Behavior of corrugated fibre cement sheets subjected to suction loads

Comportamiento de planchas onduladas de fibrocemento sometidas a cargas de succión

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ABSTRACT

This paper presents two numerical models for the evaluation of the distribution of stresses in corrugated sheets of fibre cement subjected to uplift load. The numerical simulations, in this case, were made from three-dimensional models using the software SAP2000Nonlinear, version 7:42, which has as base the finite elements method (MEF). Corrugated sheets with thickness of 5 mm considering two different spans, i.e., 1100 mm and 1530 mm were evaluated. The sheets had the 2nd and 5th high waves fixed. The load of suction applied on the sheets was 10 kN/m², and it was verified that the stresses on the sheets are distributed heterogeneously in a more complex pattern than for the bending stresses for vertical loads. The sheets suffer bending in transverse and longitudinal directions for the suction load applied, and the attachment points of sheets present concentration of stresses. The numerical results of the stresses showed good agreement with the results obtained from other researchers and these results can be used to predict the behavior of corrugated sheets of fibre cement subjected to wind load suction.

Keywords: Numerical simulation, fibre cement, stresses.

RESUMEN

Este artículo presenta dos modelos numéricos para evaluación de la distribución de tensión en planchas onduladas de fibrocemento sometido a una carga de succión. Las simulaciones numéricas en este trabajo, se hicieron a partir de modelos tridimensionales utilizando el software SAP2000Nonlinear, versión 7:42, que se basa en el método de elementos finitos (MEF). Se evaluó planchas onduladas con espesor de 5 mm, teniendo en cuenta dos tramos diferentes, 1100 mm y 1530 mm. Las planchas tuvieron las 2^a y 5^a olas altas fijas. La carga de succión aplicada en de las planchas fue de 10 kN/m², fue encontrado que las tensiones de planchas en la succión se distribuyen heterogeneamente un estándar más complejo de lo que los esfuerzos de flexión obtenidos para cargas verticales. Las planchas sufren flexión en direcciones transversales y longitudinales en la carga de succión aplicada, y los puntos de fijación de las planchas tienen concentración de esfuerzos. Los resultados numéricos de las tensiones mostraron buena concordancia con los resultados de otros investigadores y estos resultados se pueden utilizar para predecir el comportamiento de planchas onduladas de fibrocemento sometidos a cargas de viento de aspiración.

Palabras clave: Simulación numérica, fibrocemento, tensiones.

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INTRODUCTION

The mechanical behavior of corrugated sheets of fibre cement under loading conditions in use has been little studied and there are few studies available in this topic.

In Brazil the experimental work development in the 80s by the Institute of Technological Research (IPT) of São Paulo stands out considering corrugated sheets of fibre cement with different geometries in different spans and distributed loads for the simulation of the action of the wind of suction.

This study concluded that the sheets of fibre cement resisted well, safely and without the need of specific calculations to the wind, since the determinations as the mounting and fixing established by the manufacturers were followed [1].

Some numerical studies [2-3] developed abroad to evaluate the deflections in corrugated sheets considering concentrated and distributed loads stand out. Other international studies [4] discuss the risks of cracks in sheets of fibre cement subjected to wind load.

In practice, the suction wind is considered the action of higher risk for corrugated sheets used in roofing. It occurs in order to pull them out and only the points of attachment recommended by the manufacturer and the neighboring sheets of cover work prevent this pullout.

The aim of this work was to investigate from numerical simulations how the stresses are distributed in corrugated sheets of fibre cement from wind load, having the sheets the 2nd and 5th high waves fixed. The influence of neighboring sheets of cover was not considered in this study. For this specific case of load the deformations of the sheets were also evaluated in transverse and longitudinal directions. These results can help industries and researchers to solve the main problems related to this product. The strategy of the numerical modeling and the most important comments are also presented.

MATERIAL AND METHODS

The space among supports (span) has an important role in the behavior of corrugated sheets of fibre cement.

