ISTANBUL TECHNICAL UNIVERSITY

Civil Engineering Faculty

*Civil Engineering Department*

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## Technical Report of EKOPLAK Polymer Formwork

# TECHNICAL PROPERTIES

To be submitted to

**ABS Building Materials**

*This report has been prepared in accordance with the Regulations of ITU Revolving Fund Enterprise.*

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**Technical Report of EKOPLAK Polymer Formwork Technical Properties**

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# Summary

In this report, physical and mechanical properties of Second Generation Polymer Construction Formwork EKOPLAK that is released by ABS Building Materials and guidelines to be used in concrete formworks are shown.

Unit weight of panels with 18 mm nominal thickness is calculated to be 10.4 kg/m$^2$, specific weight of the panel material is calculated to be 1.627.

Using the method Differential Scanning Calorimetry, softening and melting temperatures of panel material are calculated to be 68°C and 170°C, respectively.

As expected, mechanical properties of panels are observed to be higher in longitudinal direction. For that reason, it is important to place the panel longitudinally between supports. However, in a condition where the girder spacing is 40 cm and concrete height is 30 cm, panels have satisfied the deflection and yield strength conditions.

Characteristic values of elastic and strength properties obtained from tension and bending tests performed at an ambient temperature of 15°C and sample temperature of 40°C, have been calculated and presented as a chart. For the temperatures between 15°C and 40°C, values may be calculated by interpolation method. For temperatures outside of this interval, extrapolation should be avoided and you should apply for manufacturer's approval.

Results obtained from Charpy impact tests carried out on unnotched samples at an ambient temperature of 15°C are submitted as a chart.

Using the characteristic material properties obtained from experimental studies, for deflection limits for slabs and walls defined in DIN 18202:2013-04 standards, following the design principals defined in EN 12812:2008 standard, guidelines for usage of panels in formwork applications are submitted in the report with a sample case. In the cases where the formworks are used in vertical direction, lateral pressure of fresh concrete may be calculated using the method expressed in DIN 18218:2010-01 standard and outlined in the report. Design controls to be done following the calculation of design loads, are substantially the same for formwork applications in both vertical and horizontal directions. Using the method shown and guidelines, it is possible to determine the proper girder spacing for a formwork application in certain conditions.

In unordinary applications where the concrete pressure is rather high, panels may be used double layered, yet, attention should be paid using the method specified in the report and manufacturer's approval should be obtained.

In brief, it is demonstrated in the report that basic physical and technical properties of EKOPLAK polymer panels are satisfactory for typical concrete formwork applications and relevant design calculations may be done according to the principals and methods indicated in the report.

# Technical Report of EKOPLAK Polymer Formwork Technical Properties

## 1. Introduction

In this report that has been prepared at the request of Okan Cüntay on behalf of ABS BUILDING MATERIALS, on 16/03/2018 with the request number 371280, various physical and mechanical properties of Second Generation Polymer Construction Formwork EKOPLAK marketed by mentioned company have been determined and design advices for different applications have been presented. This report has been prepared in accordance with the Regulations of ITU Revolving Fund Enterprise.

## 2. Scope of the Study

Studies outlined in this report are limited with determining of basic physical and mechanical characteristics of EKOPLAK plastic boards as construction formwork and comprising related design advices. Therefore, it does not involve the detailed characterization of polymer material and panels. Along with determining of softening and melting temperatures of polypropylene material that panels are made of, tension and bending tests on specimens cut from different panels were performed at both 15°C and 40°C. In addition to that, impact tests were performed at 15°C. In design advices for the product usage in formwork applications, bending strength and rigidity obtained from experimental studies have been based on.

## 3. General Information About the Product

The product being inspected is made of polypropylene material and has a form of hollow board (Figure 1). In the technical brochure of the product, nominal thickness is given as 18 mm, standard panel dimensions are given as 1220x2440x18 mm and average panel weight is given as 25 kg.

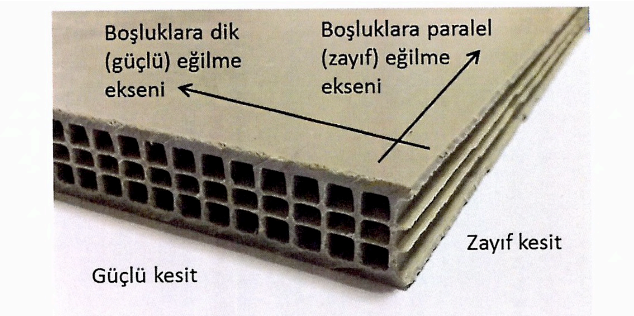



**Figure 1.** EKOPLAK polypropylene hollow board cross section

EKOPLAK panels that have been developed as an alternative product to traditional wooden or plywood formwork panels used in reinforced concrete structures, take the advantage of lightness, strength, stiffness, impact resistance and abrasion resistance, as well as multi-use, resistance to environmental conditions and chemicals and have other advantages making it considerably practical to use. Leading guidelines about the product being used as a formwork panel can be found in the product catalogue.

## 4. Experimental Studies

Required elastic and strength characteristics to create the design guidelines about the usage of EKOPLAK hollow plastic boards in concrete formwork applications have been obtained from laboratory experiments. For this purpose, following experiments have been conducted.

- Measurements of panel weight/square meter and density measurements of panel material.
- DSC (Digital Scanning Calorimetry) tests to determine the softening and melting temperatures of polypropylene material that the panels are made of.
- Tension tests in the board section perpendicular to pores (strong section) and in the section parallel to pores (weak section) at 15°C and 40°C.
- Bending tests in the board's axis of flexure perpendicular to pores (strong) and in the axis parallel to pores (weak) at 15°C and 40°C.
- Impact tests around the board's in plane and out of plane strong and weak axis at 15°C.

Results obtained from these experiments are demonstrated in the following sections.

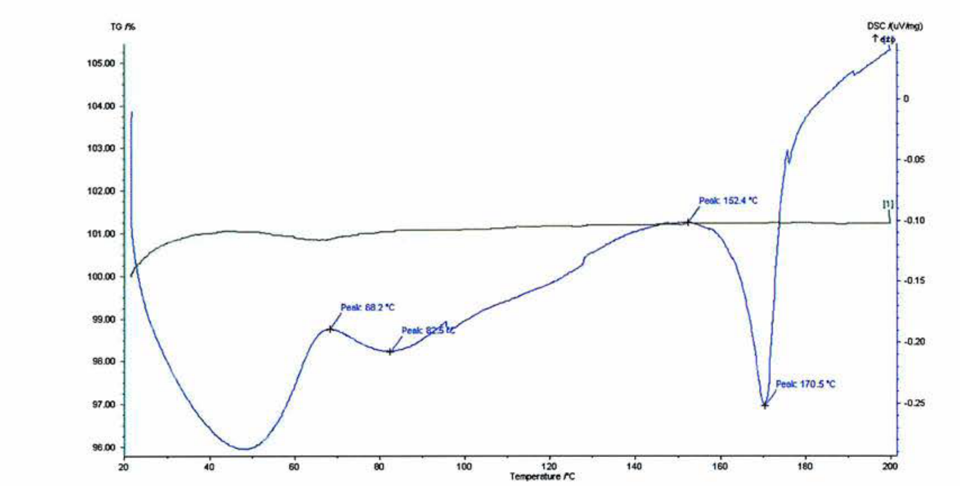
### 4.1 Density Measurements

Measurements carried out on small sized EKOPLAK specimens showed that the weight of hollow panels per square meter is approximately 10.4 kg/m$^2$, material density calculated by weighing in water is 1267 kg/m$^3$, and thereby the specific weight is determined to be 1.267.

### 4.2 Softening and Melting Temperatures

Differential Scanning Calorimetry tests have been performed to observe the availability of EKOPLAK boards in concrete formwork applications in different weather conditions and as a result of these analyses, the glass transition (softening) temperature of the sample is found to be 68°C and melting temperature to be 170°C (Figure 2).

**Figure 2.** Differential Scanning Calorimetry Analysis Results




### 4.3 Tension Tests

Tension tests on five samples cut parallel to both axis of the board have been performed at 15°C and 40°C to determine the modulus of elasticity and tensile strength in both axis of EKOPLAK boards as seen in Figure 3. With some revisions, stress-unit strain diagrams obtained from tests performed in accordance with ASTM D638 standards are given in Figure 4, and the test results are summarized in Chart 1. 40°C tests in Figure 3 does not mean the ambient temperature but the tests performed in laboratory conditions after the specimens have been kept at 40°C for 3 days and brought to experiment area in insulated boxes. Length of the samples is 250 mm, the distance between the notches is 148 mm. Width and thickness of each specimen is given in Chart 1 and calculations have been done according to these values. Modulus of elasticity has been determined as 5 MPa and 3 MPa secant modulus for longitudinal and transversal specimens, respectively. Yielding strength has been calculated with the method 0,2% offset.

Longitudinal specimens (strong section) Transversal specimens (weak section)

