

# FRC Precast Segmental Lining of TBM Tunnels

SFRC segment production for II metro line in Warsaw  
Bartłomiej Dziuban – Gulermak S.A.

27/05/2025





**Bartłomiej Dziuban**

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## EXPERIENCE



### **Gülermak S.A.**

TBM Manager  
2024 - Present

Warsaw, Poland



### **Tunnelconsult Engineering SL**

Design Site Engineer  
2023 - 2024

Cracow, Poland



### **PBDiM Sp. z o.o**

Tunnel Works Manager  
2021 - 2023

Łódź, Poland



### **Gülermak S.A.**

TBM Site Engineer  
2019 - 2021

Warsaw, Poland



### **WSP USA**

Geotechnical Engineer  
2017- 2018

New York, NY

## EDUCATION



Columbia University

Graduate Degree



Gdańsk University of Technology

Undergraduate Degree

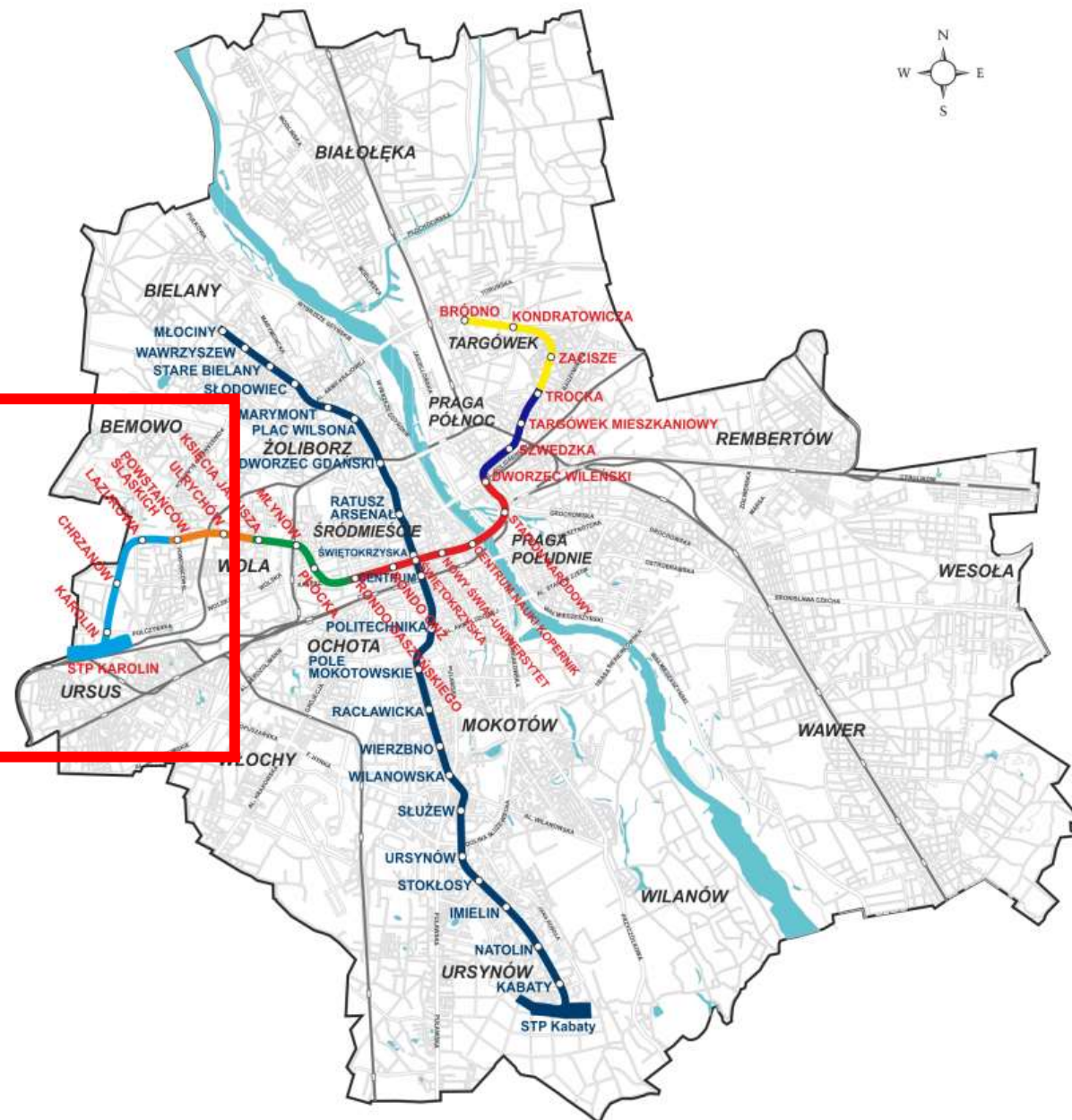


Universitat Politècnica de Catalunya

Undergraduate Degree

## C01 – C04

Left tunel            2854.5m  
Right Tunnel        2833.5m



### Earth Pressure Balance TBM S-645, S-646

|                     |                                                     |
|---------------------|-----------------------------------------------------|
| <b>Diameter</b>     | Ø 6270 mm                                           |
| <b>Manufacturer</b> | Herrenknecht                                        |
| <b>Year</b>         | 2011                                                |
| <b>Length</b>       | 95m                                                 |
| <b>Weight</b>       | 620 t (total)<br>400 t (shield)<br>220 t (gantries) |



# SFRC SEGMENT PRODUCTION

*How to replace RC with SFRC?*



## RC recipe

| Components | Quantity [kg/m³] |
|------------|------------------|
| Cement     | 400              |

- Maximum aggregate size: 16mm
- Exposure class: XC4 XD3 XF1 AX1
- Water resistance (class): W8
- Max w/c ratio: 0,4

## SFRC recipe

| Components | Quantity [kg/m³] |
|------------|------------------|
| Cement     | 410              |

- Maximum aggregate size: 16mm
- Exposure class: XC4 XD3 XF1 AX1
- Water resistance (class): W8
- Max w/c ratio: 0,4



### Bekaert Dramix 4D 80/60BG

|                  |              |
|------------------|--------------|
| Length           | 60 mm        |
| Diameter         | 0.75mm       |
| Tensile strength | 1 800 N/mm2  |
| Young's Modulus  | 210 000 N/m2 |
| Dosage           | 40 kg/m³     |

C40/50



C50/60

### „Small-scale” tests:

- Compressive Strength Test
- Tensile Splitting Strength Test
- Characteristic Residual Flexural Strength Test

*PN-EN 12390*

*PN-EN 12390*

*PN-EN 14651*

### „Real-scale” tests:

- Fire test
- Bending test
- Point load test

*RABT-ZTV 120*

*Tunnel Designer specification*

*Tunnel Designer specification*

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*RABT-ZTV 120*

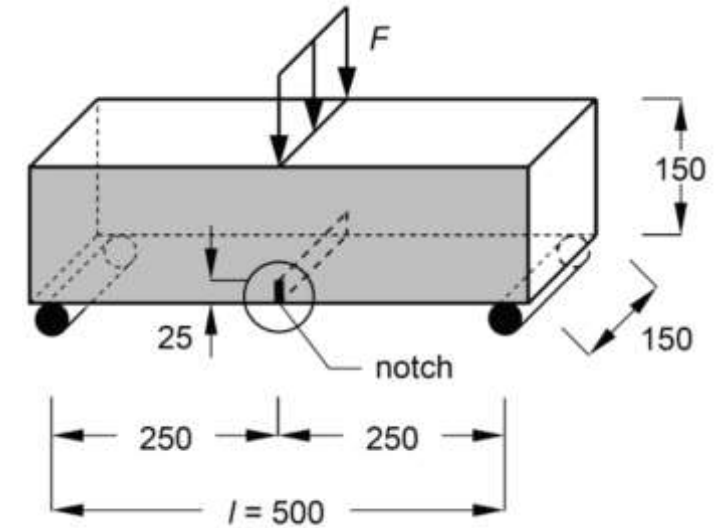
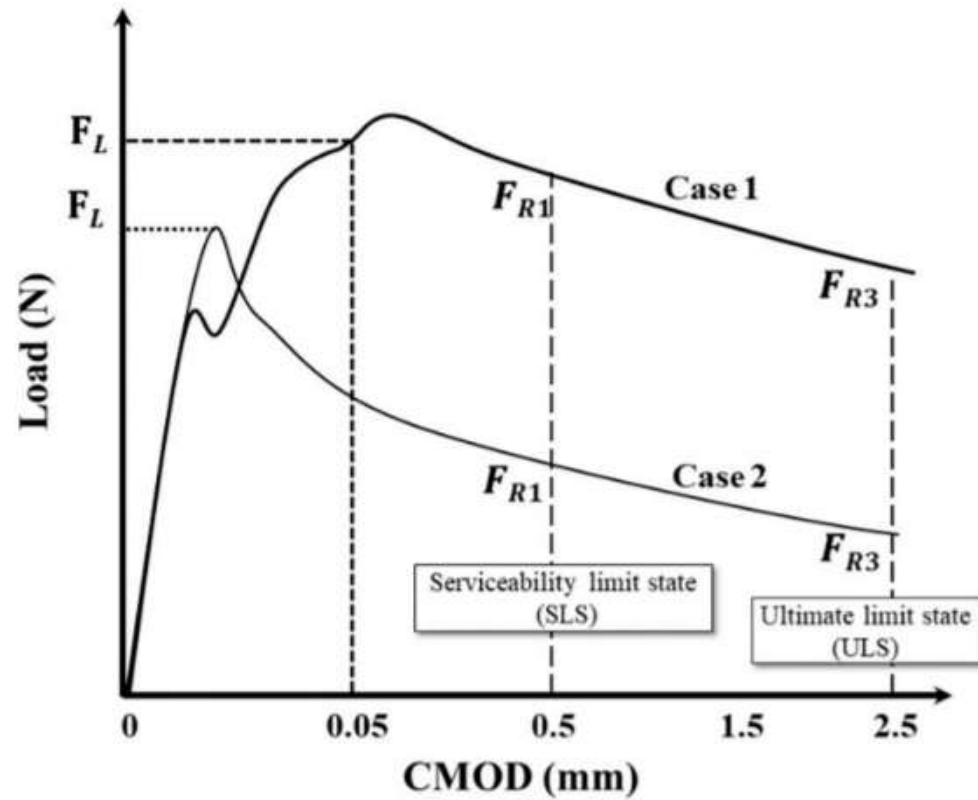
*Tunnel Designer specification*