The recommended span for tests according to national standard [5] is of 1100 mm for sheets up to nominal thickness of 6 mm. In this work, corrugated sheets of 1100 mm and 1530 mm spans were considered.

On the other hand, the wind loads have influence on the concentration of stresses at points of attachment of the corrugated sheets recommended by the manufacturer.

CONFIGURATION OF THE ANALYZED SHEETS

Corrugated sheets of fibre cement with the following configuration: Height: 51 mm; Transverse width: 1100 mm and Thickness: 5 mm, were analyzed.

Figure 1 shows the dimensions of cross section of the corrugated sheets and Figure 2 shows the nomenclature used for them.

Figure 1. Cross section of the sheets considered in the numerical models.

Figure 2. Nomenclature used for the corrugated sheets.

The corrugated sheets in the analyzed models were supported in two different spans having these sheets lateral balances. Figure 3 shows the support conditions for the sheets.

Figure 3. Support conditions for the sheet models analyzed.

Figure 4 shows the support conditions. The values of the longitudinal size as well as the balances

used for the corrugated sheets that are related to the numerical models are indicated in Table 1. The corrugated sheets were fixed in the 2nd and 5th high waves in this case.

Figure 4. Support conditions admitted for the models.

Table 1. Support conditions and size of the sheets admitted for the models.

Size of the sheets (mm)	Support spans (mm)	Lateral balance B (mm)
1100	1056.50	43.50
1530	1476.25	53.75

LOAD CONDITIONS

The load applied was equally distributed over the surface of the corrugated sheet as indicated in Figure 5.

In this case, the value of the applied load was 0.001 MPa (10 kN/m²).

In practical applications, the value of the suction load, usually applied on the sheets by the wind, corresponds to 1/3 of this value of load applied. The results presented in this work were compared with the results obtained by [1] and [8].

The value of 10 kN/m² was used for comparison of the obtained results with the results from other researchers [1] and also to verify how the stresses are distributed in sheets according to this specific type of applied load.

Figure 5. Support conditions (2nd and 5th high wave attachment) with suction load distributed over the upper surface of the sheet.

BOUNDARY CONDITIONS

To simulate the action of wind in corrugated sheets considering the lengths indicated in Table 1 and an applied load of 0.001 MPa, over the upper surface of the sheet, the following boundary conditions were considered:

- Restrain of the displacements in the x and z directions in the sections of support;
- Restrain of the displacement y at points located in the central section.

Figure 6 shows the details of boundary conditions used for the corrugated sheets in the analyzed models.

Figure 6. Displacement restraint in the supports and in the central section of the sheet.

MESH OF FINITE ELEMENTS

The mesh was discretized in a total of 1152 elements for the 1100 mm span sheet and 1536 elements for the 1530 mm span sheet.

Mesh refinement was made using the SAP2000 Nonlinear6 *software*, version 7:12, which has as base the finite elements method (FEM). However, there are specific computer programs to construct complex meshes [7].

In the models, shell elements in the mesh composition were used. The shell element has four nodes with six degrees of freedom per node, being three translations and three rotations. Each shell element was built having the same orientation for the quadrilaterals, which formed each shell element. In the SAP2000Nonlinear, the local axe 3 is oriented in perpendicular direction to the element surface.

This way the local axes 1, 2 and 3 of all shell elements were used with the same orientation facilitating the mesh refinement of finite elements and subsequently the analysis of the results.

Figure 7 shows the orientation of the local axes in the sheets and some details of the mesh of finite elements.

Figure 7. Orientation of the local axes 1, 2 and 3 in shell elements and details of mesh of finite elements.

ANALYSIS OF THE MODELS

The models were developed considering the physical linearity of the material (the stresses are proportional to the strains) and geometric non-linearity of the sheets (deformed configuration). Isotropic behavior for the material in the composition of the sheets was considered.

The elastic properties of the sheets considered for the models were:

- Module of elasticity (E): 9000 N/mm² (9000 MPa);
- Poisson ratio (ν): 0.2 (typical value for the fibre cement used in the corrugated sheets).