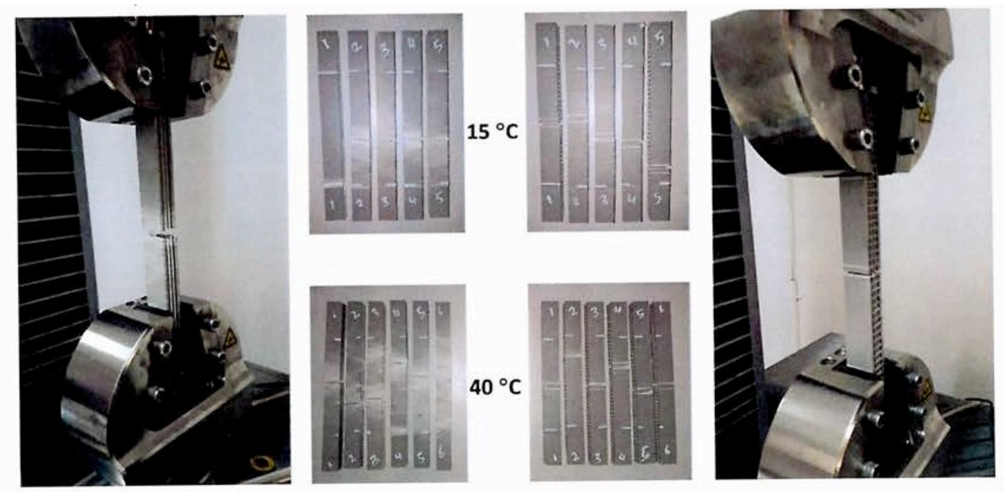



**Figure 3.** Longitudinal and transversal specimens during tension tests at 15°C and 40°C

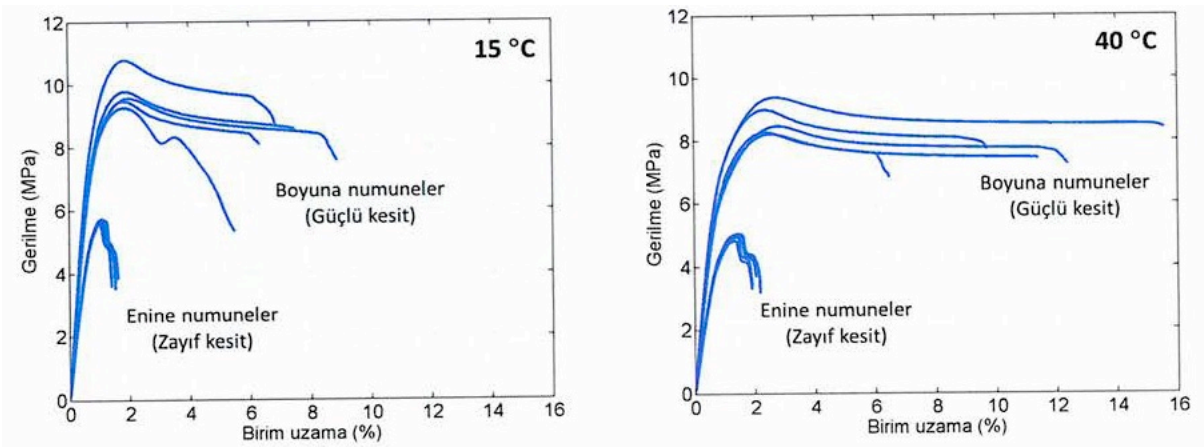



**Figure 4.** Stress-unit strain diagrams obtained from tension tests

**Chart 1.** Tension tests results

| Temp. (°C) | Direc. | Sample no | Thickness (mm) | Width (mm) | Length (mm) | Gage length (mm) | Max. load (N) | Max. strain (mm) | Modulus of elasticity (MPa) | Yield strength (MPa) | Tension strength (MPa) | Max. unit strain (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Vertically | 1 | 17.55 | 24.20 | 250 | 148 | 3939 | 8.08 | 1197 | 7.80 | 9.27 | 5.46 |
| | | 2 | 17.57 | 23.95 | | | 4120 | 11.07 | 1202 | 8.17 | 9.79 | 7.48 |
| | | 3 | 17.74 | 24.00 | | | 4593 | 10.08 | 1334 | 8.85 | 10.79 | 6.81 |
| | | 4 | 17.56 | 24.05 | | | 4007 | 9.32 | 1124 | 7.99 | 9.49 | 6.30 |
| | | 5 | 17.54 | 24.20 | | | 4066 | 13.13 | 1147 | 8.00 | 9.58 | 8.87 |
| | Horizontally | 1 | 17.70 | 24.12 | | | 2394 | 2.04 | 826 | 5.39 | 5.61 | 1.38 |
| | | 2 | 17.69 | 23.85 | | | 2394 | 2.35 | 847 | 5.43 | 5.67 | 1.59 |
| | | 3 | 17.63 | 23.80 | | | 2404 | 2.22 | 846 | 5.47 | 5.73 | 1.50 |
| | | 4 | 17.68 | 24.00 | | | 2416 | 2.21 | 845 | 5.42 | 5.69 | 1.49 |
| | | 5 | 17.67 | 23.70 | | | 2400 | 2.22 | 851 | 5.48 | 5.73 | 1.50 |
| 40 | Vertically | 1 | 17.55 | 24.10 | 250 | 148 | 3820 | 14.33 | 978 | 7.14 | 9.03 | 9.68 |
| | | 2 | 17.61 | 23.70 | | | 3483 | 9.54 | 854 | 6.72 | 8.35 | 6.45 |
| | | 3 | 17.59 | 24.20 | | | 3501 | 16.83 | 826 | 6.57 | 8.22 | 11.37 |
| | | 4 | 17.63 | 24.10 | | | 3577 | 18.28 | 826 | 6.42 | 8.42 | 12.35 |
| | | 5 | 17.83 | 24.20 | | | 3988 | 22.98 | 948 | 7.24 | 9.24 | 15.53 |
| | Horizontally | 1 | 17.77 | 24.00 | | | 2069 | 2.77 | 604 | 4.49 | 4.85 | 1.87 |
| | | 2 | 17.76 | 24.00 | | | 2100 | 2.98 | 607 | 4.53 | 4.98 | 2.01 |
| | | 3 | 17.80 | 23.50 | | | 2085 | 2.79 | 630 | 4.58 | 4.97 | 1.88 |
| | | 4 | 17.78 | 24.00 | | | 2125 | 3.18 | 620 | 4.58 | 5.01 | 2.15 |
| | | 5 | 17.75 | 24.00 | | | 2117 | 3.13 | 637 | 4.62 | 5.05 | 2.12 |

As you could see in Figure 4 and Chart 1, elasticity, strength and strain values of longitudinal specimens cut from panels in question are considerably higher than the transversal specimens.

### 4.4 Bending Tests

Bending tests performed at 15°C and 40°C on longitudinal and transversal specimens cut from EKOPLAK panels are shown in Figure 5, bending stress - unit strain diagrams are given in Figure 6 and test results are summarized in Chart 2.

Longitudinal specimens (strong section)    Transversal specimens (weak section)

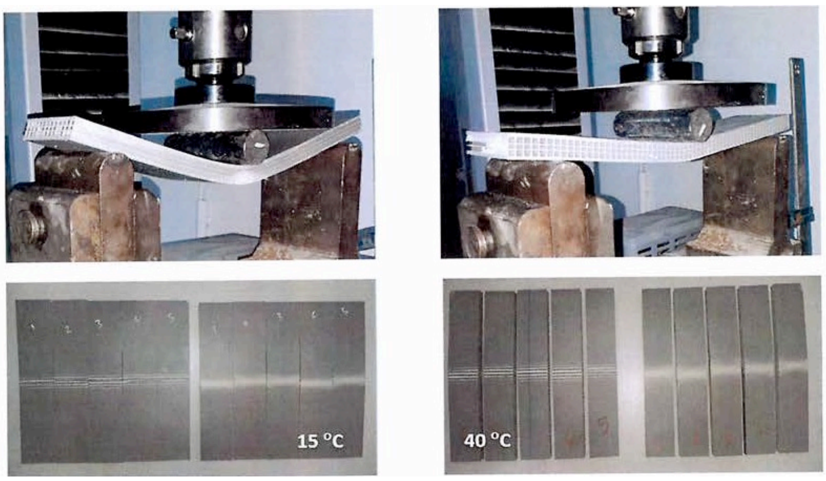


**Figure 5.** Longitudinal and transversal specimens during bending tests at 15°C and 40°C

40°C tests mean the tests performed in laboratory conditions after the specimens have been kept at 40°C temperature for 3 days and brought to experiment area in insulated boxes. Because of the displacement limits of testing apparatus, tests have been stopped at about 25 mm displacement after the longitudinal specimens reach their resistance values. Therefore in Chart 2, bending unit strain of specimens is given instead of fraction unit strain. Bending modulus of longitudinal specimens for 15°C has been calculated to be between 5 MPa and 15 MPa and for 40°C, between 5 MPa and 10 MPa (chord modulus). Stress modulus of transversal specimens for 15°C has been calculated to be between 5 MPa and 10 MPa and for 40°C, between 3 MPa and 6 MPa. Yielding strength has been calculated for all the samples with the method 0.2% offset.

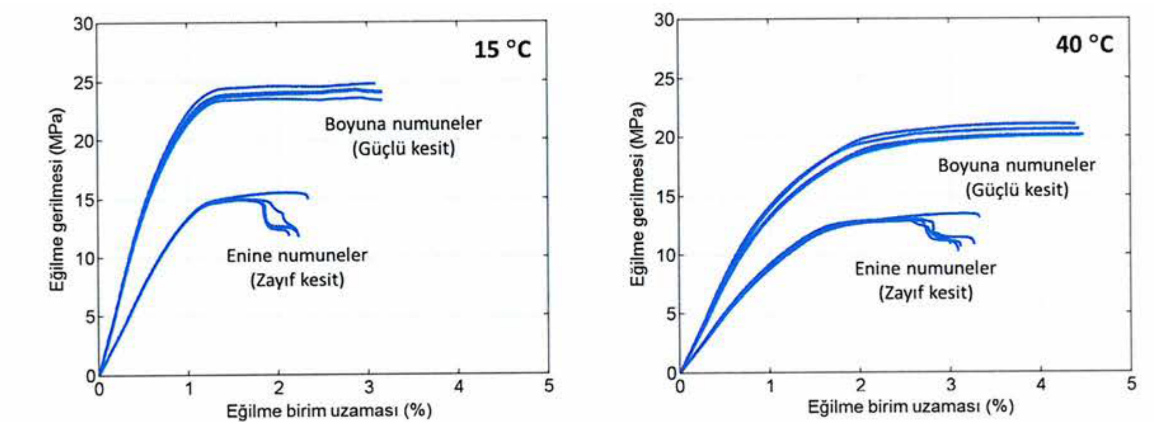



**Figure 6.** Stress-unit strain diagrams obtained from bending tests

**Chart 2.** Bending tests results

| Temp. (°C) | Direc. | Sample no | Thickness (mm) | Width (mm) | Length (mm) | Span (mm) | Max. load (N) | Depl. under max. load (mm) | Bending modulus of elasticity (MPa) | Bending yield strength (MPa) | Bending strength (MPa) | Unit strain (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Vertically | 1 | 17.53 | 71.67 | 350 | 290 | 1266 | 24.90 | 2800 | 22.26 | 25.01 | 3.11 |
| | | 2 | 17.61 | 71.76 | | | 1255 | 22.70 | 2687 | 21.60 | 24.54 | 2.88 |
| | | 3 | 17.58 | 71.53 | | | 1252 | 22.50 | 2743 | 21.77 | 24.64 | 2.82 |
| | | 4 | 17.57 | 71.73 | | | 1216 | 22.80 | 2679 | 21.33 | 23.89 | 2.91 |
| | | 5 | 17.60 | 71.31 | | | 1253 | 22.70 | 2703 | 21.70 | 24.68 | 2.86 |
| | Horizontally | 1 | 17.80 | 71.66 | | | 822 | 15.40 | 1474 | 14.61 | 15.74 | 2.07 |
| | | 2 | 17.80 | 71.50 | | | 793 | 12.00 | 1479 | 14.39 | 15.24 | 1.55 |
| | | 3 | 17.75 | 71.56 | | | 790 | 12.30 | 1476 | 14.54 | 15.25 | 1.56 |
| | | 4 | 17.75 | 71.60 | | | 788 | 12.30 | 1476 | 14.43 | 15.19 | 1.56 |
| | | 5 | 17.75 | 71.65 | | | 790 | 12.10 | 1466 | 14.50 | 15.22 | 1.53 |
| 40 | Vertically | 1 | 17.60 | 71.80 | 350 | 290 | 1077 | 34.71 | 1612 | 15.34 | 21.06 | 4.36 |
| | | 2 | 17.55 | 71.40 | | | 1034 | 34.64 | 1456 | 14.64 | 20.46 | 4.34 |
| | | 3 | 17.56 | 71.60 | | | 1037 | 31.67 | 1486 | 14.82 | 20.43 | 3.97 |
| | | 4 | 17.60 | 71.70 | | | 1051 | 34.19 | 1473 | 14.76 | 20.59 | 4.29 |
| | | 5 | 17.56 | 71.80 | | | 1091 | 30.26 | 1545 | 15.52 | 21.44 | 3.79 |
| | Horizontally | 1 | 17.74 | 71.60 | | | 688 | 20.52 | 999 | 10.75 | 13.29 | 2.60 |
| | | 2 | 17.80 | 71.80 | | | 718 | 24.52 | 955 | 10.68 | 13.72 | 3.11 |
| | | 3 | 17.80 | 71.60 | | | 683 | 20.75 | 964 | 10.71 | 13.09 | 2.63 |
| | | 4 | 17.76 | 71.70 | | | 688 | 19.63 | 1016 | 10.80 | 13.24 | 2.49 |
| | | 5 | 17.76 | 71.40 | | | 687 | 19.15 | 999 | 10.81 | 13.27 | 2.43 |

## 4.5 Impact Tests

However the impact strength of panels inspected does not directly demonstrate a design parameter, longitudinal and transversal specimens have been prepared in plane and out of plane directions of the panel to perform Charpy tests for it may give an idea about its impact resistance. Since the panel is porous, the main resistance is put up by the panel coat and in terms of the solubility of experiment results, unnotched specimens have been used in tests. Longitudinal and transversal samples cut parallel and perpendicular to panel plane with Charpy impact test apparatus are shown in Figure 7 and test results are given in Chart 3. As it can be seen from the test results, impact resistance of the panel is the highest out of plane and in longitudinal direction (strong section); and the lowest in plane and in horizontal direction (weak section). Since the panels subjected to tests are unnotched, it is expected that standard deflection values in Chart 3 are higher than usual, yet, when a notch is made on panels, specimens are tend to weaken and it is likely to cause solubility problems like the ones that can be seen in 'C' set results.

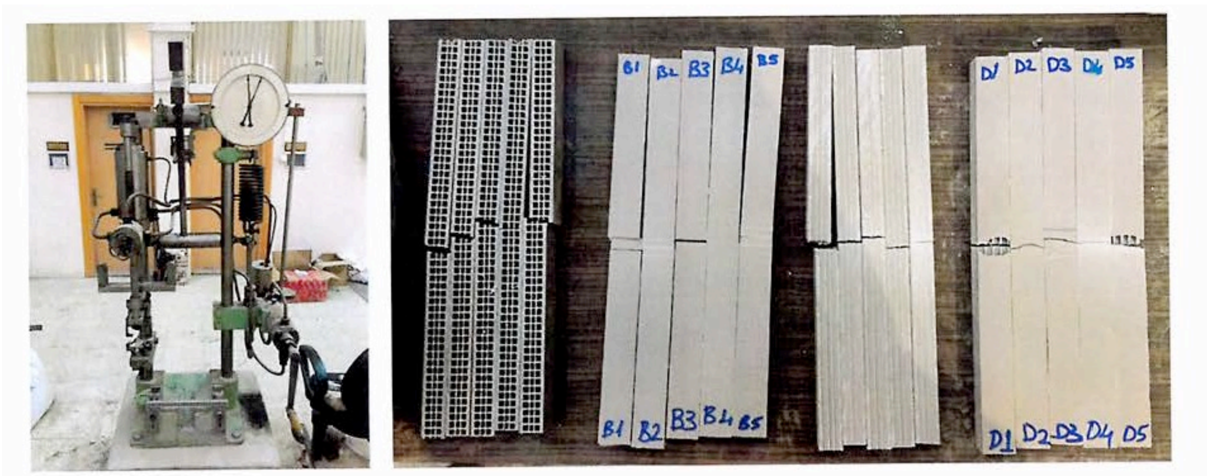



**Figure 7.** Charpy impact test apparatus and sample sets

**Chart 3.** Impact test results

| | Impact resistance (Joule/m²) | | | |
|---|---|---|---|---|
| | In plane | | Out of plane | |
| | Strong section | Weak section | Strong section | Weak section |
| Sample no | A | C | B | D |
| 1 | 7.0 | 2.0 | 11.0 | 5.2 |
| 2 | 7.1 | 2.0 | 8.1 | 5.0 |
| 3 | 8.1 | 2.0 | 9.0 | 5.1 |
| 4 | 11.0 | 2.0 | 10.6 | 4.9 |
| 5 | 14.0 | 2.0 | 11.0 | 5.6 |
| Average | 9.44 | 2.00 | 9.94 | 5.16 |
| Standard deflection | 3.02 | 0.00 | 1.32 | 0.27 |

## 4.6 Characteristic Values of Mechanical Properties

Among the test results presented in previous sections, characteristic values of the properties that might be useful when designing the EKOPLAK panels as concrete formwork are shown in Chart 4. Characteristic values for 15°C and 40°C may be calculated by interpolation method for temperatures between these temperatures. For temperatures out of this range, using extrapolation method without the manufacturer's approval should be avoided.