*Tunnel Designer specification*

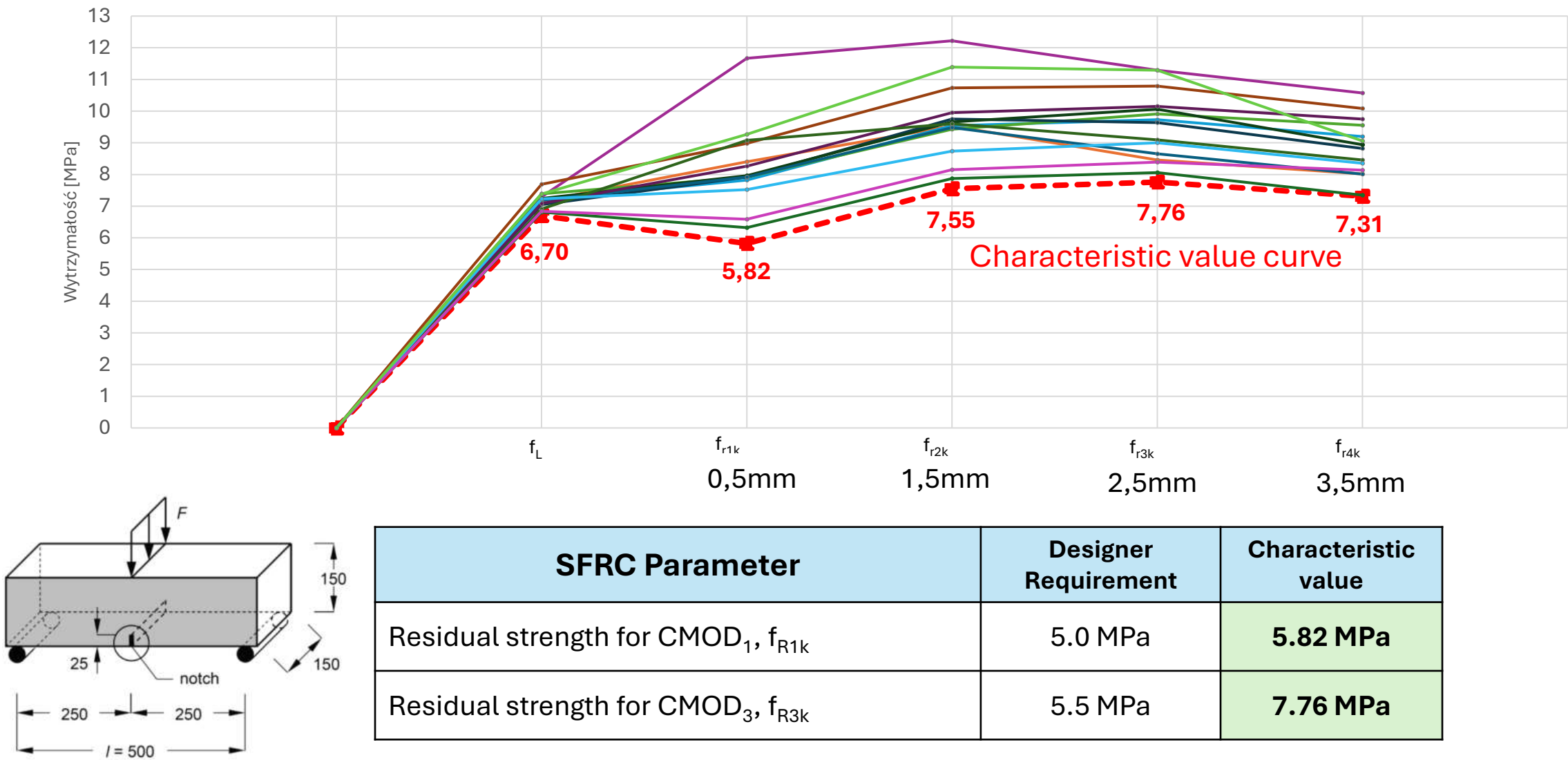
### Characteristic Residual Flexural Strength Test PN-EN 14651

Carried out by: ITB Warszawa

Number of samples: 15



Characteristic Residual Flexural Strength Test PN-EN 14651 – results



### „Small-scale” tests:

- Compressive Strength Test
- Tensile Splitting Strength Test
- Characteristic Residual Flexural Strength Test

*PN-EN 12390*

*PN-EN 12390*

*PN-EN 14651*

### „Real-scale” tests:

- **Fire test**
- Bending test
- Point load test

***RABT-ZTV 120***

*Tunnel Designer specification*

*Tunnel Designer specification*

### Carried out by:

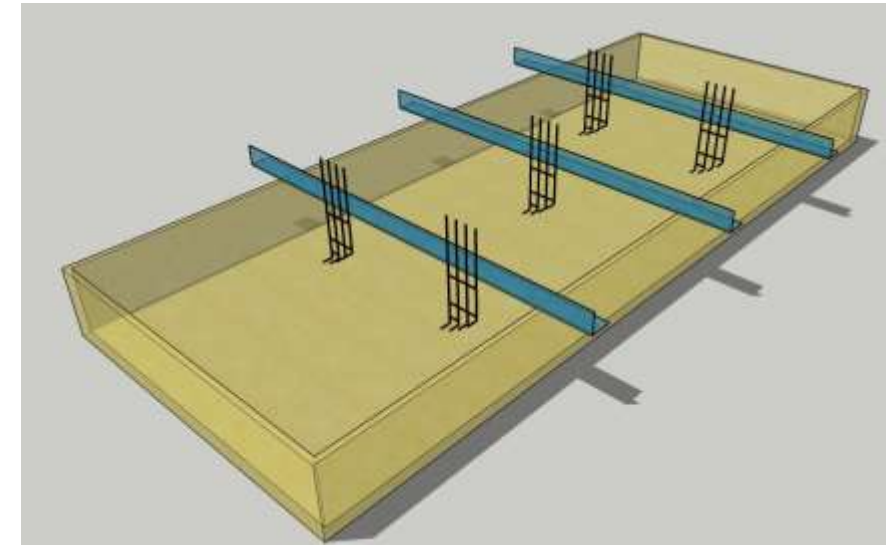
ITB Pionki – Fire testing department; fire testing lab

### Technical data:

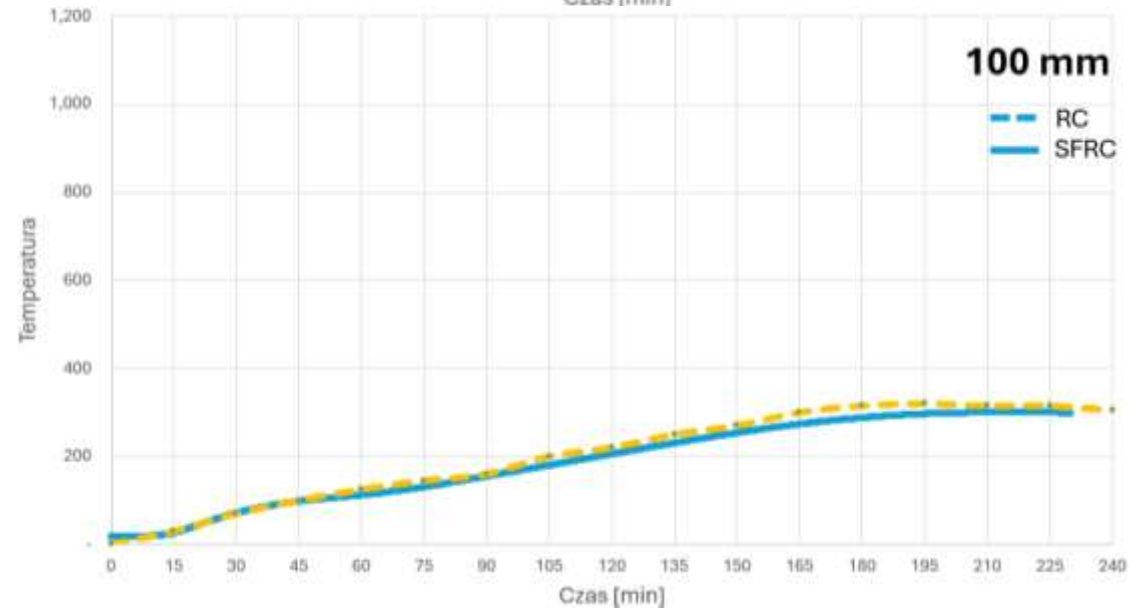
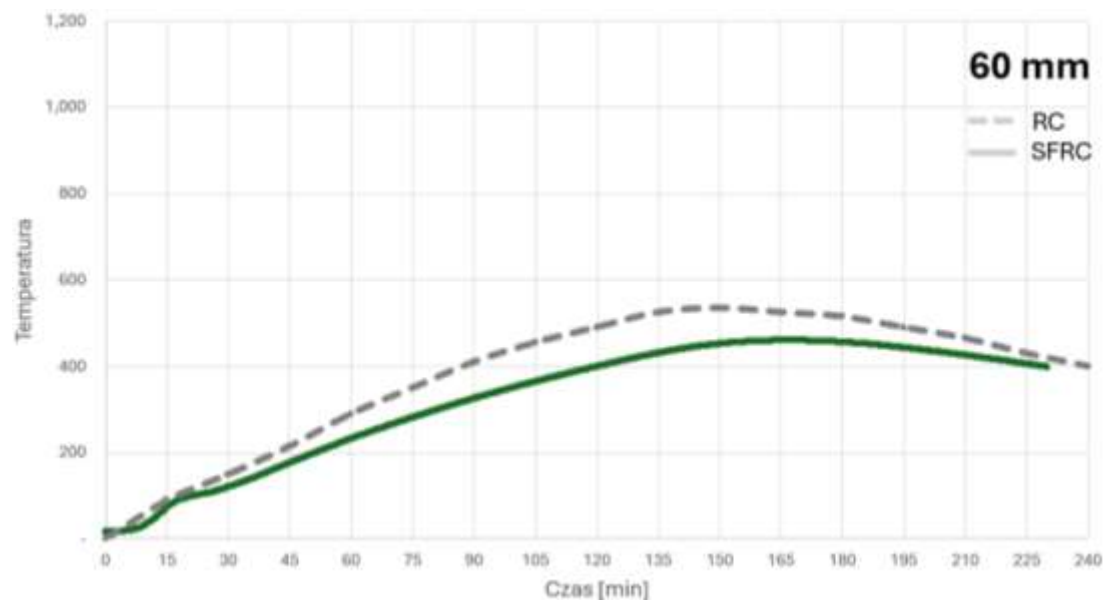
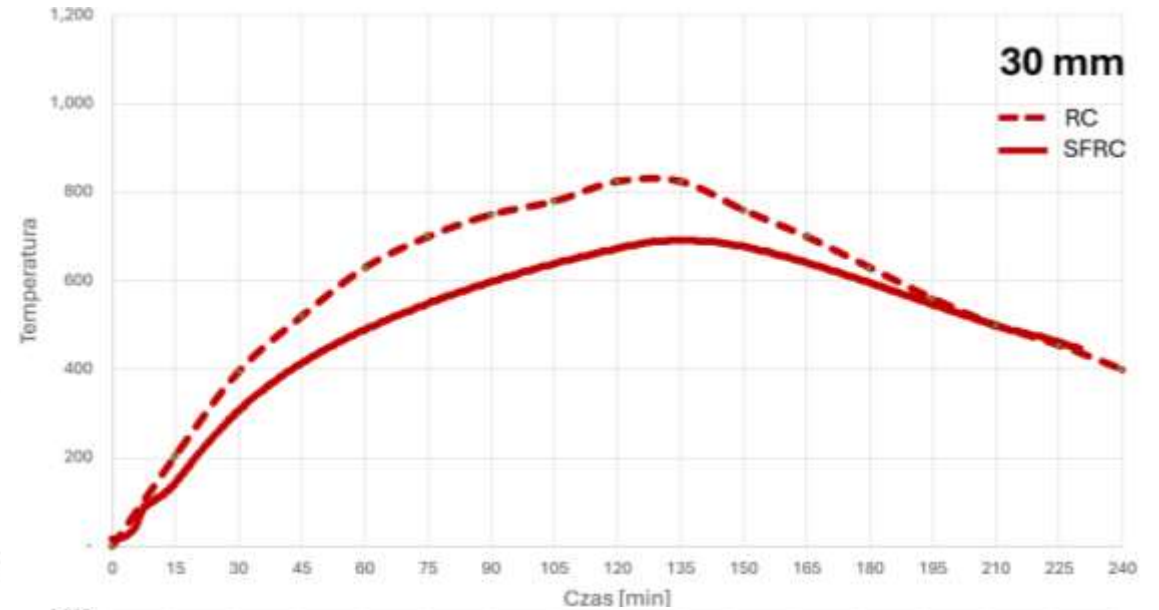
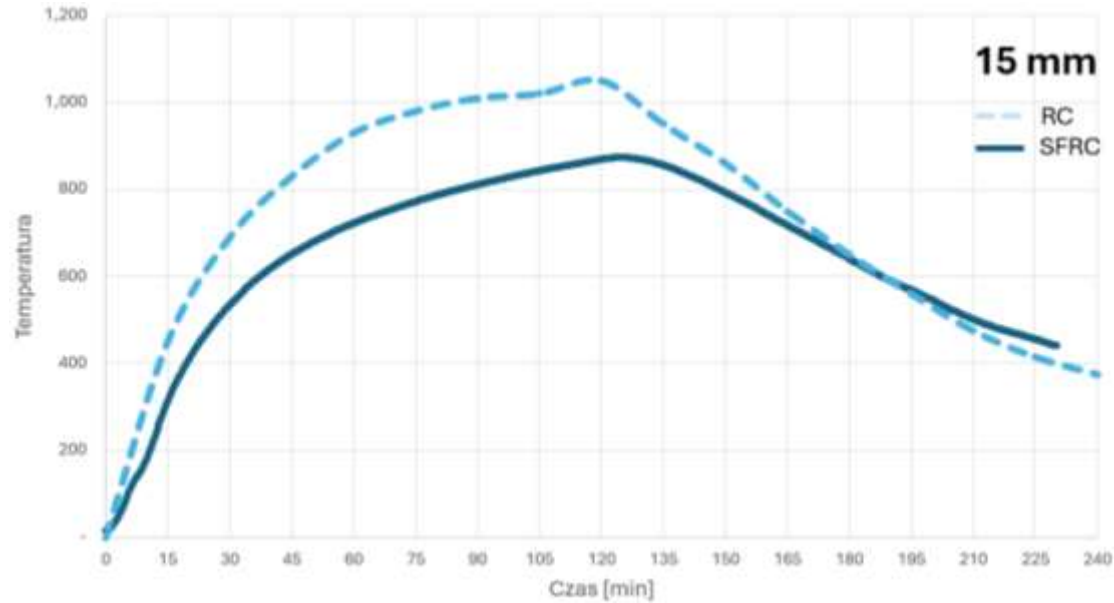
- Thermocouples 15mm, 30mm, 60mm, 100mm
- Dosage 40 kg/m<sup>3</sup> Bekaert Dramix 4 D 80/60 BG
- Seasoning 3 months
- Dimensions 3900mm x 1500mm x 300mm