According to some researchers [8, 9] the most suitable elasticity module to use in numerical models is that obtained from the direct tests of tension instead of bending.

STRESSES AND DEFORMATIONS EVALUATED IN THE MODEL

To the considered load of 10 kN/m², the analysis of the stresses with larger potential to cause damage to the component was evaluated. The stresses with this potential are the followings:

Transverse stress σ_{22} (occur in the x direction);
Longitudinal stress σ_{11} (occur in the y direction).

The values of the main stresses, σ_{22} and σ_{11} , were verified in the finite elements localized in the central section of the sheet, as indicated in Figures 8 and 9.

Figure 8. Points of the sheets where maximum stresses σ_{22} and σ_{11} take place.

Figure 9. Details of the elements in the central area of the sheet where maximum stresses σ_{22} and σ_{11} take place.

In this study, the behavior of the deformed configurations in transverse and longitudinal directions of the corrugated sheets was also analyzed.

RESULTS

The results of longitudinal stresses σ_{11} obtained from the numerical simulations are shown in Figures 10 and 11.

The stress values for the sheets in the points showed in Figure 10 are indicated in Tables 2 and 3.

LONGITUDINAL STRESSES

Figure 10. Distribution of the longitudinal stresses σ_{11} , in the model of 1100 mm span sheet, on the upper surface of the high waves.

Table 2. Values of longitudinal stresses in the central area of the 1100 mm span sheet.

σ_{11} (MPa) on the upper surface of the high waves (tension)					
2	4	6	8	10	12
1.26	2.43	0.55	0.52	2.66	0.79

Table 3. Values of longitudinal stresses in the central area of the 1100 mm span sheet.

σ_{11} (MPa) on the lower surface of the low waves (compression)					
2	4	6	8	10	3
1.26	2.43	0.55	0.52	2.66	2.48

The stress values for the sheets in the points showed in Figures 11 are indicated in Tables 4 and 5.

Table 3. Values of longitudinal stresses in the central area for the 1530 mm span sheet.

σ_{11} (MPa) on the upper surface of the high waves (tension)					
2	4	6	8	10	12
2.78	5.45	1.70	1.62	6.65	2.35

Figure 11. Distribution of the longitudinal stresses σ_{11} , in the model of sheet with span of 1530 mm, in the upper surface of the high waves.

Table 4. Values of longitudinal stresses in the central area for the 1530 mm span sheet.

σ_{11} (MPa) on the upper surface of the high waves (tension)					
3	5	7	9	11	13
5.05	3.28	1.92	4.31	5.48	1.30

TRANSVERSE STRESSES

The results of transverse stresses σ_{22} obtained from the numerical simulations are shown in Figures 12 and 13. The stress values for the sheets in the points showed in Figure 12 are shown Tables from 5 to 8 and the stress values for the sheets in the points showed in Figures 13 are shown Tables from 9 to 12.

Figure 12. Distribution of the transverse stresses σ_{22} , in the model of 1100 mm span sheet, on the upper surface of the high waves.

Table 5. Values of transverse stresses in the central area for the 1100 mm span sheet.

σ_{22} (MPa) on the upper surface of the high waves (compression)					
2	4	6	8	10	12
0.77	5.16	1.11	3.48	11.25	3.98

Table 6. Values of transverse stresses in the central area for the 1100 mm span sheet.

σ_{22} (MPa) on the upper surface of the low waves (tension/compression)					
3	5	7	9	11	13
-2.87	1.91	3.45	-3.68	-7.17	-0.99

Table 7. Values of transverse stresses in the central area for the 1100 mm span sheet.

σ_{22} (MPa) on the lower surface of the high waves (tension)					
2	4	6	8	10	12
0.67	5.54	1.34	3.62	11.58	3.84

Table 8. Values of transverse stresses in the central area for the 1100 mm span sheet.

