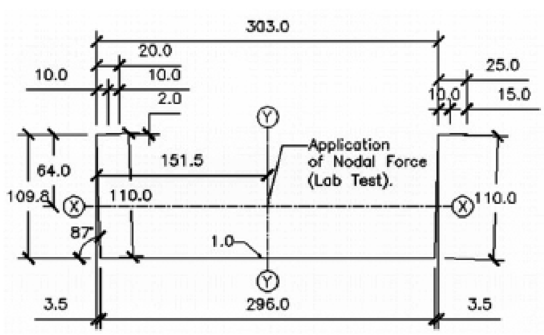

Figure 9.
Cross section of Model G and H

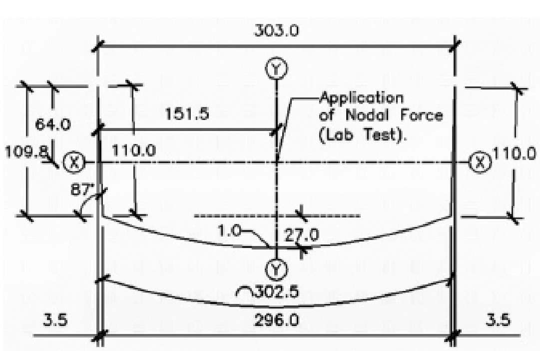

Figure 10.
Cross section of Model I and J

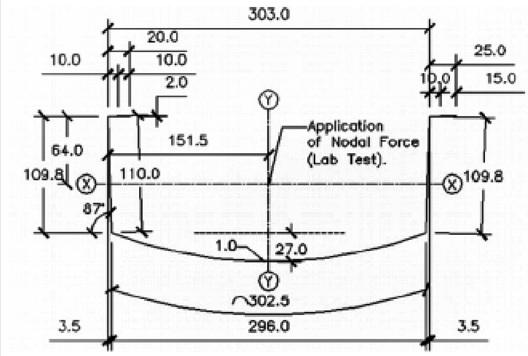

Figure 11.
Cross section of Model M and N

5. SUPPORT CONSTRAIN

The support constrains for the linear local buckling analysis in the edges of the element are:

- In the edge of the element where the compressive load will be applied, the displacements (X and Z) and rotations (X, Y, and Z) were constrained (Red line, Fig. 12).
- In the free edges of the horizontal elements located at the top of the inclined plates only the displacements (X and Z) were constrained due to future experimental investigation (Yellow line, Fig. 12).
- In the opposite side of the application of the compressive load, the displacements and rotations were constrained in all directions X, Y, and Z, as a fixed support (Orange line, Fig. 12).

These support constrains are used in all models.

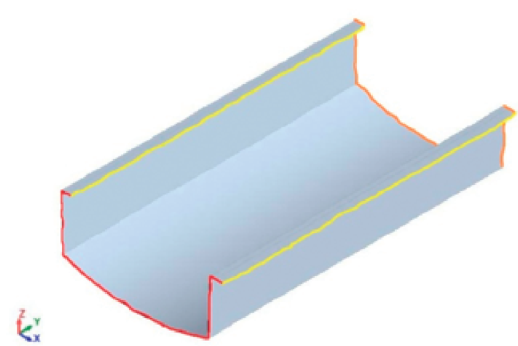

Figure 12.
Detail of support constrains

6. LOAD DEFINITION

Depending on the Main Corrugation, in some models a unitary distributed load was applied in the Y direction. With the addition of the Main Corrugation the unitary distributed load was decomposed in its vector components in the Y and Z direction. This load is symbolizing the axial compression.

7. LINEAR LOCAL BUCKLING

For this analysis we just analyze a length segment of the arch panel, and the panel length that will be used in the laboratories and in Robot will be of 600 mm.

8. RESULTS

The results of the local buckling analysis are presented in Table 2, with the resultant nodal force, maximum displacement (axial shortening), and percentage ratio of reduced force to the maximum resultant force obtained for Model C.

Table 2.
Table of results

	F. force	Resultant Disp.	Percentage Ratio
Model	[kN]	[mm]	[%]
A	55.2	8.6	34.8%
B	70.3	12.7	44.3%
C	**158.6**	**14.5**	**100.0%**
D	141.0	14.8	88.9%
E	157.6	9.5	99.3%
F	149.3	13.7	94.1%
G	8.5	15	5.3%
H	14.8	18	9.4%
I	42.5	11	26.8%
J	55.6	11.2	35.1%
K	57.5	9.3	36.2%
L	58.9	12.1	37.1%
M	55.2	8.1	34.8%
N	70.3	12.8	44.3%

The following shapes for the local buckling modes were obtained.