### Test:

- RABT-ZTV 120 curve – 120 min of heating + 110 min of cooling
- Temperature - +1200°C



# SFRC TESTING PROGRAM – FIRE TEST



**Traditional segment (RC)**



**Average value of concrete spalling – 13 mm**

**vs.**

**Segment with fibers (SFRC)**



**No concrete spalling was observed**

### „Small-scale” tests:

- Compressive Strength Test
- Tensile Splitting Strength Test
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*PN-EN 12390*

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*PN-EN 14651*

### „Real-scale” tests:

- Fire test
- **Bending test**
- Point load test

*RABT-ZTV 120*

***Tunnel Designer specification***

*Tunnel Designer specification*

# SFRC TESTING PROGRAM – BENDING TEST

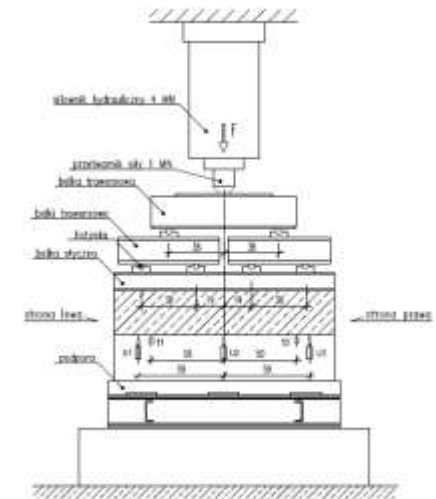
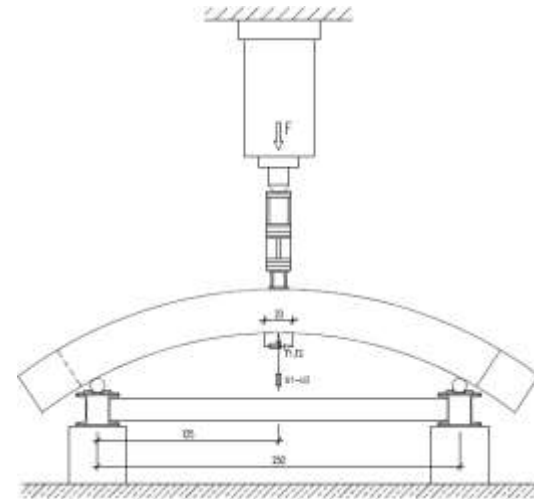
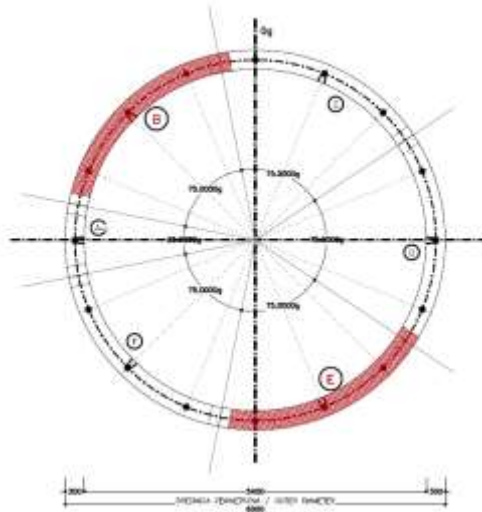
Carried out by:

Road and Bridge Research Institute in Kielce (IBDiM)

Technical data:

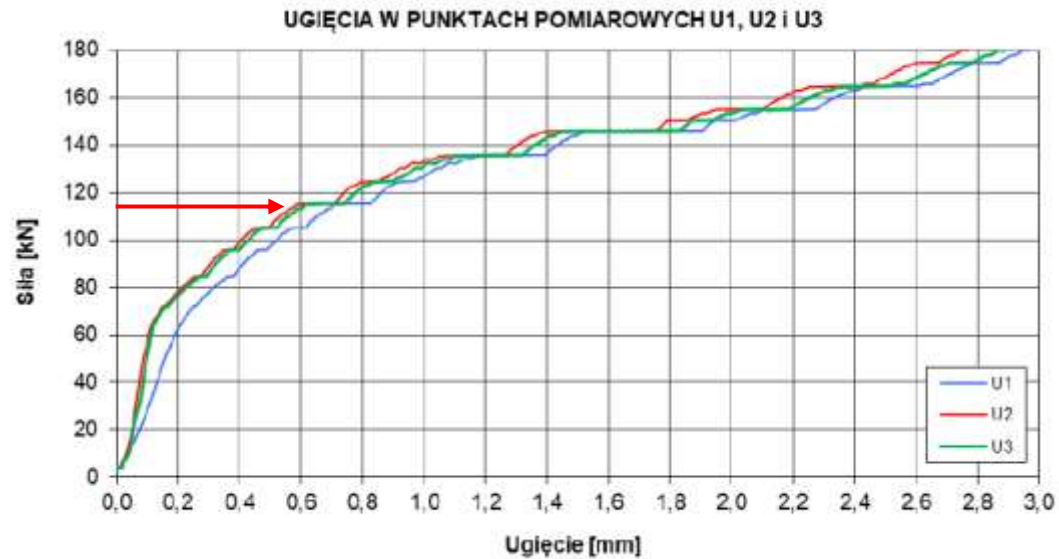
- Tested segments B, E
- Actuator max. 1000 kN

PRZEKRÓJ POPRZECZNY / CROSS SECTION



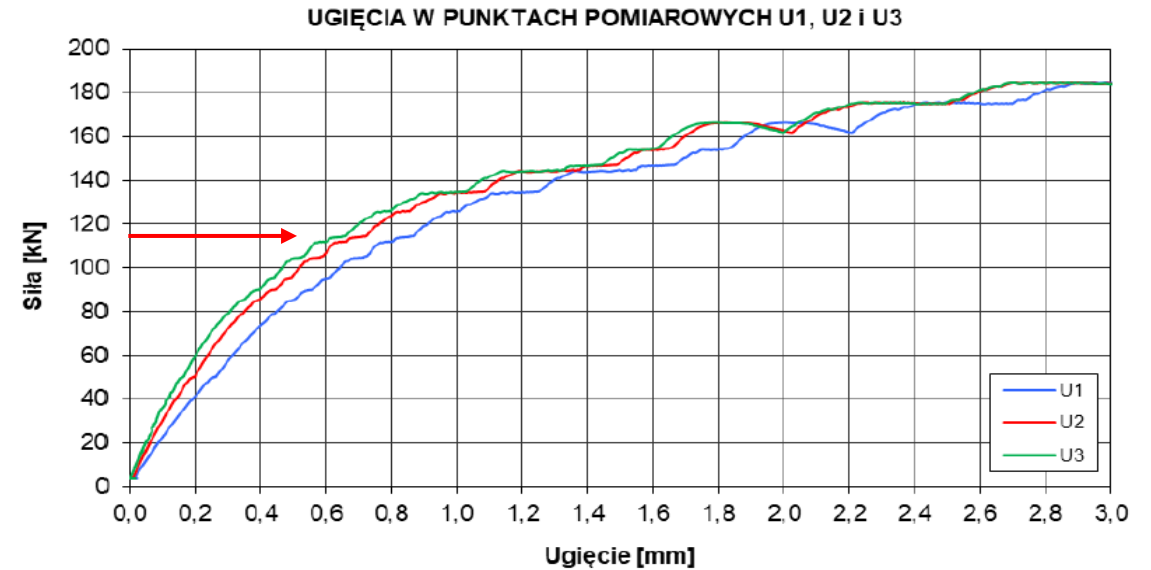
## TRADITIONAL REINFORCED CONCRETE SEGMENT