σ_{22} (MPa) on the lower surface of the low waves (tension/compression)					
3	5	7	9	11	13
3.04	-1.82	-3.35	4.01	7.42	1.03

Table 9. Values of transverse stresses in the central area for the 1530 mm span sheet.

σ_{22} (MPa) on the upper surface of the high waves (compression)					
2	4	6	8	10	12
-0.84	-4.55	-1.75	-3.88	-9.25	-4.75

Table 10. Values of transverse stresses in the central area for the 1530 mm span sheet.

σ_{22} (MPa) on the upper surface of the low waves (tension/compression)					
3	5	7	9	11	13
-2.53	1.16	2.29	-3.38	-5.56	-1.18

Table 11. Values of transverse stresses in the central area for the 1530 mm span sheet.

σ_{22} (MPa) on the lower surface of the high waves (tension)					
2	4	6	8	10	12
0.64	4.51	2.04	3.44	9.83	4.44

Table 12. Values of transverse stresses in the central area for the 1530 mm span sheet.

σ_{22} (MPa) on the lower surface of the low waves (tension/compression)					
3	5	7	9	11	13
2.80	-1.16	-2.22	3.85	6.04	1.30

Figure 13. Distribution of the transverse stresses σ_{22} , in the model of 1530 mm span sheet, on the upper surface of the high waves.

The intensification of the transverse stresses on the attached high waves (2nd and 5th high waves) is due to the evaluation of the sheet in the isolated situation, since it does not suffer the influence of the surrounding sheets that would tend to reduce the deformations and consequently the intensity of stresses in the corrugated sheets.

The most intense stresses in the transverse direction occur in the fixed waves and increase near the points of attachment, and these areas have the highest probability of failing.

The transverse stresses are distributed on the sheets in a complex way, where compression occurs on the upper surface of the high waves and tension on

the lower surface. On the other hand, for the low waves, compression and tension stresses occur on the upper surfaces of the sheets.

LONGITUDINAL DEFORMATIONS

The longitudinal deformation of high wave of sheet 10, i. e., 5th high wave, and the global deformed position of the sheet are presented in Figures 14 and 15 in the follow, respectively.

Figure 14. Longitudinal deflection of the 1530 mm span sheet: deformed position of high wave 10.

Figure 15. Longitudinal deflection of the 1530 mm span sheet: global deformed position of the sheet.

TRANSVERSE DEFORMATIONS

Figure 16 shows the way in which the sheets are deformed in the transverse direction according to distributed suction load, intensifying the stresses so that compression occur on the upper surface and tension on the lower surface of the high waves, especially on the fixed waves.

The occurrence of cracks in corrugated sheets without asbestos has been reported in the literature [4], since the cause of the cracks is related to stresses generated by the action of wind.

Figure 16. Deformed position of the 1530 mm length sheet subjected to suction load of 0.001 MPa.

Figure 17 shows the global view of the transversal deformed subjected to suction load of 0.001 MPa.

All the values of stress obtained from the numerical simulations were compared with the results from other researchers [1] and these results showed a good agreement.

Is important to say that [1] developed a extensive work about the effect of different loads in corrugated fibre cement sheets

Figure 17. Global view of the transversal deformed of the 1530 mm length sheet subjected to suction load of 0.001 MPa.

CONCLUSIONS

For the specific conditions of fixing and loading used in the simulations of suction load, the sheets suffer bending in both transverse and longitudinal directions.

For suction loads, the stresses are distributed heterogeneously in a more complex pattern than for the bending stresses with vertical loads.

The transverse stresses tend to lift the lateral parts of the sheet, since the most intense stresses occur in the fixed waves. In this case, the intensities of the stresses increase in direction of the attachment points, and these points are those with most likelihood to fail.

Differently from bending tests with vertical loads, in the suction loads the longitudinal stresses are predominantly of compression in the low waves, and of tension in the high waves.

The most intense stress occurs in the central area of the sheet, on the attached waves (2nd and 5th high waves).

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