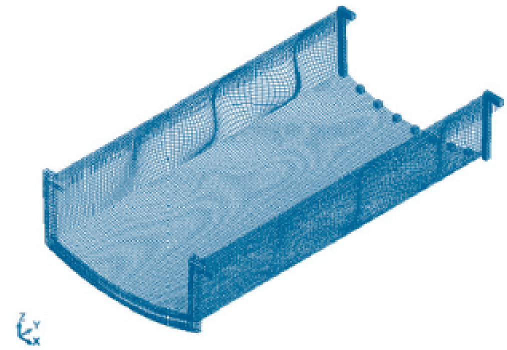

Figure 13.
Model A deformations

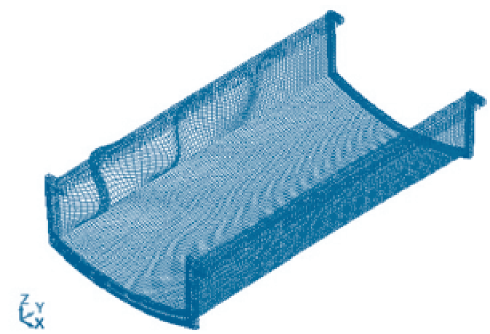

Figure 14.
Model B deformations

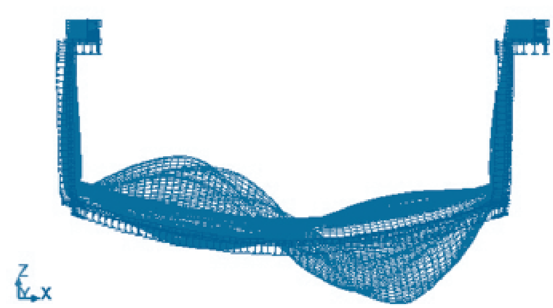

Figure 15.
Model C cross section view of deformations

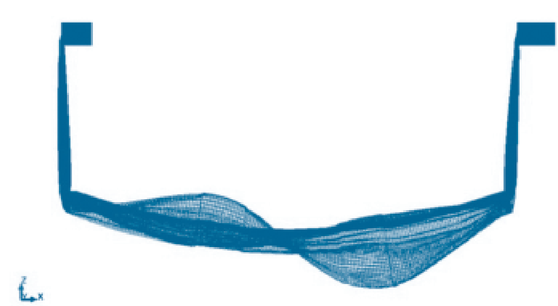

Figure 16.
Model D cross section view of deformations

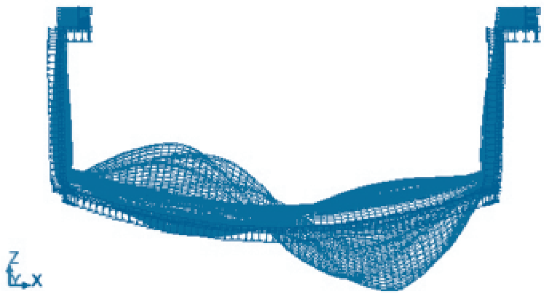

Figure 17.
Model E cross section view of deformations

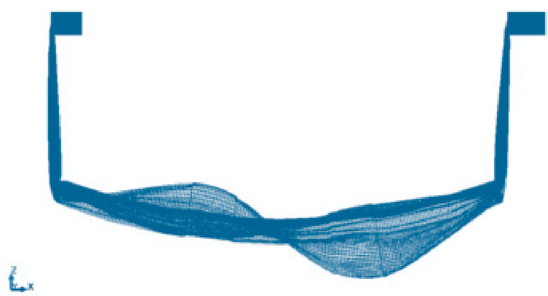

Figure 18.
Model F cross section view of deformations

Model I, J, K, L, M and N have very similar diagrams of deformation to Model A and B.

9. COMPARISON OF RESULTS

This section provides results comparison between all model analyses.

If we compare Model A and B we can conclude that the original cross section geometry (see Figure 2) can resist a compressive force of 55.2 kN and when we add the main corrugation it gives a compressive force of 70.3 kN, what means that the main corrugation provides additional resistance to the arch panel.

If we compare Model B and C we may conclude that when we include the main and secondary corrugation an increment in the compressive force is seen, the total force is 158.6 kN, thus the secondary corrugation provides additional resistance to the arch panel.

If we compare Model C and D we may conclude that tertiary corrugations do not provide essential additional resistance to the arch panel.