Segment B  
deflections at measurement points  
load/deflection

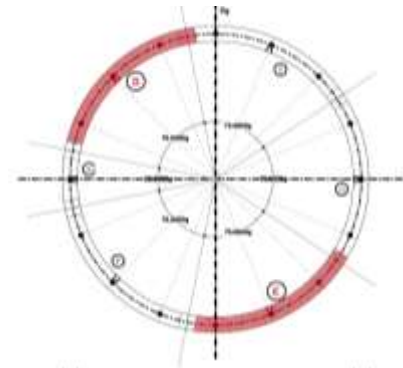


**First crack**      **115 kN**

Segment E  
deflections at measurement points  
load/deflection



**First crack**      **115 kN**



Segment B  
deflections at measurement points  
load/deflection

### TRADITIONAL REINFORCED CONCRETE SEGMENT

Segment E  
deflections at measurement points  
load/deflection



Fot. 6 Segment B - pierwsza powstająca rysa nr 1 przy sile 115 kN

**First crack**      **115 kN**

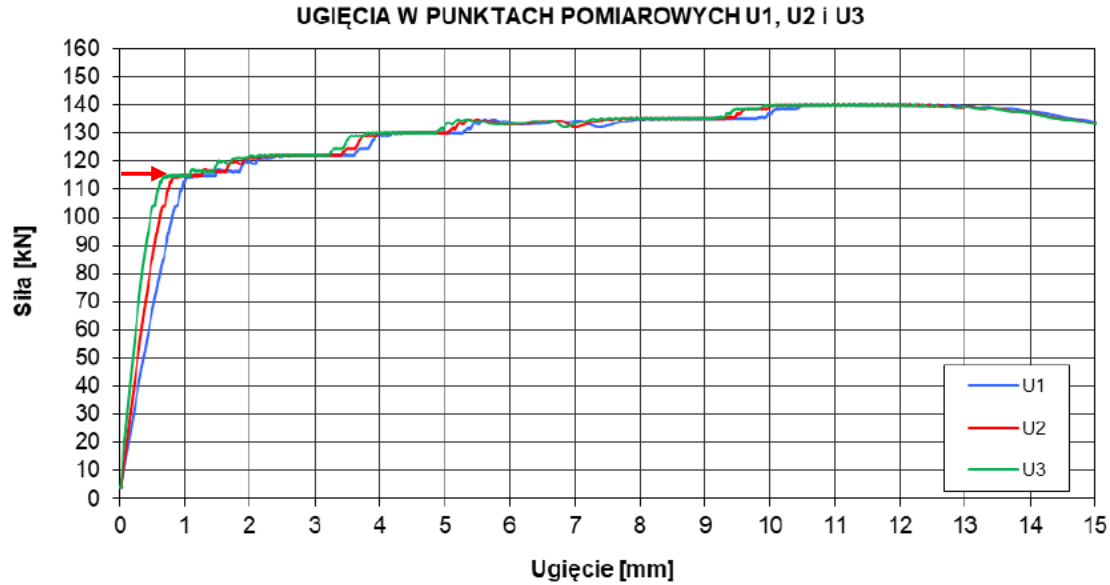


Fot. 13 Segment E - pierwsza powstająca rysa nr 1 przy sile 115 kN

**First crack**      **115 kN**

## SFRC SEGMENTS

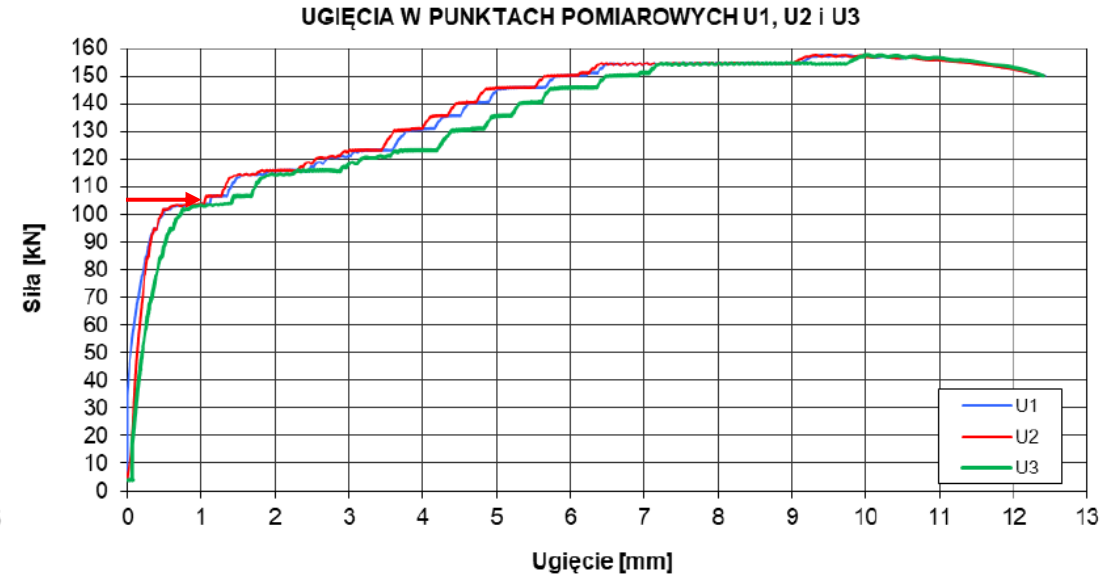
Segment B  
deflections at measurement points  
load/deflection



**First crack**

**115 kN**

Segment E  
deflections at measurement points  
load/deflection



**First crack**

**104 kN**



### SFRC SEGMENTS

Segment B  
deflections at measurement points  
load/deflection



Fot. 6 Segment B - pierwsza powstająca rysa nr 1 przy sile 115 kN

**First crack**

**115 kN**

Segment E  
deflections at measurement points  
load/deflection



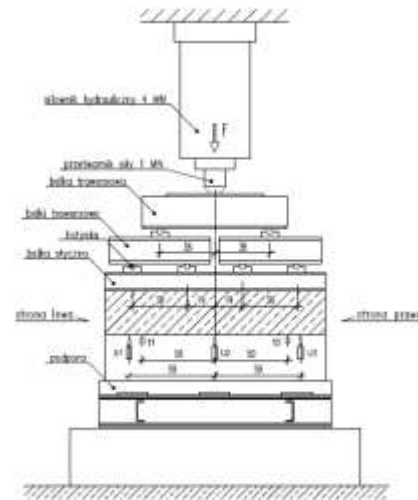
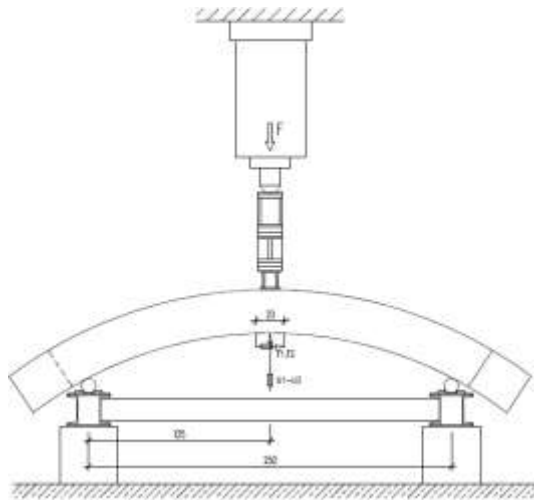
Fot. 12 Segment E - pierwsze powstające rysy nr 1 i nr 2 przy sile 104 kN

**First crack**

**104 kN**

## FIRST CRACK MEASUREMENT

|           | REINFORCED<br>CONCRETE | STEEL-FIBRE<br>REINFORCED<br>CONCRETE |
|-----------|------------------------|---------------------------------------|
| Segment B | 115 kN                 | 115 kN                                |
| Segment E | 115 kN                 | 104 kN                                |



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*PN-EN 12390*

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- Fire test
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- **Point load test**

*RABT-ZTV 120*

*Tunnel Designer specification*

**Tunnel Designer specification**

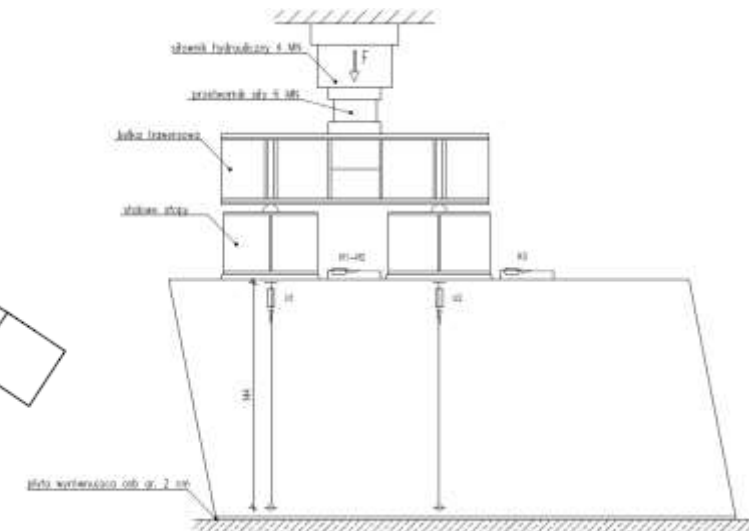
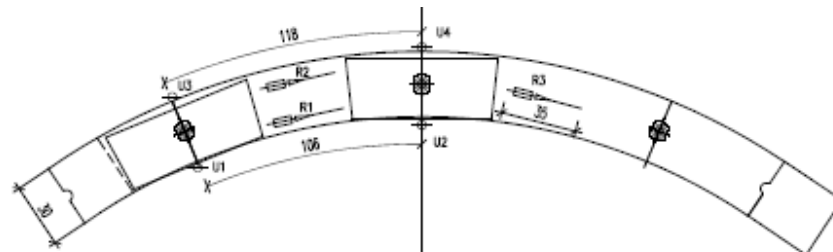
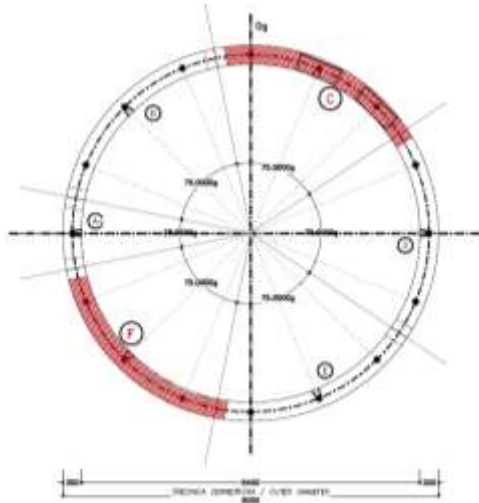
# SFRC TESTING PROGRAM – POINT LOAD TEST

## Carried out by:

Road and Bridge Research Institute in Kielce (IBDiM)

## Technical data:

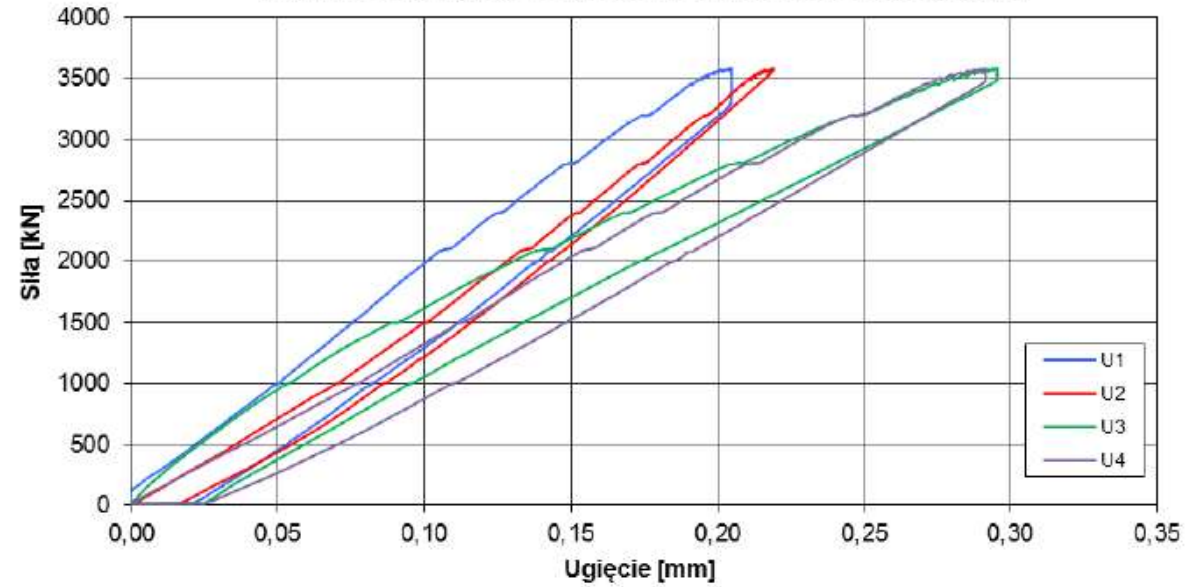
- Tested segments C, F
- Actuator max. 4000kN
- TBM Cylinder force max. 2800 kN



## SFRC SEGMENTS

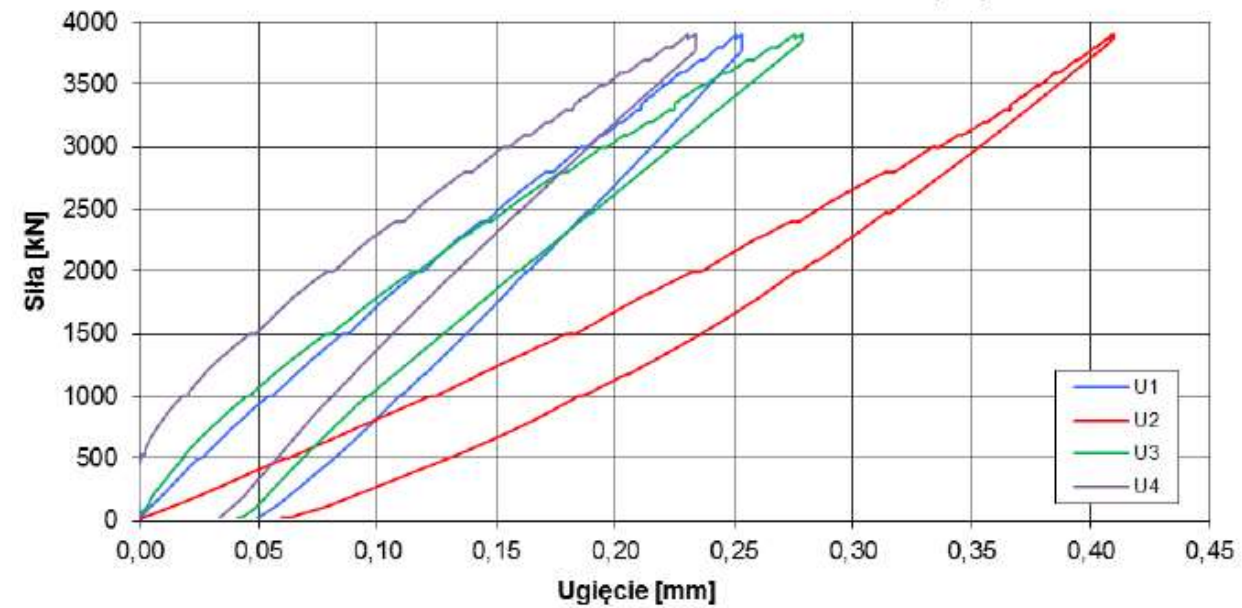
Segment F  
displacements at measurement  
points