Characteristic values given in Chart 4 are calculated for 90% safety level using the equation below after the average and standard deflection of related values in Chart 1 and 2 are calculated using t-distribution on five samples and taking the degree of freedom 5.

*Characteristic value = Average – 1.476 x Standard deflection*

**Chart 4.** EKOPLAK mechanical properties characteristic values

<table>
<tr><th></th><th></th><th></th><th></th><th>Average</th><th>Standard dev.</th><th>Characteristic value</th></tr>
<tr><td rowspan="16">Longitudinal samples (strong section)</td><td rowspan="8">Tension</td><td rowspan="2">Modulus of elasticity (MPa)</td><td>15°C</td><td>1201</td><td>81</td><td>1081</td></tr>
<tr><td>40°C</td><td>886</td><td>72</td><td>781</td></tr>
<tr><td rowspan="2">Yield strength (MPa)</td><td>15°C</td><td>8.2</td><td>0.41</td><td>7.6</td></tr>
<tr><td>40°C</td><td>6.8</td><td>0.36</td><td>6.3</td></tr>
<tr><td rowspan="2">Strength (MPa)</td><td>15°C</td><td>9.8</td><td>0.59</td><td>8.9</td></tr>
<tr><td>40°C</td><td>8.7</td><td>0.51</td><td>7.9</td></tr>
<tr><td rowspan="2">Rupture unit strain (%)</td><td>15°C</td><td>7.0</td><td>1.29</td><td>5.1</td></tr>
<tr><td>40°C</td><td>11.1</td><td>3.35</td><td>6.1</td></tr>
<tr><td rowspan="8">Bending</td><td rowspan="2">Modulus of elasticity (GPa)</td><td>15°C</td><td>2723</td><td>50</td><td>2649</td></tr>
<tr><td>40°C</td><td>1514</td><td>64</td><td>1420</td></tr>
<tr><td rowspan="2">Yield strength (MPa)</td><td>15°C</td><td>21.7</td><td>0.34</td><td>21.2</td></tr>
<tr><td>40°C</td><td>15.0</td><td>0.39</td><td>14.4</td></tr>
<tr><td rowspan="2">Strength (MPa)</td><td>15°C</td><td>24.6</td><td>0.41</td><td>23.9</td></tr>
<tr><td>40°C</td><td>20.8</td><td>0.44</td><td>20.1</td></tr>
<tr><td rowspan="2">Unit strain (%)</td><td>15°C</td><td>2.9</td><td>0.11</td><td>2.7</td></tr>
<tr><td>40°C</td><td>4.1</td><td>0.26</td><td>3.8</td></tr>
<tr><td rowspan="16">Transversal samples (weak section)</td><td rowspan="8">Tension</td><td rowspan="2">Modulus of elasticity (MPa)</td><td>15°C</td><td>843</td><td>10</td><td>829</td></tr>
<tr><td>40°C</td><td>619</td><td>14</td><td>598</td></tr>
<tr><td rowspan="2">Yield strength (MPa)</td><td>15°C</td><td>5.4</td><td>0.04</td><td>5.4</td></tr>
<tr><td>40°C</td><td>4.6</td><td>0.05</td><td>4.5</td></tr>
<tr><td rowspan="2">Strength (MPa)</td><td>15°C</td><td>5.7</td><td>0.05</td><td>5.6</td></tr>
<tr><td>40°C</td><td>5.0</td><td>0.08</td><td>4.9</td></tr>
<tr><td rowspan="2">Rupture unit strain (%)</td><td>15°C</td><td>1.5</td><td>0.08</td><td>1.4</td></tr>
<tr><td>40°C</td><td>2.0</td><td>0.13</td><td>1.8</td></tr>
<tr><td rowspan="8">Bending</td><td rowspan="2">Modulus of elasticity (GPa)</td><td>15°C</td><td>1474</td><td>5</td><td>1467</td></tr>
<tr><td>40°C</td><td>986</td><td>26</td><td>948</td></tr>
<tr><td rowspan="2">Yield strength (MPa)</td><td>15°C</td><td>14.5</td><td>0.09</td><td>14.4</td></tr>
<tr><td>40°C</td><td>10.7</td><td>0.06</td><td>10.7</td></tr>
<tr><td rowspan="2">Strength (MPa)</td><td>15°C</td><td>15.3</td><td>0.23</td><td>15.0</td></tr>
<tr><td>40°C</td><td>13.3</td><td>0.24</td><td>13.0</td></tr>
<tr><td rowspan="2">Unit strain (%)</td><td>15°C</td><td>1.7</td><td>0.23</td><td>1.3</td></tr>
<tr><td>40°C</td><td>2.7</td><td>0.27</td><td>2.3</td></tr>
</table>

## 5. Instructions for Panel Formwork Design

Guidelines of using EKOPLAK panels as concrete panels in horizontal and vertical directions are given in this section as its technical properties and design parameters were given in previous sections.

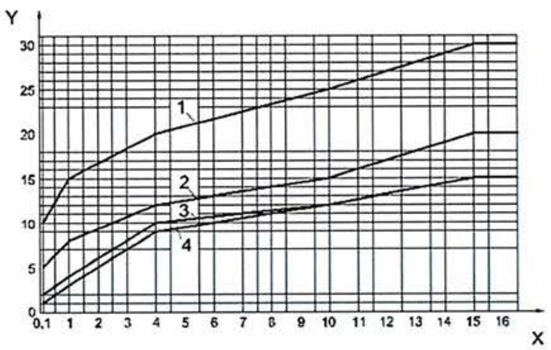
### 5.1 Deflection Limits for Slabs and Walls

Deflection limits for different spans of slabs and walls in buildings in accordance with DIN 18202:2013 standard are given in Figure 8. Typical deflection limits for EKOPLAK panels are given in Chart 5.

**Table 3 — Permitted flatness deviations**

| Column | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Group | Reference | Permitted position deviations, in mm, for distances between measuring points, in m, up to | | | | |
| | | 0,1 | 1 [a] | 4 [a] | 10 [a] | 15 [ab] |
| 1 | unfinished upper surfaces of floors, subfloors and concrete bases | 10 | 15 | 20 | 25 | 30 |
| 2a | unfinished upper surfaces of floors or base slabs (e.g. to receive bonded, unbonded or floating screed, industrial floors, tile and slab flooring in mortar bed) | 5 | 8 | 12 | 15 | 20 |
| 2b | finished upper surfaces of floors or base slabs for minor purposes (e.g. in storerooms, basements or monolithic concrete floors) | 5 | 8 | 12 | 15 | 20 |
| 3 | finished floors (e.g. screed as wearing courses or screed to receive flooring, flooring including tiled, trowelled or bonded floorings) | 2 | 4 | 10 | 12 | 15 |
| 4 | as for Group 3, but subject to more stringent requirements (e.g. self-levelling compounds) | 1 | 3 | 9 | 12 | 15 |
| 5 | unfinished walls and unfinished ceilings | 5 | 10 | 15 | 25 | 30 |
| 6 | finished walls and soffits (e.g. plastered walls, wall claddings and linings, suspended ceilings) | 3 | 5 | 10 | 20 | 25 |
| 7 | as for Group 6, but subject to more stringent requirements | 2 | 3 | 8 | 15 | 20 |

[a] Intermediate values shall be taken from Figures 5 and 6, and shall be given to the nearest mm.
[b] The values in Column 6 also apply to distances between measuring points of over 15 m.

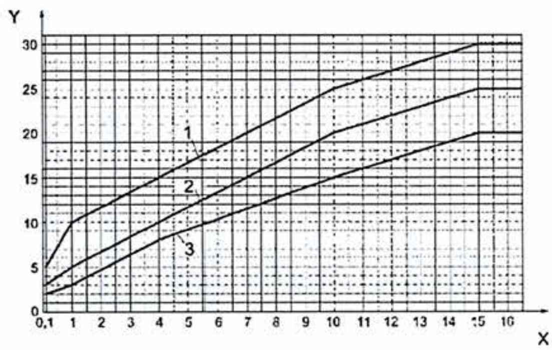



**Key**

1 Group 1
2 Groups 2a and 2b
3 Group 3
4 Group 4

X Distance between measuring points (m)
Y Permitted flatness deviations (mm)

**Figure 5 — Permitted flatness deviations for upper surfaces of floors an screed (groups from Table 3)**




**Key**

1 Group 5
2 Group 6
3 Group 7

X Distance between measuring points (m)
Y Permitted flatness deviations (mm)

**Figure 6 — Permitted flatness deviations for wall surfaces and soffits (groups from Table 3)**

**Figure 8.** Deflection limits defined in DIN 18202 for slabs and walls

**Chart 5.** Deflection limits for slab and wall groups (DIN 18202)

| Group | Explanation | Span, deflection limit for L (m), $\eth_m$ (mm) | |
|---|---|---|---|
| | | 0.1 | 1 |
| 1 | Rough flooring surface layers, surfaces under the coverings and concrete floors | 10 | 15 |
| 2a | Rough flooring surface layers, surfaces under the coverings and concrete floors (e.g. cohesive/incohesive coverings, surfaces to apply floating screed, industrial floors, floorings to apply ceramic and mosaic) | 5 | 8 |
| 2b | Secondary intended use finished floorings surface layers or concrete floors (e.g. warehouse, basement or bare surfaces) | 5 | 8 |
| 3 | Covered floorings (e.g. cladding surfaces, floorings to apply ceramic, cohesive surfaces) | 2 | 4 |
| 4 | Situations when lower deflection is needed like Group 3 (e.g. self consolidating surface coverings) | 1 | 3 |
| 5 | Rough wall and ceiling surfaces | 5 | 10 |
| 6 | Finished wall surfaces and lower surfaces (plastered walls, covered walls, dropped ceilings) | 3 | 5 |
| 7 | Situations when lower deflection is needed like Group 6 | 2 | 3 |

## 5.2 Design Loads and Load Combinations

Loads and load combinations that should be taken in consideration when using supporting scaffolds are given in Chart 6 in accordance with EN 12812:2008 standard. In fact, this standard does not specifically contain formwork designing guidelines yet it is practicable since it shows constant and live loads acting on the formwork and related safety coefficients. As well as all loads and loading types should be taken in consideration in formwork and scaffold design methods, while inspecting EKOPLAK panels as formwork panels, only $Q_1$, $Q_2$ and $Q_4$ loads have been deemed in effect.

$Q_1$ load is the panel weight itself and is given as 10,4 kg/m$^2$ as indicated in previous sections.

$Q_2$ load is the construction and material load together with operational live load in working area. Vertical load of fresh reinforced concrete is given as 2500 kg/m$^3$ (25 kN/m$^3$). In the case that any material will be stocked on the formwork, higher value of the weight of the material or 1.5 kN/m$^2$ should be applied as uniformly distributed load. In case of using formwork in horizontal direction, live load to be applied is given as minimum 0,75 kN/m$^2$. Snow load and icing on the formwork should be taken into account if the load effect exceeds 0,75 kN/m$^2$.