Comparing Model C and E we may conclude that when we have only the secondary corrugation there is no resistance loss, so the maximum resistance is given by the secondary corrugation.

Comparing Model E and F we may conclude that

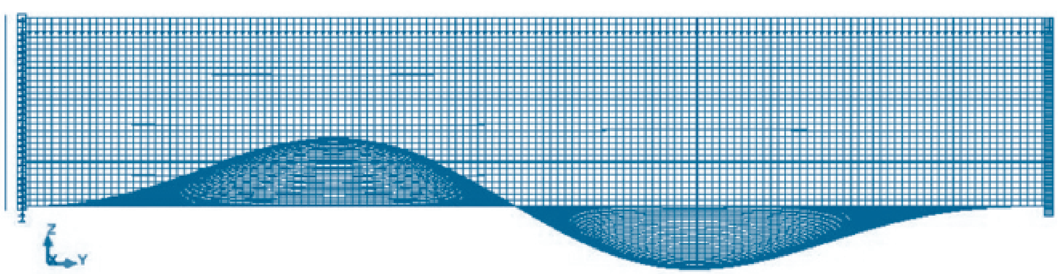

Figure 19.
Model G lateral view of deformations

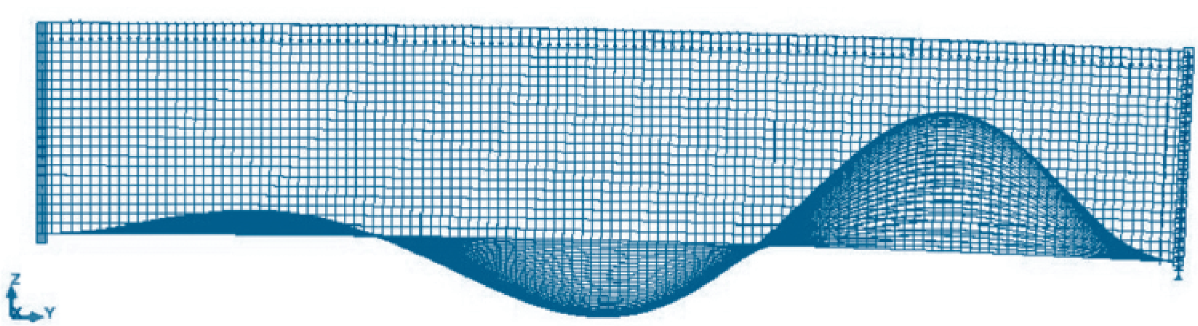

Figure 20.
Model H lateral view of deformations

when we only have the secondary and tertiary corrugations and in another model only the tertiary corrugation this type of corrugation does not give any additional resistance.

Comparing Model G and H, both having a flat web, and Model H also with the main corrugation with Model A we may conclude, that curve web provides resistance to the arch panel and is an important element of the arch panel.

Comparing Model I and J, both without the flat lips at the top of both flanges and Model J with the main corrugation, with Model A, we may conclude that these flat lips do provide certain resistance to the arch panel.

Comparing Model K and L, where both models only have the tertiary corrugation, and Model L with the main corrugation with Model A, we may conclude that the tertiary corrugation is influenced by the secondary corrugation. Due to the results obtained, Model K and L show higher critical force than Model A.

Comparing Model M and N, where both models have the flat lips towards the inner part of the panel and Model N includes the main corrugation with Model A and B respectively, we may conclude that it does not give any loss of resistance to the arch panel.

10. CONCLUSIONS

This paper briefly described the ABM technology and computer models with different changes to the cross section of the arch panel to determine which part of this technology is important and which combination does give a reduction to the critical load force. Linear analyses were performed with the use of Robot Structural Analysis software. With the analyses, results, and comparison of results we can conclude the following:

- The combination of the main, secondary, and curved web at the cross section give the maximum resistance to the arch panel for the local buckling analysis.
- The tertiary corrugation when combined with the secondary corrugation reduces the critical compressive force of the arch panel by about 11%.
- The flat lips at the top of the cross section do not change the value of the critical compressive force if placed inward or outward of the cross section. But it should be included in the cross section because if not the panel critical compressive force will be reduced (like for Models I and J).

Information presented in this work, give a better understanding of the ABM panel cross section resistance to local buckling and which elements give a gain or reduction to the critical compressive force.

ACKNOWLEDGEMENT

I cordially thank MSc. Krzysztof Kozieł for his help and advice during the realization of this research paper – *Rafael Sánchez.*

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