PRZEMIESZCZENIA W PUNKTACH POMIAROWYCH U1, U2, U3 i U4



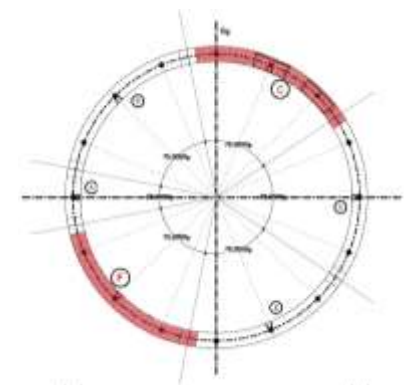
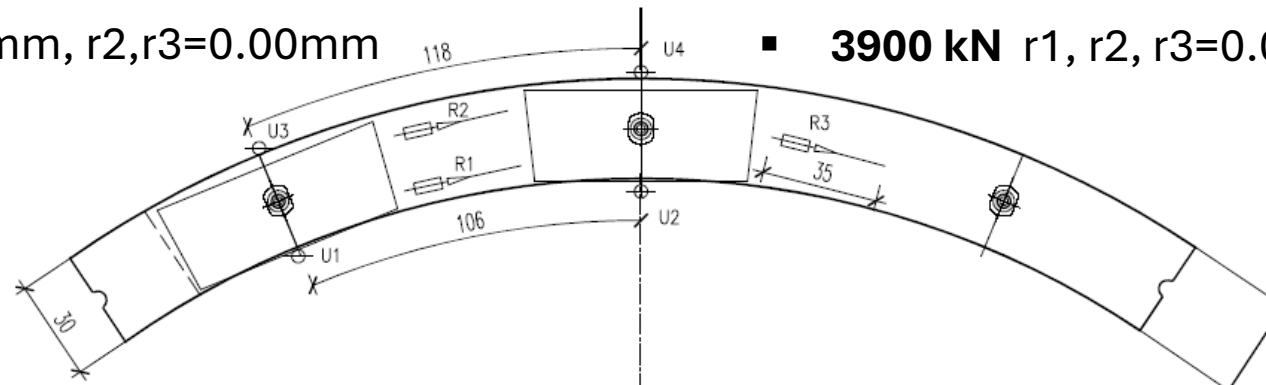
Segment C  
displacements at measurement  
points

PRZEMIESZCZENIA W PUNKTACH POMIAROWYCH U1, U2, U3 i U4

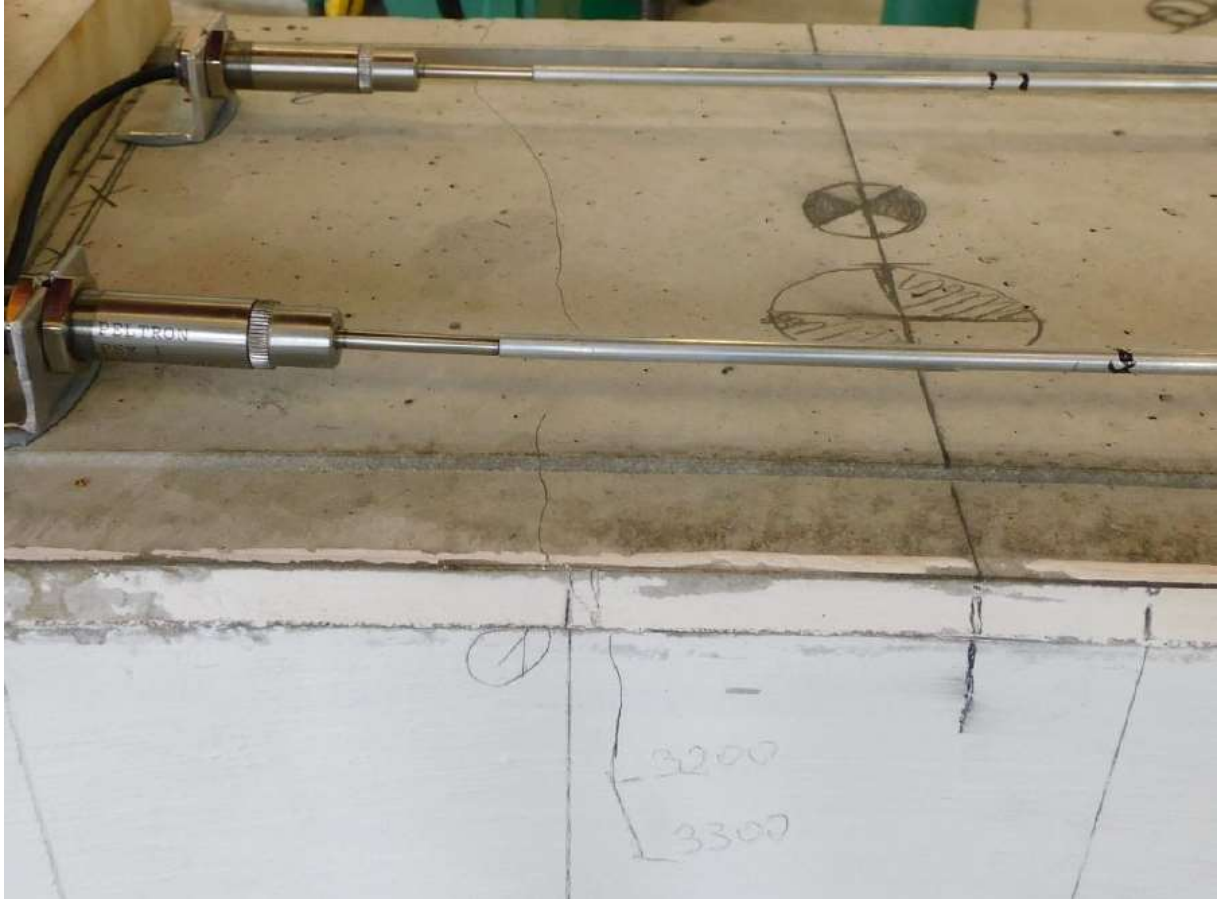


■ **3590 kN**  $r_1=0.120\text{mm}$ ,  $r_2, r_3=0.00\text{mm}$

■ **3900 kN**  $r_1, r_2, r_3=0.00\text{mm}$



### SFRC SEGMENTS



Segment F – crack r1 at the load of 3590 kN



Segment F – testing equipment

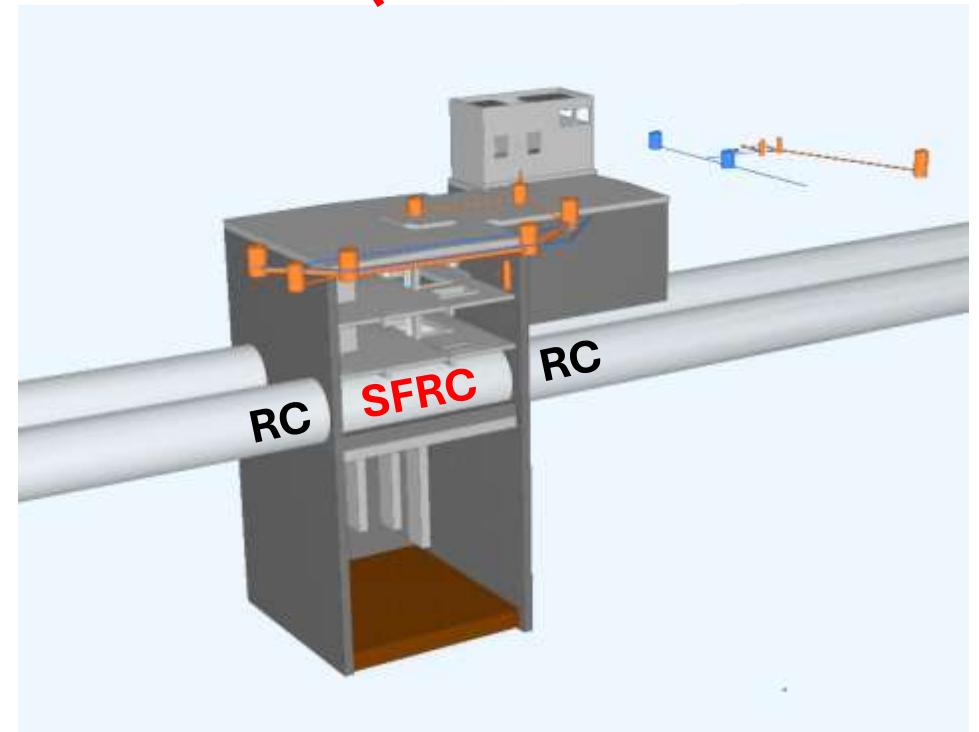
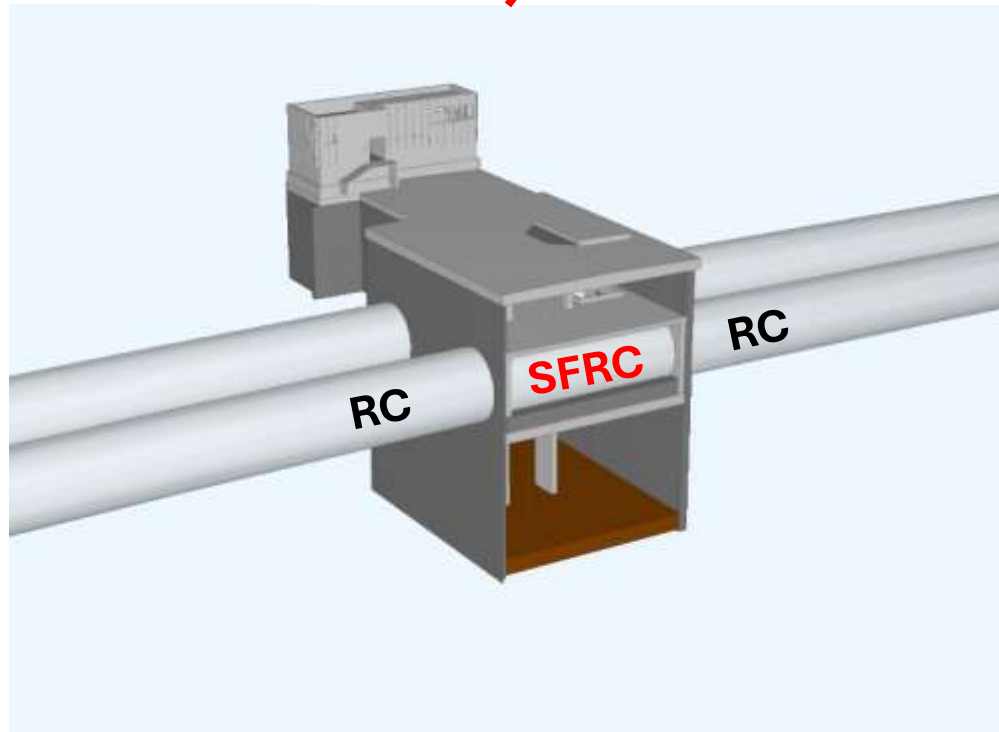
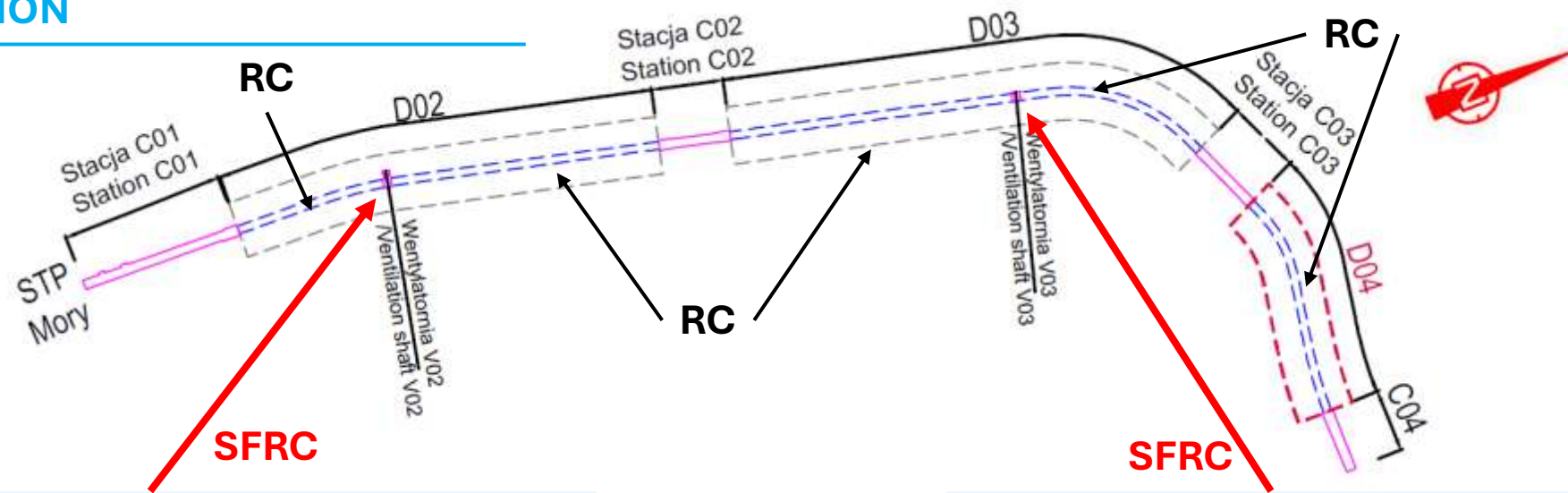
## SFRC TESTING PROGRAM – SUMMARY