**Chart 6.** Load combination coefficients (EN 12812:2008)

| Effect | Type of effect | Combination coefficients | | | |
|---|---|---|---|---|---|
| | | 1.Loading Case | 2.Loading Case | 3.Loading Case | 4.Loading Case |
| Direct effects | | | | | |
| $Q_1$ | Constant effects | 1.0 | 1.0 | 1.0 | 1.0 |
| $Q_2$ | Inconstant permanent vertical effects | 0 | 1.0 | 1.0 | 1.0 |
| $Q_3$ | Inconstant permanent horizontal effects | 0 | 1.0 | 1.0 | 0 |
| $Q_4$ | Inconstant temporary effects | 0 | 1.0 | 0 | 0 |
| $Q_5$ | Max. wind | 1.0 | 0 | 1.0 | 0 |
| | Normal wind | 0 | 1.0 | 0 | 0.00 |
| $Q_6$ | Running water effect | 0.7 | 0.7 | 0.7 | 0.7 |
| $Q_7$ | Seismic effects | 0 | 0 | 0 | 1.0 |
| Indirect effects | | | | | |
| $Q_{8,j}$ | Temp. | | 1.0 | 1.0 | 1.0 |
| | Settlement | 0 | 0 | 1.0 | 1.0 |
| | Prestress | | 0 | 1.0 | 1.0 |
| $Q_9$ | Other load effects | 0 | 1.0 | 1.0 | 1.0 |

$Q_4$ temporary load effect means the surcharge caused by concrete casting and the lateral concrete pressure. In the case of fresh concrete casting, 0,75 kN/m$^2$ live load defined in $Q_2$ load effect is added to 10% of fresh concrete weight as live load. Minimum value of this live load is specified as 0,75 kN/m$^2$ and maximum value is specified as 1,75 kN/m$^2$. This additional load is expected to apply on a 3m x 3m area as shown in Figure 9.

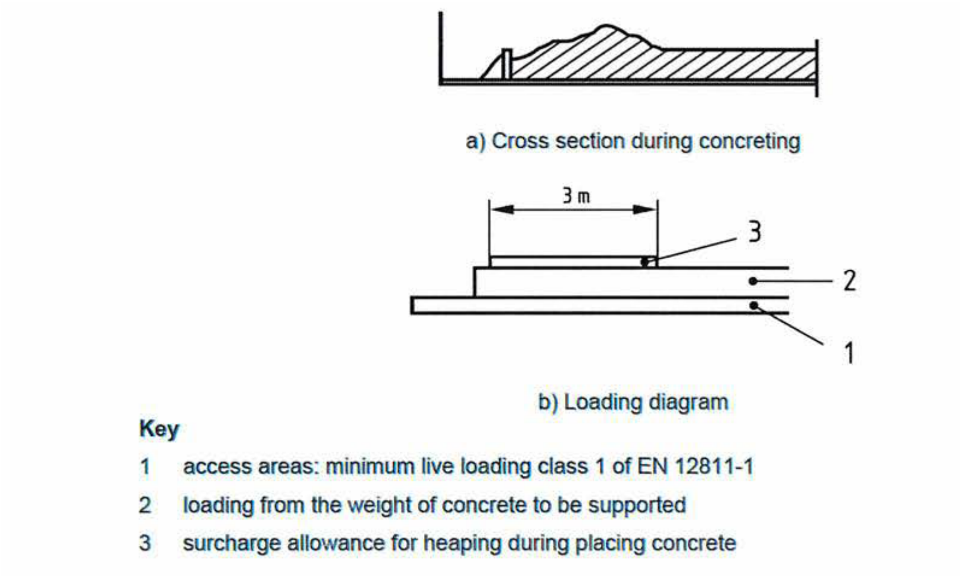



**Figure 9.** Design loads considered in fresh concrete casting (EN 12812:2008)

Fresh concrete pressure applied on formwork may be calculated in accordance with DIN 18218:2010-1 standard taking the $Q_4$ load as temporary load. Diagram showing the height and the pressure of fresh concrete poured vertically at speed y is shown in Figure 10. Lateral pressure of fresh concrete is dependent on many parameters such as kind of the cement and additive used, setting time and ambient temperature.

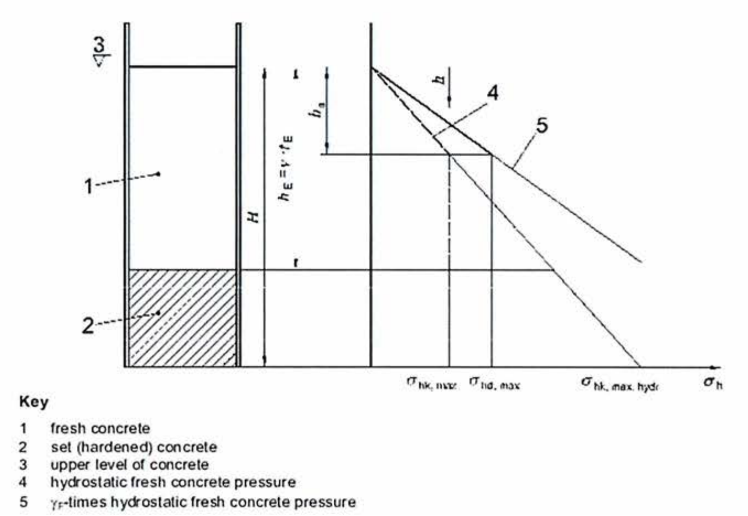



**Figure 10.** Fresh concrete pressure-vertical formwork height diagram (DIN 18218:2010-01)

Maximum values of lateral pressure of fresh concrete types with different consistency in different pouring rate and setting time are given in Chart 7 and Chart 8.

**Chart 7.** Maximum fresh concrete pressure characteristic values (DIN 18218:2010-01)

| | 1 | 2 |
|---|---|---|
| 1 | Consistency class | Maximum lateral fresh concrete pressure when placed in opposite direction to the rise in level (from above) $\sigma_{hk,max}$ kN/m$^2$ |
| 2 | F1 | $(5 \cdot v + 21) \cdot KI \geq 25$ |
| 3 | F2 | $(10 \cdot v + 19) \cdot KI \geq 25$ |
| 4 | F3 | $(14 \cdot v + 18) \cdot KI \geq 25$ |
| 5 | F4 | $(17 \cdot v + 17) \cdot KI \geq 25$ |
| 6 | F5 | $25 + 30 \cdot v \cdot KI \geq 30$ |
| 7 | F6 | $25 + 38 \cdot v \cdot KI \geq 30$ |
| 8 | SCC | $25 + 33 \cdot v \cdot KI \geq 30$ |

Where
$v$ is the placing rate (pouring rate) in m/h;
$KI$ is the factor taking into account the setting behaviour according to Table 2.

**Chart 8.** *KI* factors dependent on setting time

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | Consistency class | Factors $KI$ | | | |
| 2 | | End of setting $t_E$ = 5 h | End of setting $t_E$ = 10 h | End of setting $t_E$ = 20 h | General [b] |
| 3 | F1 [a] | 1,0 | 1,15 | 1,45 | $1 + 0{,}03 \cdot (t_E - 5)$ |
| 4 | F2 [a] | 1,0 | 1,25 | 1,80 | $1 + 0{,}053 \cdot (t_E - 5)$ |
| 5 | F3 [a] | 1,0 | 1,40 | 2,15 | $1 + 0{,}077 \cdot (t_E - 5)$ |
| 6 | F4 [a] | 1,0 | 1,70 | 3,10 | $1 + 0{,}14 \cdot (t_E - 5)$ |
| 7 | F5, F6, SCC | 1,0 | 2,00 | 4,00 | $t_E / 5$ |

[a] Applies for concreting sections of a height $H$ up to 10 m.
[b] Applies for 5 h $\leq t_E \leq$ 20 h; $t_E$ in h.

The highest fresh concrete pressure value obtained from Figure 10 and Chart 7 and 8 gives the characteristic value. It increases hydrostatically from the peak point depending on the vertical formwork height along the height calculated by the $h_e = \gamma t_e$ equation and from this height it is fixed on $\sigma_{hd}$ value.

After the calculation of characteristic values of the load effects defined above, strength and deflection controls of the formwork may be done in accordance with EN 12812:2008 standard for the following limits:

- Bearing capacity limit case -> Strength controls
- Usability limit case -> Deflection controls

In the case of bearing capacity limit with strength controls, design parameters are calculated by the help of following equation (EN 12812:2008):

$$Q_{d,i} = \gamma_{F,i} \times \Psi_i \times Q_{k,i}$$

In here, $Q_{d,i}$ defines the design value of load effect, ¥$_i$ means the combination factor given in Chart 6 and $\gamma_{F,i}$ is 1.35 for permanent load effects ($Q_1$) and 1.50 for other load effects.

Design value of related material resistance is calculated by the following equation:

$$R_{d,i} = \frac{R_{k,i}}{\gamma_{m,i}}$$

In here, $\gamma_{m,i}$ value may be taken as 1.1 unless otherwise indicated.

In the case of usability limit with deflection controls, $\gamma_{F,i}$ and $\gamma_{m,i}$ coefficients may be taken 1.0.

### 5.3 Usage of Panels as Slab Formworks

By the help of the information given above, designing EKOPLAK panels as slab formworks may be done as follows.

**Default Design Parameters:**

Slab *Group 3* in Chart 5

Slab thickness: 30 cm

Girder spacing: 40 cm

Ambient temperature: 25°C

**Load Effects:**

| | | |
|---|---|---|
| $Q_1$: Panel weight for 1 meter width = 10.4 kg/m$^2$/m = | 0.104 | kN/m$^2$/m |
| $Q_2$: Fresh concrete weight for 1 meter width = | 25x0.3=7.5 | kN/m$^2$/m |
| Operational live load = | 0.75 | kN/m$^2$/m |
| $Q_4$: Live load as 10% of fresh concrete = | 0.1x25x0.3=0.75 | kN/m$^2$/m |
| (0.75 minimum; 1.75 kN/m$^2$ maximum) | | |

Since the second loading case is predicted to be inconvenient viewing Chart 6, design load may be calculated as follows:

For bearing capacity limit case:

$$\text{Design load: } Q_d = w_d = 1.35(1)(0.104) + 1.5(1)(7.5 + 0.75 + 0.75) = 13.64\ kN/m^2/m$$

For usability limit case:

$$\text{Service load: } Q_s = w_s = (1)(1)(0.104) + (1)(1)(7.5 + 0.75 + 0.75) = 9.10\ kN/m^2/m$$

Maximum design and service torque may be calculated as follows assuming the panel will be with minimum 2 spans considering the compulsion of flexural members in Figure 11.

*Design torque:* $M_d = (13.64)(0.4^2)/8 = 0.273$ *kNm/m*

*Service torque:* $Ms = (9.10)(0.4^2)/8 = 0.182$ *kNm/m*

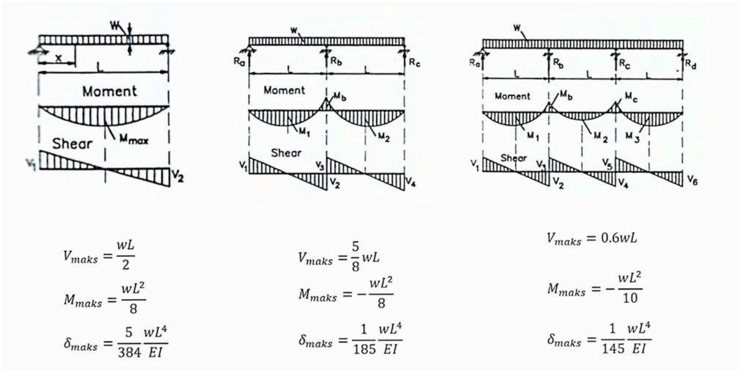



**Figure 11.** Maximum shear, torque and deflection values for single span and multispan beams

**EKOPLAK Bending Modulus of Elasticity and Yield Strength:**

Bending modulus:

In vertical direction: $E_{fb}$ (15°C) = 2649 MPa $E_{fb}$ (40°C) = 1420 MPa

By interpolation: $E_{fb}$ (25°C) = 2157 MPa

In horizontal direction: $E_{fe}$ (15°C) = 1467 MPa $E_{fe}$ (40°C) = 948 MPa

By interpolation: $E_{fe}$ (25°C) = 1259 MPa

Bending yield strength:

In vertical direction: $\sigma_{yb}$ (15°C) = 21.1 MPa $\sigma_{yb}$ (40°C) = 14.4 MPa

By interpolation: $\sigma_{yb}$ (25°C) = 18.42 MPa

Design value of yield strength: $\sigma_{ybd}$ (25°C) = 18.42/1.1 = 16.75 MPa

In horizontal direction: $\sigma_{ye}$ (15°C) = 14.4 MPa $\sigma_{ye}$ (40°C) = 10.7 MPa

By interpolation: $\sigma_{ye}$ (25°C) = 12.92 MPa

Design value of yield strength: $\sigma_{ye}$ (25°C) = 12.92/1.1 = 11.75 MPa

**Deflection Limit:**

Using the values given for Group 3 slab in Chart 5 by interpolation method

$$\eth_{lim} = 2 + (40 - 10)(4\text{-}2)/(100\text{-}10) = 2.67 \ mm$$

**Strength Control:**

Bending stress arising in the panel under the effect of design moment for bearing capacity limit case:

$$\sigma_f = \frac{M_d}{S} = \frac{M_d}{bh^2/6} = \frac{0.273\times10^6}{1000(18^2)/6} = 5.06 \text{ MPa}$$

Bending stress arising in the panel under the effect of design loads is much lower than the yield strength design values that have been calculated as 16.75 MPa and 11.75 MPa for longitudinal and horizontal directions of the panel, respectively. Therefore it satisfies the yield strength conditions.

**Deflection Control:**

For usability limit case

Deflection value when the panel is placed longitudinally between the supports:

$$\delta_{maks} = \frac{1}{145}\frac{wL^4}{EI} = \frac{1}{145}\frac{9.10(400^4)}{2157[\frac{1}{12}1000(18^3)]} = 1.53\ mm < 2.67\ mm \ \checkmark$$

Deflection value when the panel is placed transversely between the supports:

$$\delta_{maks} = \frac{1}{145}\frac{wL^4}{EI} = \frac{1}{145}\frac{9.10(400^4)}{1259[\frac{1}{12}1000(18^3)]} = 2.62\ mm < 2.67\ mm \ \checkmark$$

Panel satisfies the deflection limit condition in both cases.

Following the strength and deflection controls, it can be seen from the case above that at 25°C ambient temperature, the limit conditions are satisfied independently of the direction the panel is placed between the supports. However, when the deflection controls are analyzed, it is seen that the deflection limit is approached when the panel is placed transversely. When the panel heat exceeds 26°C because of the ambient temperature or the concrete heat of hydration which causes the transverse bending modulus dropping below 1238 MPa limit value, deflection limit is exceeded. Therefore, the panels should be placed longitudinally between the supports so that the strong section is exposed to bending effects. Moreover, temperature should also be considered in design calculations of panels as formworks.

As you could see from the calculations above, to get a design convenience defining mechanical properties, total hollow section was taken in consideration instead of net cross sectional area or moment of inertia. The results will be consistent since the gross section was also taken in consideration defining the material properties in Chart 4. That is the reason why the material properties were defined differently in tension and bending conditions. Since the panel section stays the same in both conditions, gross section assumption provides an easier designing. For this reason, it is appropriate to take gross section in design calculations.

Shear strength controls have not been performed since the laboratory studies do not involve shear strength tests. Shear strength controls should be done in the case that the panel is exposed to high concrete pressure.

In the section Appendix at the end of the report, deflection diagrams in different girder spacings are given for T=15°C concrete temperature in the case EKOPLAK is used as formwork panel for slabs with thickness between 10~40 cm.

### 5.4 Usage of Panels as Wall Formworks

Deflection and stress controls when using EKOPLAK panels in vertical formwork applications are nearly the same with transversal formwork applications except for the calculation of lateral concrete pressure. In vertical formwork applications, additional live load case does not count, as expected. However, lateral concrete pressure may be high due to the height of the wall. Besides, lateral pressure value fixed at a certain height limits the load effects and compulsions on the panel to a certain level. That is why the right prediction of lateral concrete pressure is highly important for the design of vertical formwork applications. It is also possible to keep the concrete pressure on panels in acceptable limits adjusting the casting rate and setting time by the help of the methods in DIN 18218:2010-01 standard. In the section Appendix at the end of the report, deflection diagrams in different girder spacings are given for T=15°C concrete temperature and plastic consistency (K2) for a casting rate of 2~7 m/h in the case EKOPLAK is used as formwork panel for shear walls with 3m and 5m height.

## 6. Conclusion

In this report, basic technical properties of EKOPLAK polymer panels to be used in concrete formwork applications are specified with experimental studies and design guidelines are presented.

Unit weight of panels with 18 mm nominal thickness is calculated as 10.4 kg/$m^2$ and the specific weight of the panel material is calculated as 1.627.

Using the method Differential Scanning Calorimetry, softening and melting temperatures of panel material are calculated to be 68°C and 170°C, respectively.

As expected, mechanical properties of the panels are observed to be higher in longitudinal direction. For that reason, it is important to place the panel longitudinally between supports so that the strong section is exposed to bending effects. However, in a condition where the girder spacing is 40 cm and concrete height is 30 cm, panels have satisfied the deflection and yield strength conditions in 25°C.

Characteristic values of elastic and strength properties obtained from tension and bending tests performed at an ambient temperature of 15°C and sample temperature of 40°C, have been calculated and presented as a chart. For the temperatures between 15°C and 40°C, values may be calculated by interpolation method. For temperatures out of this range, extrapolation without the manufacturer’s approval should be avoided.

Results obtained from Charpy impact tests carried out on unnotched samples at an ambient temperature of 15°C are submitted as a chart.

Using the characteristic material properties obtained from experimental studies, for deflection limits for slabs and walls defined in DIN 18202:2013-04 standards, following the design principals defined in EN 12812:2008 standard, guidelines about usage of panels in formwork applications are submitted in the report with a sample case. In the cases where the formworks are used in vertical direction, lateral pressure of fresh concrete may be calculated using the method expressed in DIN 18218:2010-01 standard and outlined in the report. Design controls to be done following the calculation of design loads, are substantially the same for formwork applications in both vertical and transversal directions. Using the method shown and guidelines, it is possible to determine the proper girder spacing for a formwork application in certain conditions.

In unordinary applications where the concrete pressure is high, the panels may be used double layered, yet, attention should be paid using the method specified in the report and manufacturer's approval should be obtained.

In brief, it is demonstrated in the report that basic physical and technical properties of EKOPLAK polymer panels are satisfactory for typical concrete formwork applications and relevant design calculations may be done according to the principals and methods indicated in the report.

Respectfully submitted for your consideration.

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ITU Civil Engineering Faculty RC Structures and Building Materials Study Group Lecturers

March, 2018

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**APPENDIX-A: Transversal Use**

**Charts of Deflection and Strength on Strong Section of**

**Single Span EKOPLAK Formwork Surface**

| | Döşeme Beton Kalınlığı (cm) / Slab Concrete Thickness (cm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 15 | 18 | 20 | 25 | 30 | 35 | 40 | |
| Servis Yükü (kN/m²/m) / Service Load (kN/m²/m) | 4.104 | 4.604 | 5.354 | 6.104 | 6.604 | 7.854 | 9.104 | 10.604 | 12.104 | |
| Tasarım Yükü (kN/m²/m) / Design Load (kN/m²/m) | 6.1404 | 6.8904 | 8.0154 | 9.1404 | 9.8904 | 11.7654 | 13.6404 | 15.5154 | 17.3904 | |
| EI = 1.287 kNm² | | | | | | | | T= 15°C | | |
| **Sehim (mm) / Deflection (mm)** — Mesnet Aralığı (cm) / Girder Spacing (cm) | | | | | | | | | | **Limit** |
| 15 | 0.021 | 0.024 | 0.027 | 0.031 | 0.034 | 0.040 | 0.047 | 0.054 | 0.062 | 2.111 |
| 20 | 0.066 | 0.075 | 0.087 | 0.099 | 0.107 | 0.127 | 0.147 | 0.172 | 0.196 | 2.222 |
| 25 | 0.162 | 0.182 | 0.212 | 0.241 | 0.261 | 0.310 | 0.360 | 0.419 | 0.478 | 2.333 |
| 30 | 0.336 | 0.377 | 0.439 | 0.500 | 0.541 | 0.643 | 0.746 | 0.869 | 0.992 | 2.444 |
| 35 | 0.623 | 0.699 | 0.813 | 0.926 | 1.002 | 1.192 | 1.382 | 1.609 | 1.837 | 2.556 |
| 40 | 1.063 | 1.192 | 1.386 | 1.580 | 1.710 | 2.034 | 2.357 | 2.746 | 3.134 | 2.667 |
| 45 | 1.702 | 1.909 | 2.220 | 2.532 | 2.739 | 3.257 | 3.776 | 4.398 | 5.020 | 2.778 |
| 50 | 2.594 | 2.910 | 3.384 | 3.858 | 4.175 | 4.965 | 5.755 | 6.703 | 7.651 | 2.889 |
| 55 | 3.798 | 4.261 | 4.955 | 5.649 | 6.112 | 7.269 | 8.426 | 9.814 | 11.202 | 3.000 |
| 60 | 5.379 | 6.035 | 7.018 | 8.001 | 8.656 | 10.295 | 11.933 | 13.899 | 15.866 | 3.111 |
| 65 | 7.409 | 8.312 | 9.666 | 11.020 | 11.923 | 14.180 | 16.436 | 19.144 | 21.853 | 3.222 |
| 70 | 9.966 | 11.180 | 13.001 | 14.823 | 16.037 | 19.072 | 22.108 | 25.750 | 29.393 | 3.333 |
| 75 | 13.133 | 14.733 | 17.133 | 19.534 | 21.134 | 25.134 | 29.134 | 33.934 | 38.734 | 3.444 |
| **Gerilme (MPa) / Stress (MPa)** — Mesnet Aralığı (cm) / Girder Spacing (cm) | | | | | | | | | | **Limit** |
| 15 | 0.320 | 0.359 | 0.417 | 0.476 | 0.515 | 0.613 | 0.710 | 0.808 | 0.906 | 19.18 |
| 20 | 0.569 | 0.638 | 0.742 | 0.846 | 0.916 | 1.089 | 1.263 | 1.437 | 1.610 | |
| 25 | 0.888 | 0.997 | 1.160 | 1.322 | 1.431 | 1.702 | 1.973 | 2.245 | 2.516 | |
| 30 | 1.279 | 1.436 | 1.670 | 1.904 | 2.061 | 2.451 | 2.842 | 3.232 | 3.623 | |
| 35 | 1.741 | 1.954 | 2.273 | 2.592 | 2.805 | 3.336 | 3.868 | 4.400 | 4.931 | |
| 40 | 2.274 | 2.552 | 2.969 | 3.385 | 3.663 | 4.358 | 5.052 | 5.746 | 6.441 | |
| 45 | 2.878 | 3.230 | 3.757 | 4.285 | 4.636 | 5.515 | 6.394 | 7.273 | 8.152 | |
| 50 | 3.553 | 3.988 | 4.639 | 5.290 | 5.724 | 6.809 | 7.894 | 8.979 | 10.064 | |
| 55 | 4.300 | 4.825 | 5.613 | 6.400 | 6.926 | 8.239 | 9.551 | 10.864 | 12.177 | |
| 60 | 5.117 | 5.742 | 6.680 | 7.617 | 8.242 | 9.805 | 11.367 | 12.930 | 14.492 | |
| 65 | 6.005 | 6.739 | 7.839 | 8.939 | 9.673 | 11.507 | 13.340 | 15.174 | 17.008 | |
| 70 | 6.965 | 7.816 | 9.092 | 10.368 | 11.218 | 13.345 | 15.472 | 17.598 | 19.725 | |
| 75 | 7.995 | 8.972 | 10.437 | 11.902 | 12.878 | 15.320 | 17.761 | 20.202 | 22.644 | |