| Parameter                                                                        | RC                        | SFRC                  |                              |
|----------------------------------------------------------------------------------|---------------------------|-----------------------|------------------------------|
| Small-scale                                                                      | Requirement               | Designer Requirements | Test results                 |
| Concrete class                                                                   | C40/50                    | C50/60                | <b>C50/60</b>                |
| Characteristic value for compressive strength, $f_{ck}$ , after 28 days          | 40 MPa                    | 50 MPa                | <b>55.60 MPa</b>             |
| Characteristic value for compressive strength, $f_{ck}$ , after 24 hours         | 12 MPa                    | 20 MPa                | <b>31.92 MPa</b>             |
| Characteristic value for tensile splitting strength, $f_{ct,sp}$ , after 28 days | -                         | 3.2 MPa               | <b>4.94 MPa</b>              |
| Residual strength for $CMOD_1$ , $f_{R1k}$                                       | -                         | 5.0 MPa               | <b>5.82 MPa</b>              |
| Residual strength for $CMOD_3$ , $f_{R3k}$                                       | -                         | 5.5 MPa               | <b>7.76 MPa</b>              |
| Real-scale                                                                       | Results                   | Results               |                              |
| Bending test (first crack)                                                       | 115 kN & 115 kN           | -                     | <b>115 kN &amp; 104 kN</b>   |
| Point load test (first crack)                                                    | -                         | -                     | <b>3590 kN &amp; 3900 kN</b> |
| Fire test                                                                        | 13 mm (concrete spalling) | -                     | <b>None</b>                  |

# SEGMENT PRODUCTION RC + SFRC



# SFRC APPLICATION



RING TYPE

OUTER DIAMETER

INNER DIAMETER

THICKNESS

LENGTH

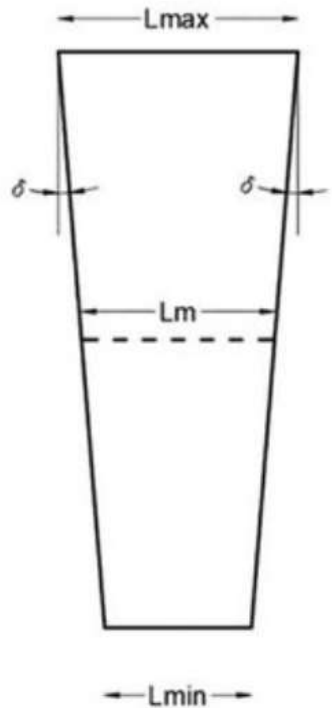
UNIVERSAL (5+1)

6000 mm

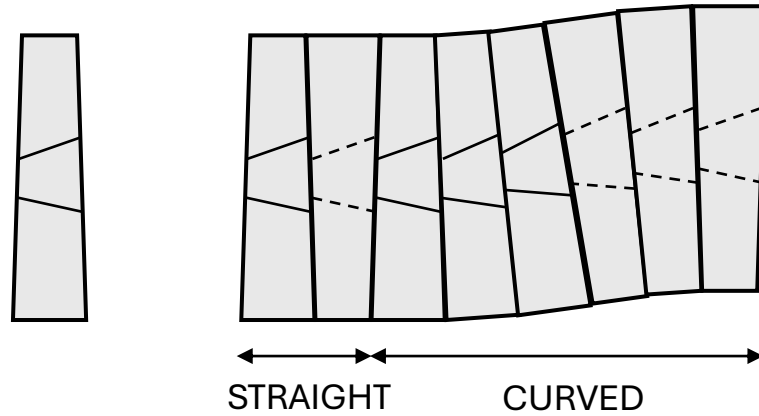
5400 mm

300 mm

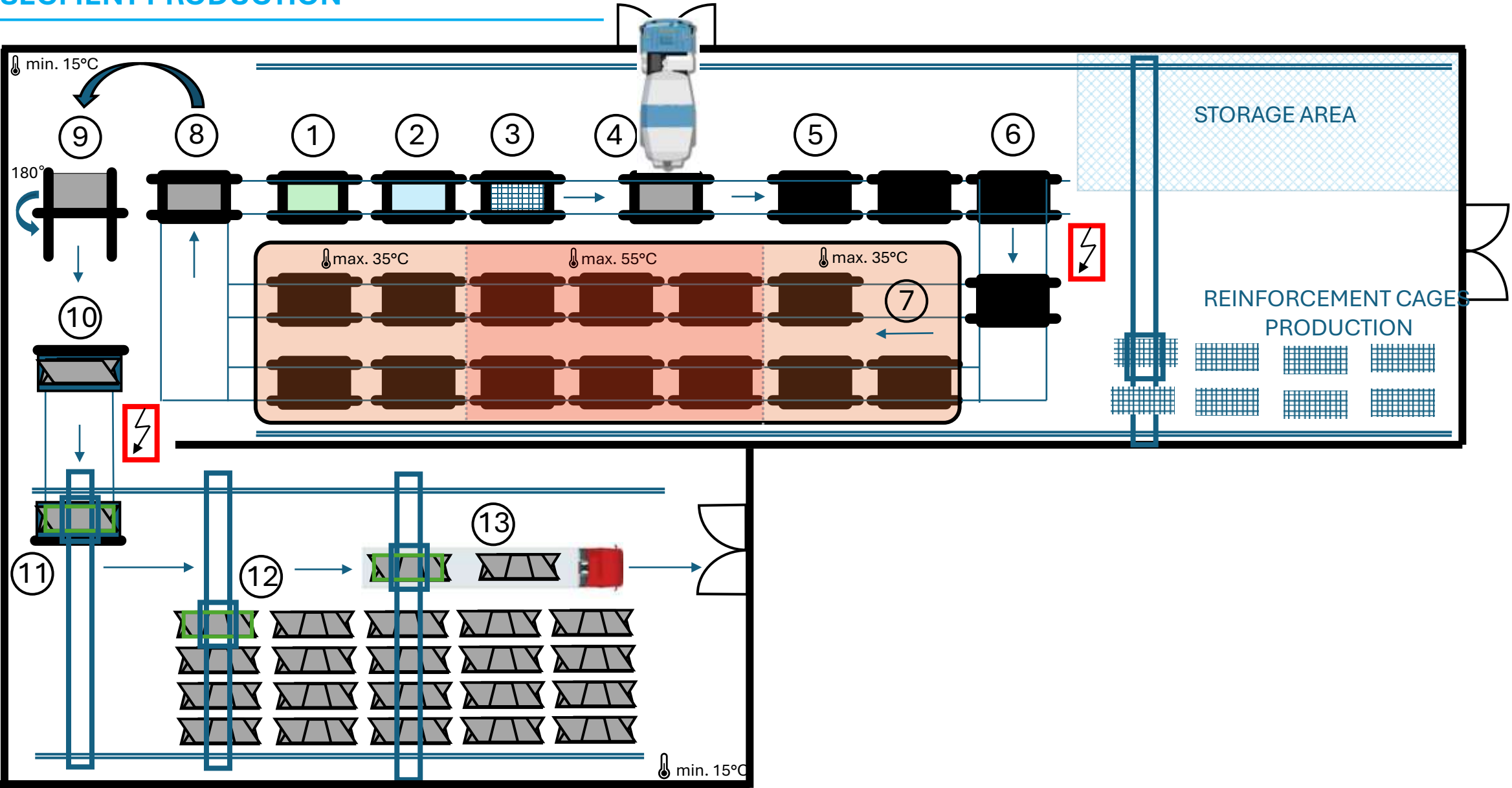
1500mm (1475mm – 1525mm)