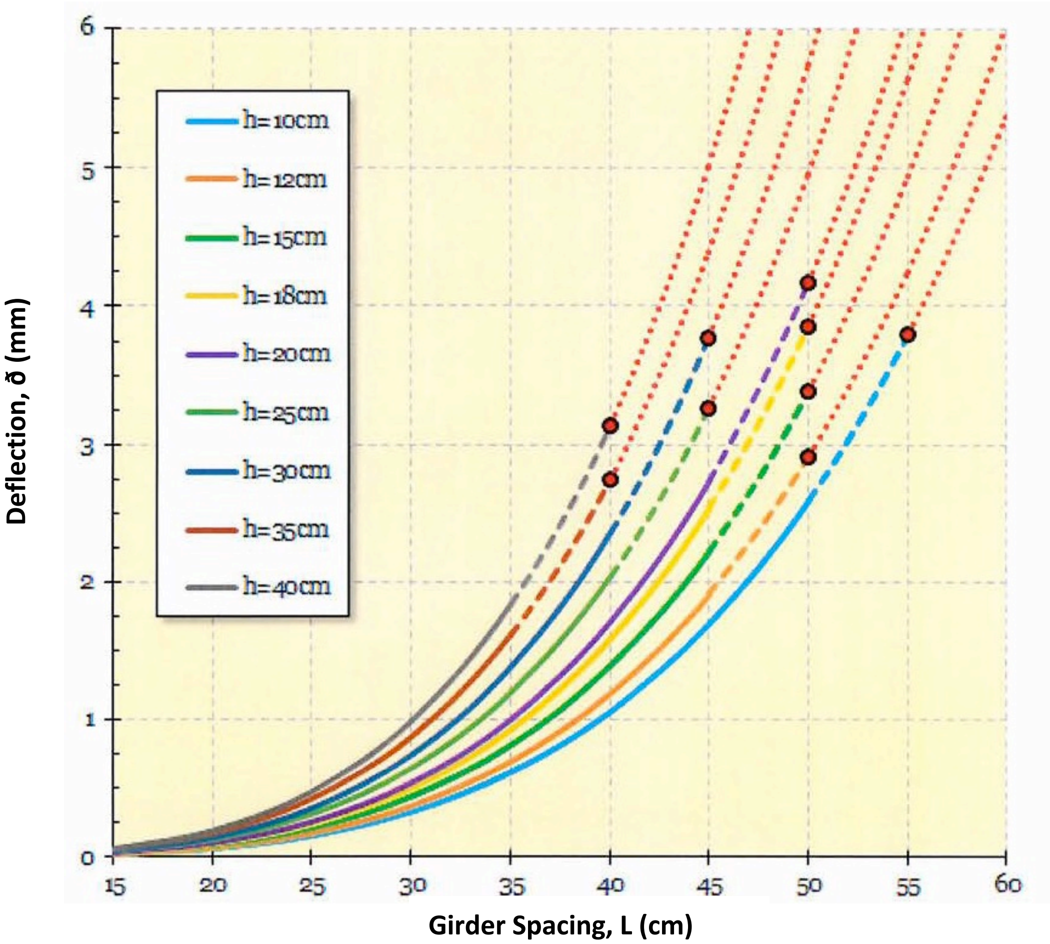


**Figure A.** Deflection diagrams for EKOPLAK strong section in single span application

**APPENDIX-B: Transversal Use**

**Charts of Deflection and Strength on Weak Section of**

**Single Span EKOPLAK Formwork Surface**

| | Döşeme Beton Kalınlığı (cm) / Slab Concrete Thickness (cm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 15 | 18 | 20 | 25 | 30 | 35 | 40 | |
| | *Servis Yükü (kN/m² /m) / Service Load (kN/m² /m)* | | | | | | | | | |
| | 4.104 | 4.604 | 5.354 | 6.104 | 6.604 | 7.854 | 9.104 | 10.604 | 12.104 | |
| | *Tasarım Yükü (kN/m² /m) / Design Load (kN/m² /m)* | | | | | | | | | |
| | 6.1404 | 6.8904 | 8.0154 | 9.1404 | 9.8904 | 11.7654 | 13.6404 | 15.5154 | 17.3904 | |
| | EI = | 0.713 kNm² | | | | | T = 15°C | | | |
| **Mesnet Aralığı (cm) / Girder Spacing (cm)** | **Sehim (mm) / Deflection (mm)** | | | | | | | | | ***Limit*** |
| 15 | 0.038 | 0.043 | 0.050 | 0.056 | 0.061 | 0.073 | 0.084 | 0.098 | 0.112 | 2.111 |
| 20 | 0.120 | 0.135 | 0.156 | 0.178 | 0.193 | 0.230 | 0.266 | 0.310 | 0.354 | 2.222 |
| 25 | 0.293 | 0.328 | 0.382 | 0.435 | 0.471 | 0.560 | 0.649 | 0.756 | 0.863 | 2.333 |
| 30 | 0.607 | 0.681 | 0.792 | 0.903 | 0.977 | 1.162 | 1.347 | 1.569 | 1.791 | 2.444 |
| 35 | 1.125 | 1.262 | 1.467 | 1.673 | 1.810 | 2.152 | 2.495 | 2.906 | 3.317 | 2.556 |
| 40 | 1.919 | 2.153 | 2.503 | 2.854 | 3.088 | 3.672 | 4.256 | 4.958 | 5.659 | 2.667 |
| 45 | 3.073 | 3.448 | 4.010 | 4.571 | 4.946 | 5.882 | 6.818 | 7.941 | 9.065 | 2.778 |
| 50 | 4.684 | 5.255 | 6.111 | 6.967 | 7.538 | 8.965 | 10.392 | 12.104 | 13.816 | 2.889 |
| 55 | 6.859 | 7.694 | 8.947 | 10.201 | 11.036 | 13.125 | 15.214 | 17.721 | 20.228 | 3.000 |
| 60 | 9.714 | 10.897 | 12.672 | 14.447 | 15.631 | 18.590 | 21.548 | 25.098 | 28.649 | 3.111 |
| 65 | 13.379 | 15.009 | 17.454 | 19.899 | 21.529 | 25.605 | 29.680 | 34.570 | 39.460 | 3.222 |
| 70 | 17.996 | 20.188 | 23.477 | 26.766 | 28.958 | 34.439 | 39.921 | 46.498 | 53.075 | 3.333 |
| 75 | 23.715 | 26.604 | 30.938 | 35.272 | 38.161 | 45.385 | 52.608 | 61.276 | 69.943 | 3.444 |
| **Mesnet Aralığı (cm) / Girder Spacing (cm)** | **Gerilme (MPa) / Stress (MPa)** | | | | | | | | | ***Limit*** |
| 15 | 0.320 | 0.359 | 0.417 | 0.476 | 0.515 | 0.613 | 0.710 | 0.808 | 0.906 | 13.09 |
| 20 | 0.569 | 0.638 | 0.742 | 0.846 | 0.916 | 1.089 | 1.263 | 1.437 | 1.610 | |
| 25 | 0.888 | 0.997 | 1.160 | 1.322 | 1.431 | 1.702 | 1.973 | 2.245 | 2.516 | |
| 30 | 1.279 | 1.436 | 1.670 | 1.904 | 2.061 | 2.451 | 2.842 | 3.232 | 3.623 | |
| 35 | 1.741 | 1.954 | 2.273 | 2.592 | 2.805 | 3.336 | 3.868 | 4.400 | 4.931 | |
| 40 | 2.274 | 2.552 | 2.969 | 3.385 | 3.663 | 4.358 | 5.052 | 5.746 | 6.441 | |
| 45 | 2.878 | 3.230 | 3.757 | 4.285 | 4.636 | 5.515 | 6.394 | 7.273 | 8.152 | |
| 50 | 3.553 | 3.988 | 4.639 | 5.290 | 5.724 | 6.809 | 7.894 | 8.979 | 10.064 | |
| 55 | 4.300 | 4.825 | 5.613 | 6.400 | 6.926 | 8.239 | 9.551 | 10.864 | 12.177 | |
| 60 | 5.117 | 5.742 | 6.680 | 7.617 | 8.242 | 9.805 | 11.367 | 12.930 | 14.492 | |
| 65 | 6.005 | 6.739 | 7.839 | 8.939 | 9.673 | 11.507 | 13.340 | 15.174 | 17.008 | |
| 70 | 6.965 | 7.816 | 9.092 | 10.368 | 11.218 | 13.345 | 15.472 | 17.598 | 19.725 | |
| 75 | 7.995 | 8.972 | 10.437 | 11.902 | 12.878 | 15.320 | 17.761 | 20.202 | 22.644 | |

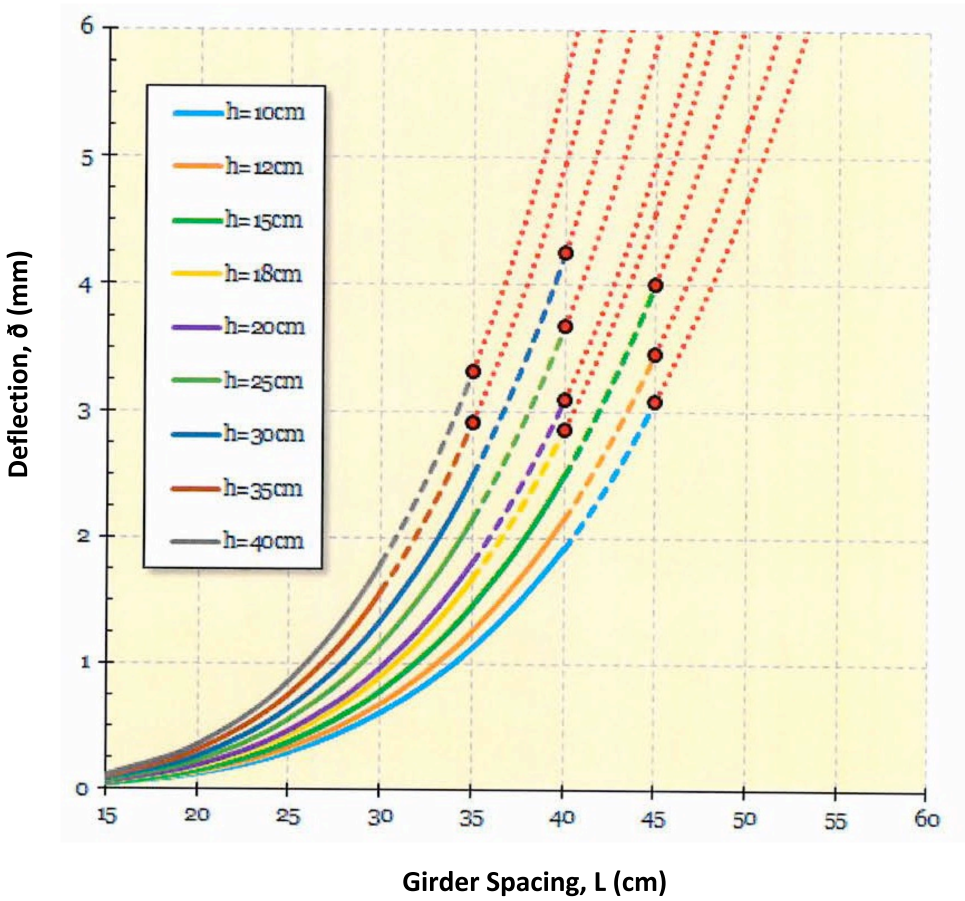


**Figure B.** Deflection diagrams for EKOPLAK weak section in single span application

**APPENDIX-C: Transversal Use**

**Charts of Deflection and Strength on Strong Section of**

**Multi Span EKOPLAK Formwork Surface**

| | Döşeme Beton Kalınlığı (cm) / Slab Concrete Thickness (cm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 15 | 18 | 20 | 25 | 30 | 35 | 40 | |
| Servis Yükü (kN/m² /m) / Service Load (kN/m² /m) | 4.104 | 4.604 | 5.354 | 6.104 | 6.604 | 7.854 | 9.104 | 10.604 | 12.104 | |
| Tasarım Yükü (kN/m² /m) / Design Load (kN/m² /m) | 6.1404 | 6.8904 | 8.0154 | 9.1404 | 9.8904 | 11.7654 | 13.6404 | 15.5154 | 17.3904 | |
| EI = 1.287 kNm² | | | | | | | | T= 15°C | | |
| **Sehim (mm) / Deflection (mm)** — Mesnet Aralığı (cm) / Girder Spacing (cm) | | | | | | | | | | **Limit** |
| 15 | 0.011 | 0.012 | 0.015 | 0.017 | 0.018 | 0.021 | 0.025 | 0.029 | 0.033 | 2.111 |
| 20 | 0.035 | 0.039 | 0.046 | 0.052 | 0.057 | 0.067 | 0.078 | 0.091 | 0.104 | 2.222 |
| 25 | 0.086 | 0.096 | 0.112 | 0.128 | 0.138 | 0.164 | 0.191 | 0.222 | 0.253 | 2.333 |
| 30 | 0.178 | 0.200 | 0.232 | 0.265 | 0.287 | 0.341 | 0.395 | 0.460 | 0.525 | 2.444 |
| 35 | 0.330 | 0.370 | 0.430 | 0.491 | 0.531 | 0.631 | 0.732 | 0.852 | 0.973 | 2.556 |
| 40 | 0.563 | 0.631 | 0.734 | 0.837 | 0.906 | 1.077 | 1.248 | 1.454 | 1.660 | 2.667 |
| 45 | 0.902 | 1.011 | 1.176 | 1.341 | 1.451 | 1.725 | 2.000 | 2.329 | 2.659 | 2.778 |
| 50 | 1.374 | 1.541 | 1.793 | 2.044 | 2.211 | 2.630 | 3.048 | 3.550 | 4.052 | 2.889 |
| 55 | 2.012 | 2.257 | 2.624 | 2.992 | 3.237 | 3.850 | 4.463 | 5.198 | 5.933 | 3.000 |
| 60 | 2.849 | 3.196 | 3.717 | 4.238 | 4.585 | 5.453 | 6.320 | 7.362 | 8.403 | 3.111 |
| 65 | 3.924 | 4.403 | 5.120 | 5.837 | 6.315 | 7.510 | 8.706 | 10.140 | 11.574 | 3.222 |
| 70 | 5.279 | 5.922 | 6.886 | 7.851 | 8.494 | 10.102 | 11.709 | 13.639 | 15.568 | 3.333 |
| 75 | 6.956 | 7.804 | 9.075 | 10.346 | 11.193 | 13.312 | 15.431 | 17.973 | 20.516 | 3.444 |
| **Gerilme (MPa) / Stress (MPa)** — Mesnet Aralığı (cm) / Girder Spacing (cm) | | | | | | | | | | **Limit** |
| 15 | 0.256 | 0.287 | 0.334 | 0.381 | 0.412 | 0.490 | 0.568 | 0.646 | 0.725 | 19.18 |
| 20 | 0.455 | 0.510 | 0.594 | 0.677 | 0.733 | 0.872 | 1.010 | 1.149 | 1.288 | |
| 25 | 0.711 | 0.798 | 0.928 | 1.058 | 1.145 | 1.362 | 1.579 | 1.796 | 2.013 | |
| 30 | 1.023 | 1.148 | 1.336 | 1.523 | 1.648 | 1.961 | 2.273 | 2.586 | 2.898 | |
| 35 | 1.393 | 1.563 | 1.818 | 2.074 | 2.244 | 2.669 | 3.094 | 3.520 | 3.945 | |
| 40 | 1.819 | 2.042 | 2.375 | 2.708 | 2.930 | 3.486 | 4.042 | 4.597 | 5.153 | |
| 45 | 2.303 | 2.584 | 3.006 | 3.428 | 3.709 | 4.412 | 5.115 | 5.818 | 6.521 | |
| 50 | 2.843 | 3.190 | 3.711 | 4.232 | 4.579 | 5.447 | 6.315 | 7.183 | 8.051 | |
| 55 | 3.440 | 3.860 | 4.490 | 5.120 | 5.540 | 6.591 | 7.641 | 8.691 | 9.742 | |
| 60 | 4.094 | 4.594 | 5.344 | 6.094 | 6.594 | 7.844 | 9.094 | 10.344 | 11.594 | |
| 65 | 4.804 | 5.391 | 6.271 | 7.152 | 7.738 | 9.205 | 10.672 | 12.139 | 13.606 | |
| 70 | 5.572 | 6.252 | 7.273 | 8.294 | 8.975 | 10.676 | 12.377 | 14.079 | 15.780 | |
| 75 | 6.396 | 7.178 | 8.349 | 9.521 | 10.303 | 12.256 | 14.209 | 16.162 | 18.115 | |