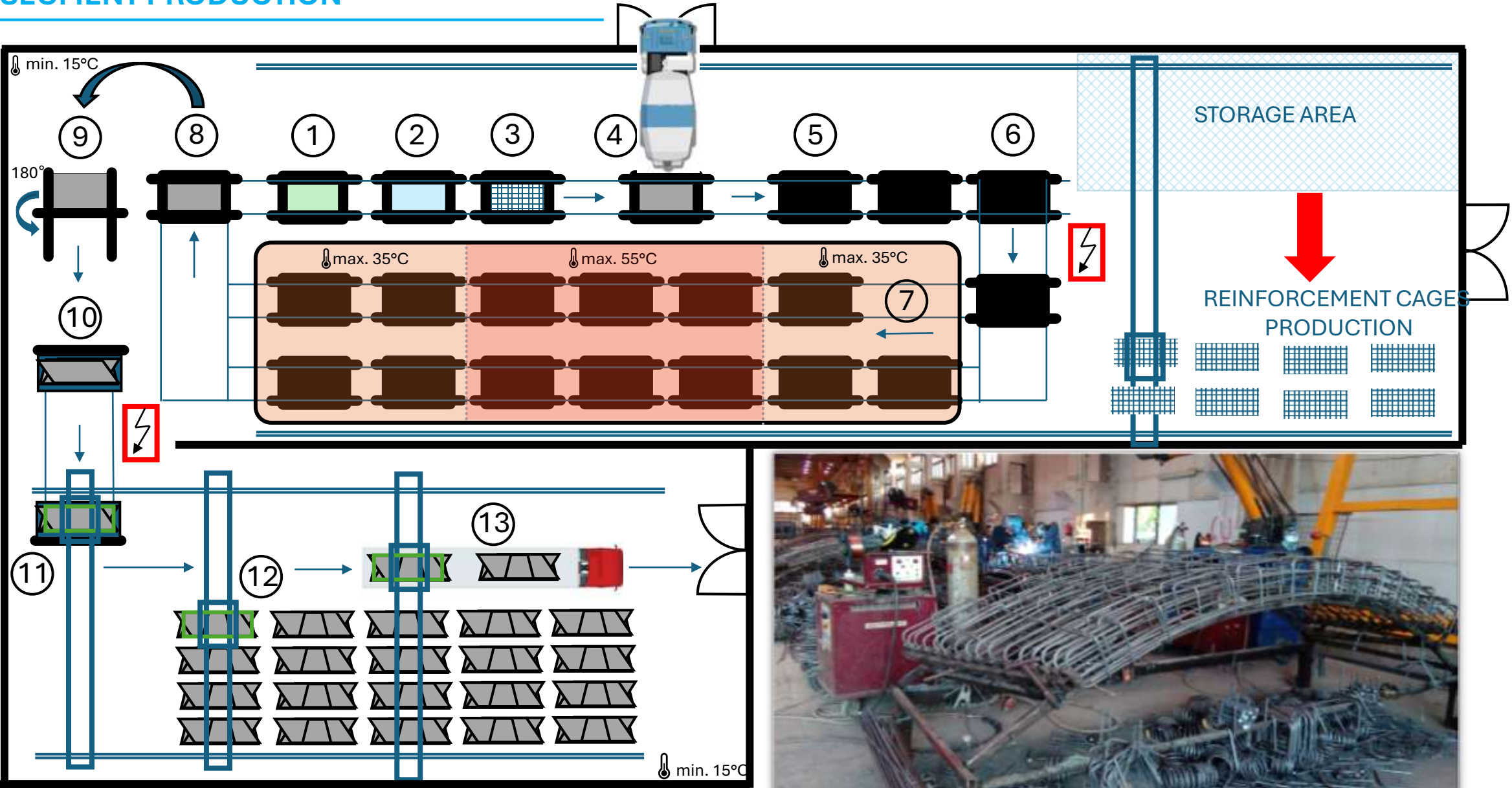
### UNIVERSAL RINGS



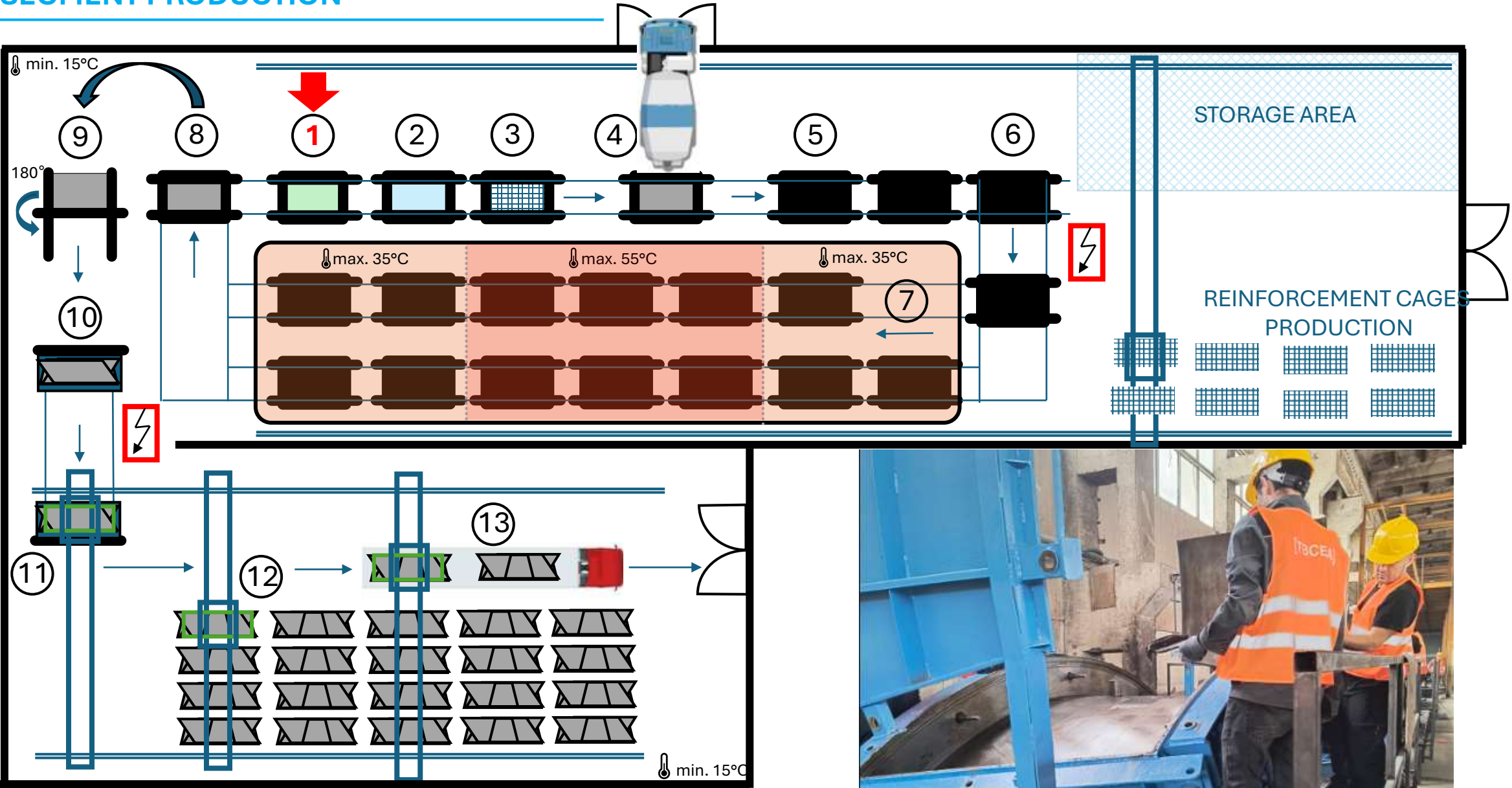
SEGMENT PRODUCTION



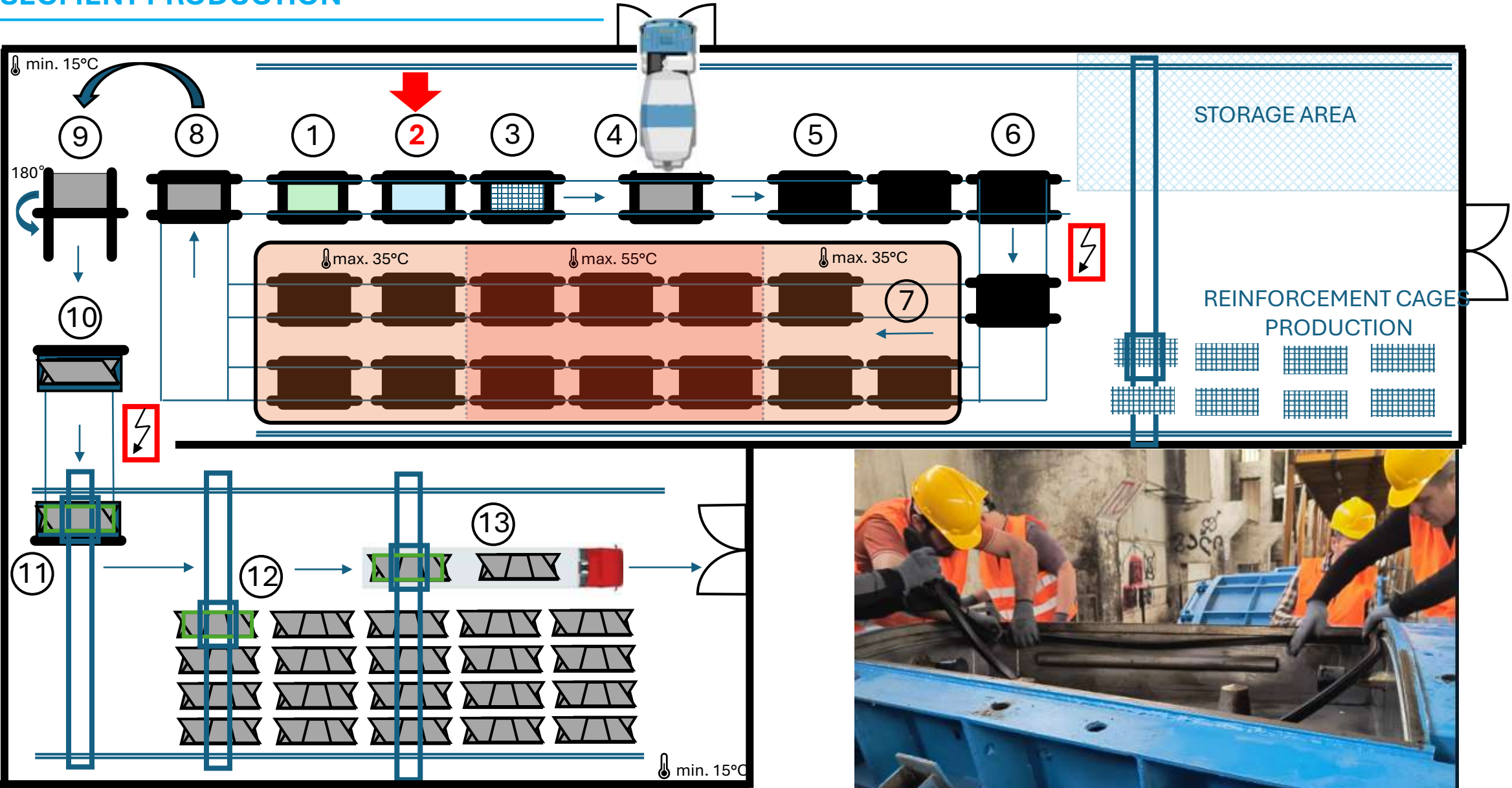
SEGMENT PRODUCTION



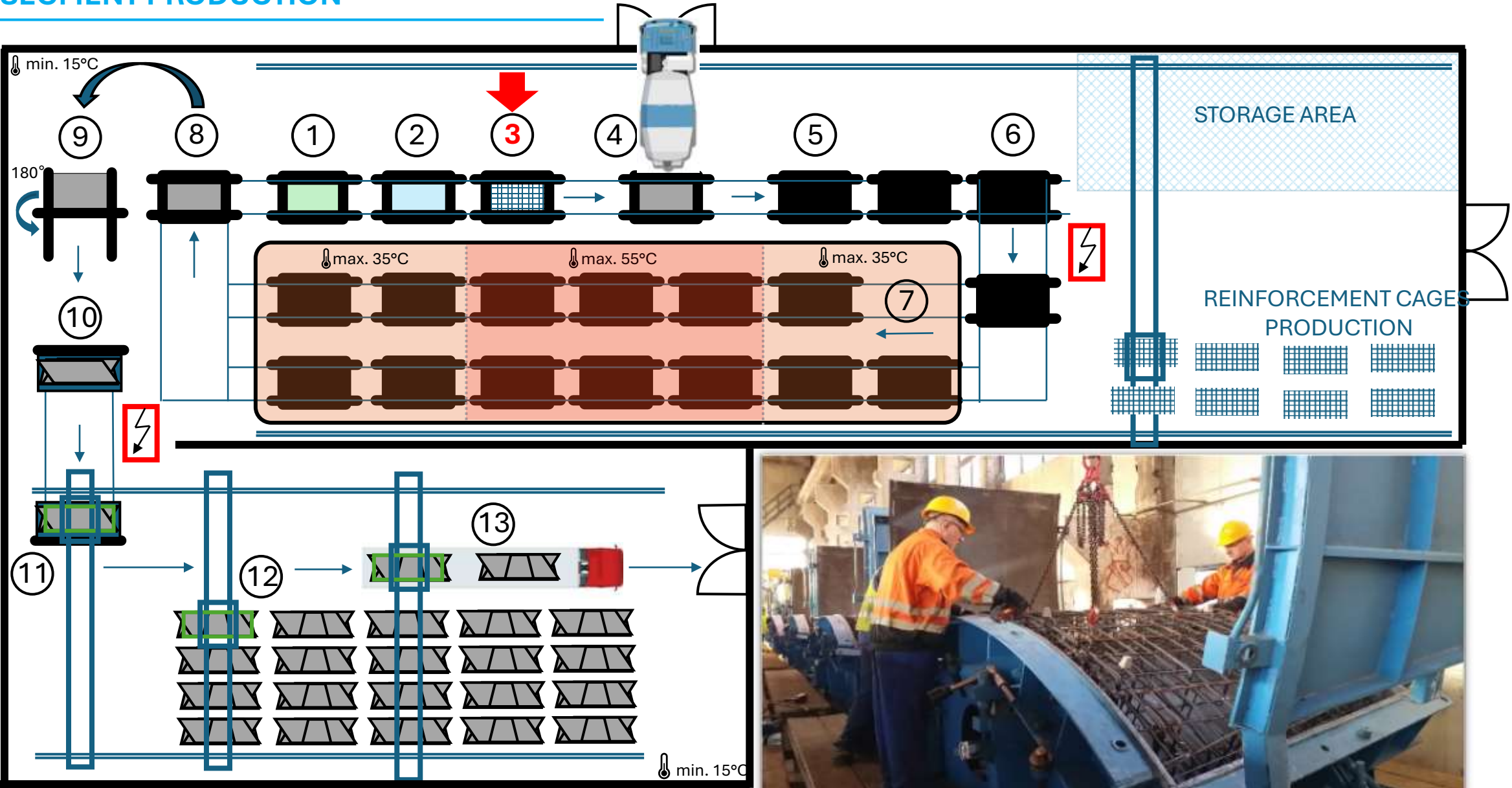