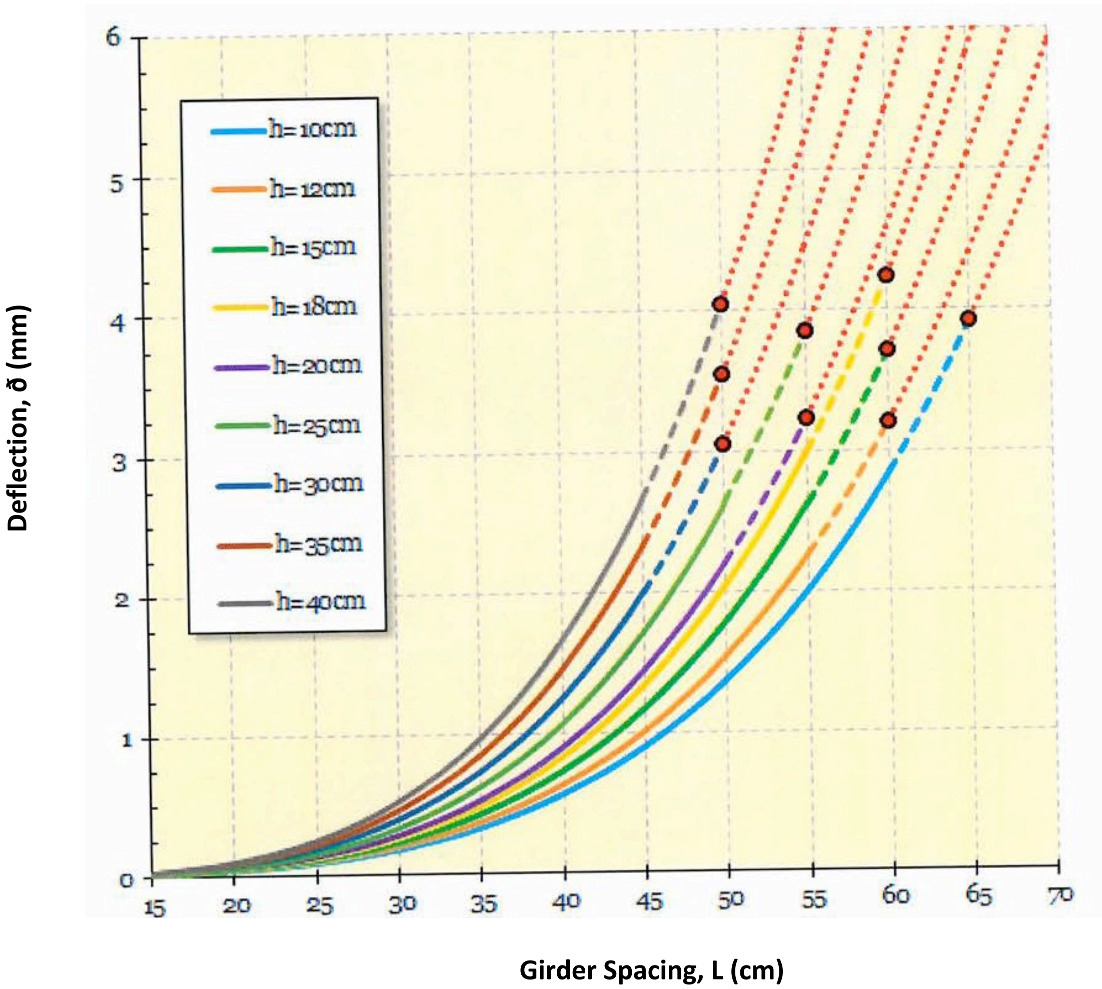


**Figure C.** Deflection diagrams for EKOPLAK strong section in multi span application

**APPENDIX-D: Transversal Use**

**Charts of Deflection and Strength on Weak Section of**

**Multi Span EKOPLAK Formwork Surface**

| | Döşeme Beton Kalınlığı (cm) / Slab Concrete Thickness (cm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 15 | 18 | 20 | 25 | 30 | 35 | 40 | |
| Servis Yükü (kN/m²/m) / Service Load (kN/m²/m) | 4.104 | 4.604 | 5.354 | 6.104 | 6.604 | 7.854 | 9.104 | 10.604 | 12.104 | |
| Tasarım Yükü (kN/m²/m) / Design Load (kN/m²/m) | 6.1404 | 6.8904 | 8.0154 | 9.1404 | 9.8904 | 11.7654 | 13.6404 | 15.5154 | 17.3904 | |
| EI = 0.713 kNm² | | | | | | | | T = 15°C | | |
| **Sehim (mm) / Deflection (mm)** — Mesnet Aralığı (cm) / Girder Spacing (cm) | | | | | | | | | | ***Limit*** |
| 15 | 0.020 | 0.023 | 0.026 | 0.030 | 0.032 | 0.038 | 0.045 | 0.052 | 0.059 | 2.111 |
| 20 | 0.064 | 0.071 | 0.083 | 0.094 | 0.102 | 0.122 | 0.141 | 0.164 | 0.187 | 2.222 |
| 25 | 0.155 | 0.174 | 0.202 | 0.231 | 0.250 | 0.297 | 0.344 | 0.401 | 0.457 | 2.333 |
| 30 | 0.322 | 0.361 | 0.419 | 0.478 | 0.517 | 0.615 | 0.713 | 0.831 | 0.948 | 2.444 |
| 35 | 0.596 | 0.668 | 0.777 | 0.886 | 0.959 | 1.140 | 1.322 | 1.539 | 1.757 | 2.556 |
| 40 | 1.016 | 1.140 | 1.326 | 1.512 | 1.635 | 1.945 | 2.254 | 2.626 | 2.997 | 2.667 |
| 45 | 1.628 | 1.826 | 2.124 | 2.421 | 2.620 | 3.115 | 3.611 | 4.206 | 4.801 | 2.778 |
| 50 | 2.481 | 2.783 | 3.237 | 3.690 | 3.993 | 4.748 | 5.504 | 6.411 | 7.318 | 2.889 |
| 55 | 3.633 | 4.075 | 4.739 | 5.403 | 5.846 | 6.952 | 8.058 | 9.386 | 10.714 | 3.000 |
| 60 | 5.145 | 5.772 | 6.712 | 7.652 | 8.279 | 9.846 | 11.413 | 13.294 | 15.174 | 3.111 |
| 65 | 7.086 | 7.950 | 9.245 | 10.540 | 11.403 | 13.562 | 15.720 | 18.310 | 20.900 | 3.222 |
| 70 | 9.532 | 10.693 | 12.435 | 14.177 | 15.338 | 18.241 | 21.144 | 24.628 | 28.112 | 3.333 |
| 75 | 12.561 | 14.091 | 16.387 | 18.682 | 20.212 | 24.038 | 27.864 | 32.455 | 37.046 | 3.444 |
| **Gerilme (MPa) / Stress (MPa)** — Mesnet Aralığı (cm) / Girder Spacing (cm) | | | | | | | | | | ***Limit*** |
| 15 | 0.256 | 0.287 | 0.334 | 0.381 | 0.412 | 0.490 | 0.568 | 0.646 | 0.725 | 13.09 |
| 20 | 0.455 | 0.510 | 0.594 | 0.677 | 0.733 | 0.872 | 1.010 | 1.149 | 1.288 | |
| 25 | 0.711 | 0.798 | 0.928 | 1.058 | 1.145 | 1.362 | 1.579 | 1.796 | 2.013 | |
| 30 | 1.023 | 1.148 | 1.336 | 1.523 | 1.648 | 1.961 | 2.273 | 2.586 | 2.898 | |
| 35 | 1.393 | 1.563 | 1.818 | 2.074 | 2.244 | 2.669 | 3.094 | 3.520 | 3.945 | |
| 40 | 1.819 | 2.042 | 2.375 | 2.708 | 2.930 | 3.486 | 4.042 | 4.597 | 5.153 | |
| 45 | 2.303 | 2.584 | 3.006 | 3.428 | 3.709 | 4.412 | 5.115 | 5.818 | 6.521 | |
| 50 | 2.843 | 3.190 | 3.711 | 4.232 | 4.579 | 5.447 | 6.315 | 7.183 | 8.051 | |
| 55 | 3.440 | 3.860 | 4.490 | 5.120 | 5.540 | 6.591 | 7.641 | 8.691 | 9.742 | |
| 60 | 4.094 | 4.594 | 5.344 | 6.094 | 6.594 | 7.844 | 9.094 | 10.344 | 11.594 | |
| 65 | 4.804 | 5.391 | 6.271 | 7.152 | 7.738 | 9.205 | 10.672 | 12.139 | 13.606 | |
| 70 | 5.572 | 6.252 | 7.273 | 8.294 | 8.975 | 10.676 | 12.377 | 14.079 | 15.780 | |
| 75 | 6.396 | 7.178 | 8.349 | 9.521 | 10.303 | 12.256 | 14.209 | 16.162 | 18.115 | |

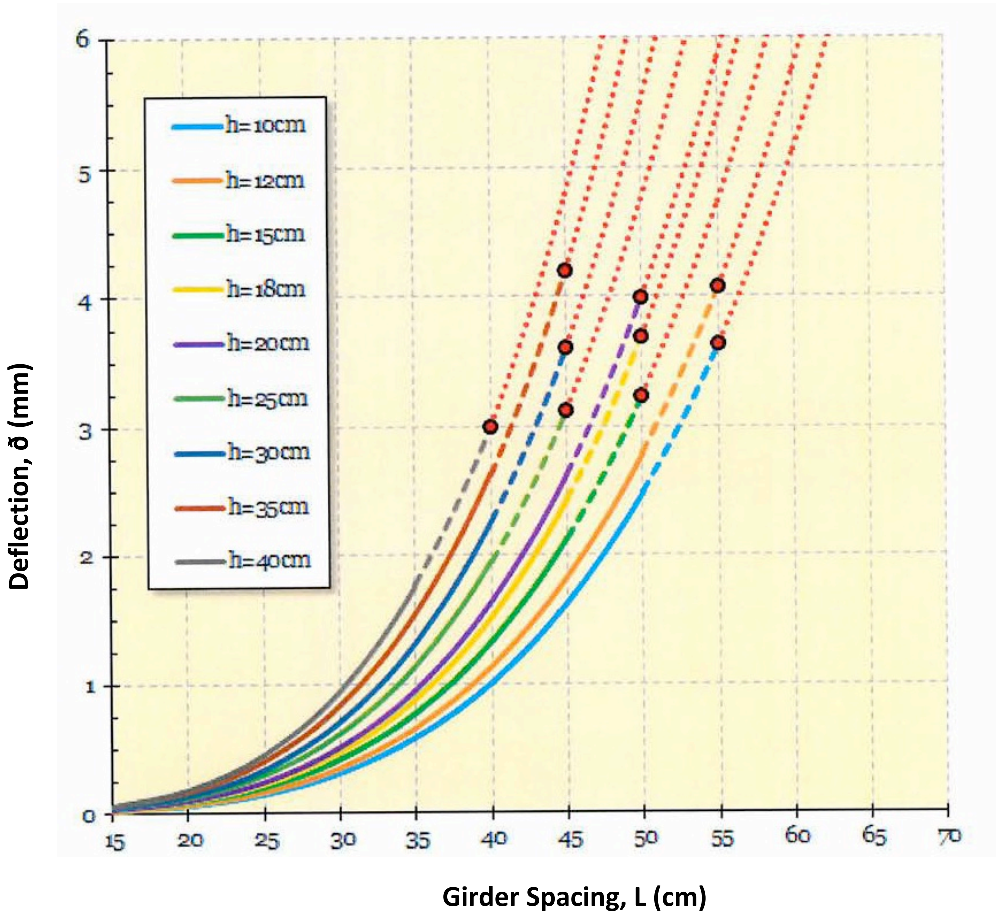


**Figure D.** Deflection diagrams for EKOPLAK weak section in multi span application

**APPENDIX-E: Vertical Use**

**Charts of Deflection and Strength on Strong Section**

**of Multi-Span EKOPLAK Formwork Surface**

| | | Beton Döküm Hızı (m/h) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | 6 | 7 | |
| | | Maks.Beton Basıncı (kN/m $^2$) | | | | | Kıvam: K2 | |
| | | 39.0 | 49.0 | 59.0 | 69.0 | 79.0 | 89.0 | |
| | | EI = | 1.287 kNm$^2$ | | | | T=15°C | |
| | | **Sehim (mm)** | | | | | | **Limit** |
| Boylama Aralığı (cm) | 20 | 0.334 | 0.420 | 0.506 | 0.591 | 0.677 | 0.763 | 3.222 |
| | 25 | 0.816 | 1.025 | 1.235 | 1.444 | 1.653 | 1.862 | 3.333 |
| | 30 | 1.692 | 2.126 | 2.560 | 2.994 | 3.428 | 3.862 | 3.444 |
| | 35 | 3.135 | 3.939 | 4.743 | 5.547 | 6.351 | 7.154 | 3.556 |
| | 40 | 5.348 | 6.720 | 8.091 | 9.462 | 10.834 | 12.205 | 3.667 |
| | | Maks.Beton Basıncı (kN/m $^2$) | | | | | Kıvam: K3 | |
| | | 46.0 | 60.0 | 74.0 | 88.0 | 102.0 | 116.0 | |
| Boylama Aralığı (cm) | 20 | 0.394 | 0.514 | 0.634 | 0.754 | 0.874 | 0.994 | 3.222 |
| | 25 | 0.963 | 1.256 | 1.548 | 1.841 | 2.134 | 2.427 | 3.333 |
| | 30 | 1.996 | 2.603 | 3.211 | 3.818 | 4.426 | 5.033 | 3.444 |
| | 35 | 3.698 | 4.823 | 5.949 | 7.074 | 8.199 | 9.325 | 3.556 |
| | 40 | 6.308 | 8.228 | 10.148 | 12.068 | 13.988 | 15.908 | 3.667 |
| | | **Gerilme (MPa)** | | | | | Kıvam: K2 | **Limit** |
| Boylama Aralığı (cm) | 20 | 4.333 | 5.444 | 6.556 | 7.667 | 8.778 | 9.889 | 19.18 |
| | 25 | 6.771 | 8.507 | 10.243 | 11.979 | 13.715 | 15.451 | |
| | 30 | 9.750 | 12.250 | 14.750 | 17.250 | 19.750 | 22.250 | |
| | 35 | 13.271 | 16.674 | 20.076 | 23.479 | 26.882 | 30.285 | |
| | 40 | 17.333 | 21.778 | 26.222 | 30.667 | 35.111 | 39.556 | |
| | | | | | | | Kıvam: K3 | |
| Boylama Aralığı (cm) | 20 | 5.111 | 6.667 | 8.222 | 9.778 | 11.333 | 12.889 | |
| | 25 | 7.986 | 10.417 | 12.847 | 15.278 | 17.708 | 20.139 | |
| | 30 | 11.500 | 15.000 | 18.500 | 22.000 | 25.500 | 29.000 | |
| | 35 | 15.653 | 20.417 | 25.181 | 29.944 | 34.708 | 39.472 | |
| | 40 | 20.444 | 26.667 | 32.889 | 39.111 | 45.333 | 51.556 | |

Fresh concrete pressure values have been calculated according to DIN-18218.

Fresh concrete pressure values are independent of casting height.

Maximum pressure on the walls should not exceed 80 kN/m$^2$.

Maximum pressure on the columns should not exceed 100 kN/m$^2$.

## APPENDIX-F: Vertical Use

## Charts of Deflection and Strength on Weak Section

## of Multi-Span EKOPLAK Formwork Surface

| | Beton Döküm Hızı (m/h) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | |
| Maks.Beton Basıncı (kN/m²) — Kıvam: K2 | 39.0 | 49.0 | 59.0 | 69.0 | 79.0 | 89.0 | |
| EI = 0.713 kNm² | | | | | | T=15°C | |
| **Sehim (mm)** | | | | | | | **Limit** |
| Boylama Aralığı (cm) 20 | 0.604 | 0.758 | 0.913 | 1.068 | 1.223 | 1.377 | 3.222 |
| 25 | 1.474 | 1.851 | 2.229 | 2.607 | 2.985 | 3.363 | 3.333 |
| 30 | 3.056 | 3.839 | 4.623 | 5.406 | 6.190 | 6.973 | 3.444 |
| 35 | 5.661 | 7.113 | 8.564 | 10.016 | 11.467 | 12.919 | 3.556 |
| 40 | 9.658 | 12.134 | 14.610 | 17.087 | 19.563 | 22.039 | 3.667 |
| Maks.Beton Basıncı (kN/m²) — Kıvam: K3 | 46.0 | 60.0 | 74.0 | 88.0 | 102.0 | 116.0 | |
| Boylama Aralığı (cm) 20 | 0.712 | 0.929 | 1.145 | 1.362 | 1.579 | 1.795 | 3.222 |
| 25 | 1.738 | 2.267 | 2.796 | 3.325 | 3.854 | 4.383 | 3.333 |
| 30 | 3.604 | 4.701 | 5.798 | 6.895 | 7.992 | 9.089 | 3.444 |
| 35 | 6.677 | 8.709 | 10.742 | 12.774 | 14.806 | 16.838 | 3.556 |
| 40 | 11.391 | 14.858 | 18.325 | 21.792 | 25.258 | 28.725 | 3.667 |
| **Gerilme (MPa)** — Kıvam: K2 | | | | | | | **Limit** |
| Boylama Aralığı (cm) 20 | 4.333 | 5.444 | 6.556 | 7.667 | 8.778 | 9.889 | 13.09 |
| 25 | 6.771 | 8.507 | 10.243 | 11.979 | 13.715 | 15.451 | |
| 30 | 9.750 | 12.250 | 14.750 | 17.250 | 19.750 | 22.250 | |
| 35 | 13.271 | 16.674 | 20.076 | 23.479 | 26.882 | 30.285 | |
| 40 | 17.333 | 21.778 | 26.222 | 30.667 | 35.111 | 39.556 | |
| Kıvam: K3 | | | | | | | |
| Boylama Aralığı (cm) 20 | 5.111 | 6.667 | 8.222 | 9.778 | 11.333 | 12.889 | |
| 25 | 7.986 | 10.417 | 12.847 | 15.278 | 17.708 | 20.139 | |
| 30 | 11.500 | 15.000 | 18.500 | 22.000 | 25.500 | 29.000 | |
| 35 | 15.653 | 20.417 | 25.181 | 29.944 | 34.708 | 39.472 | |
| 40 | 20.444 | 26.667 | 32.889 | 39.111 | 45.333 | 51.556 | |

Fresh concrete pressure values have been calculated according to DIN-18218.

Fresh concrete pressure values are independent of casting height.

Maximum pressure on the walls should not exceed 80 kN/m².

Maximum pressure on the columns should not exceed 100 kN/m².

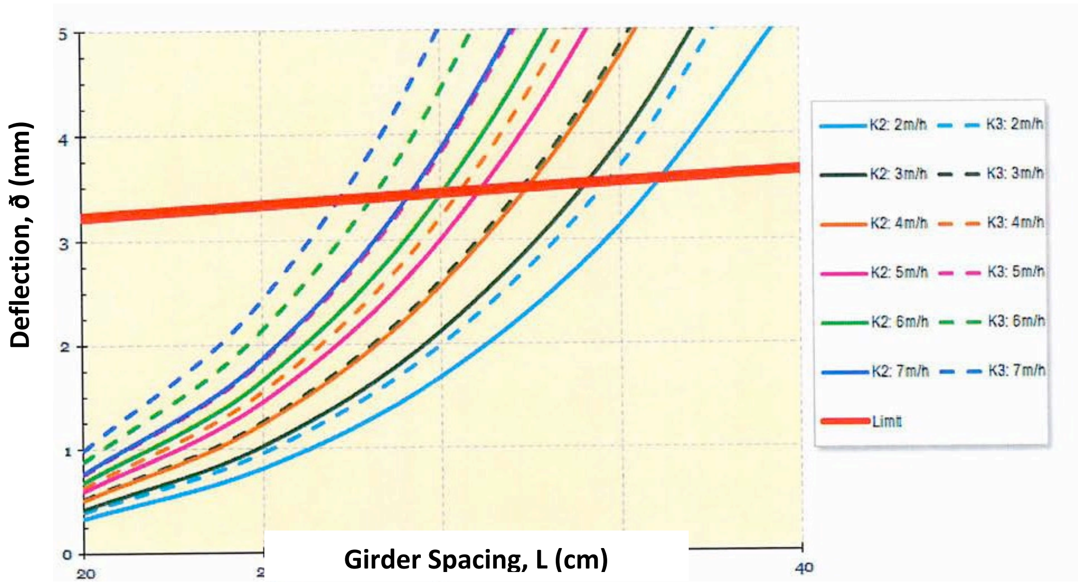


**Figure E.** Deflection diagrams for EKOPLAK strong section in multi span vertical application

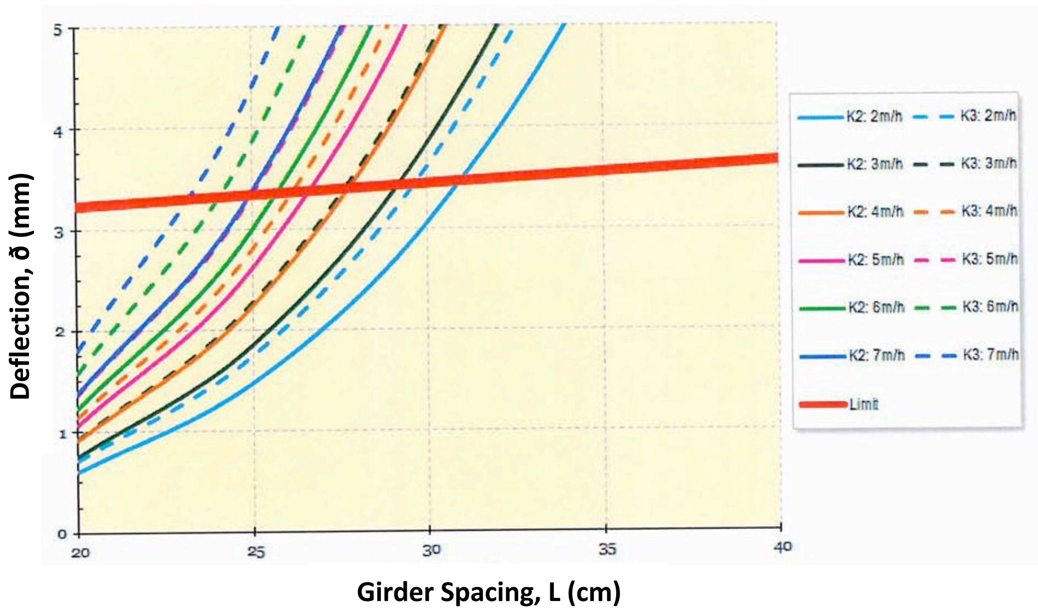


**Figure F.** Deflection diagrams for EKOPLAK weak section in multi span vertical application