SEGMENT PRODUCTION



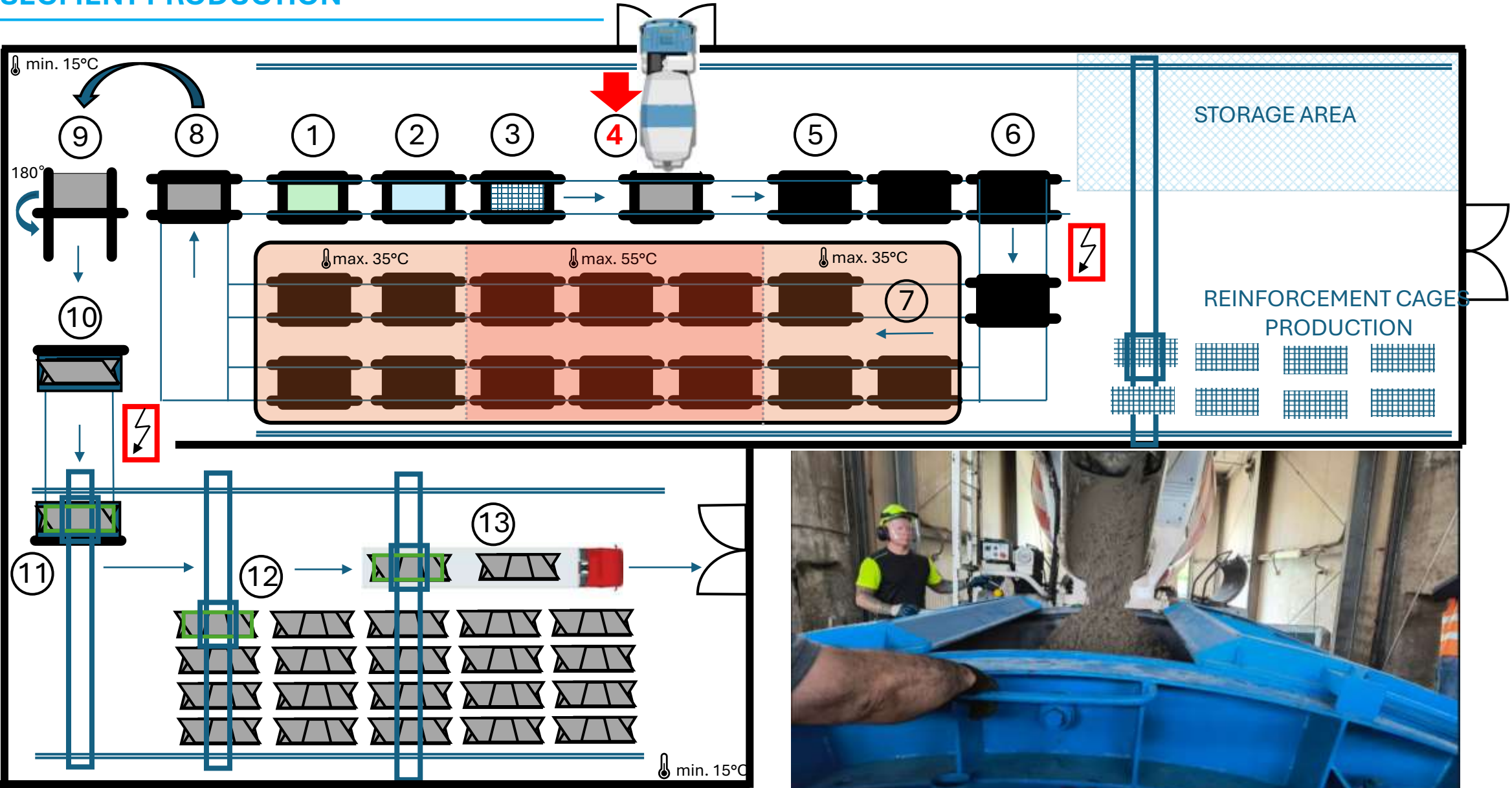
SEGMENT PRODUCTION



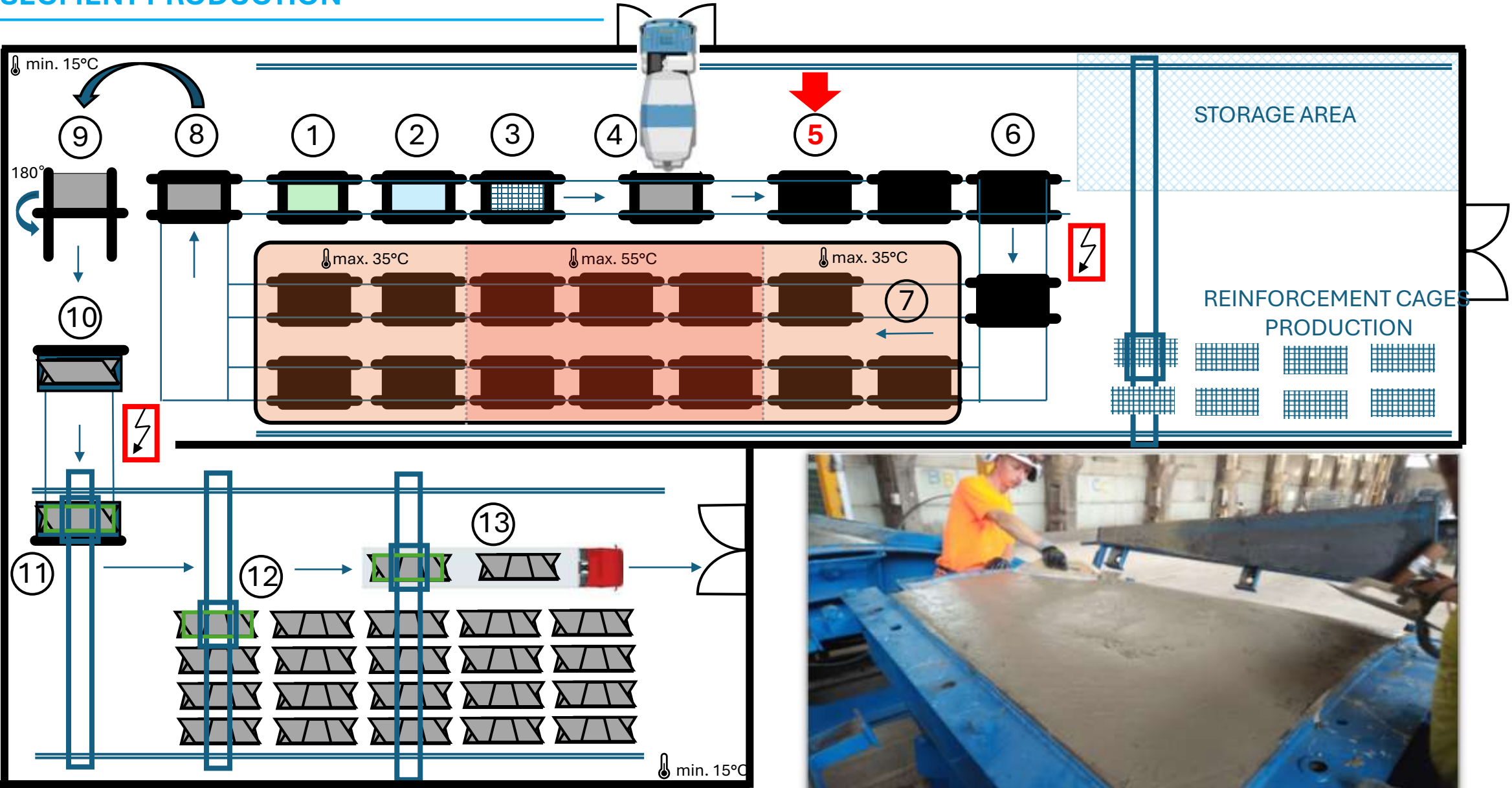
SEGMENT PRODUCTION



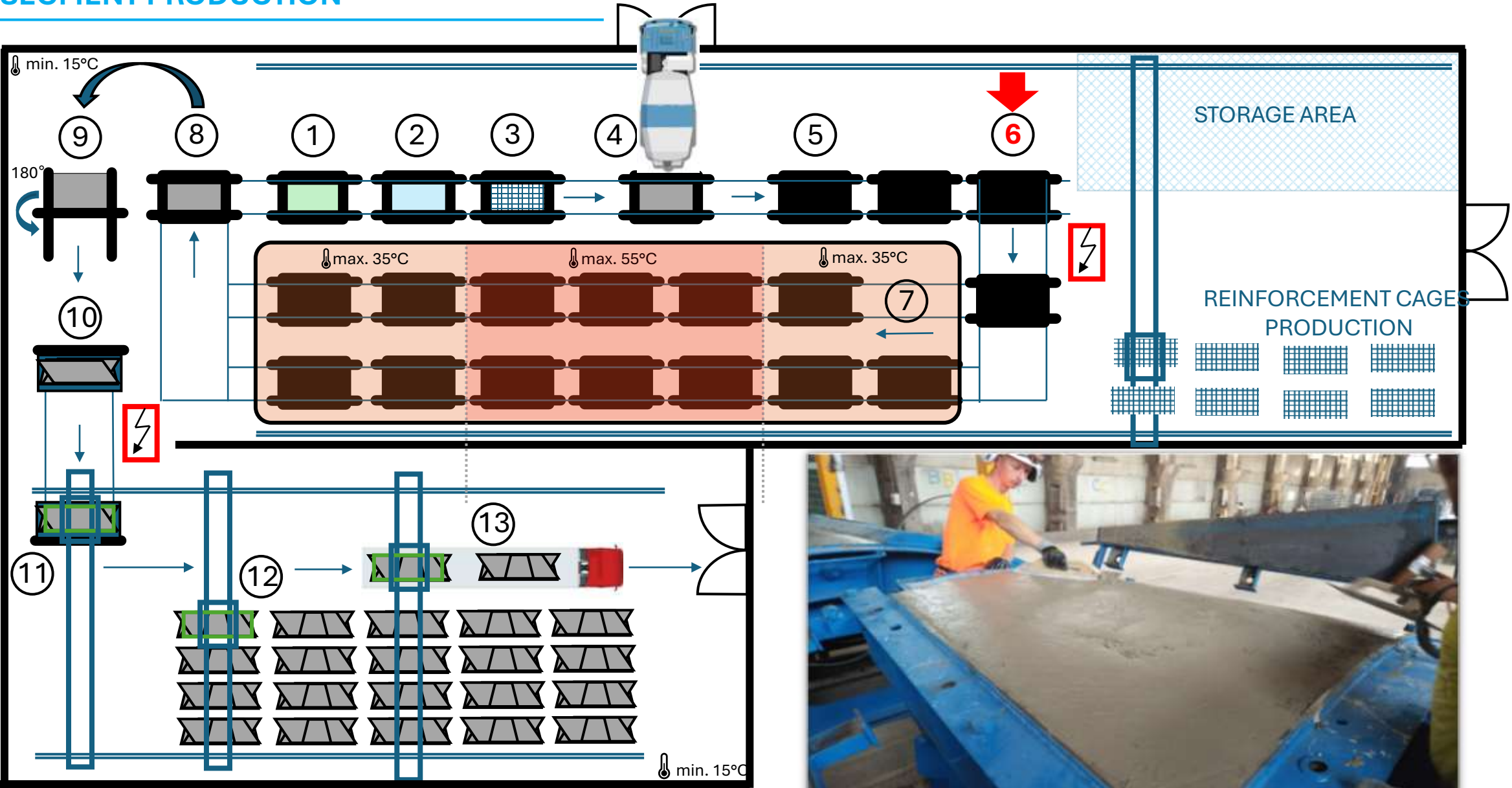
SEGMENT PRODUCTION



SEGMENT PRODUCTION

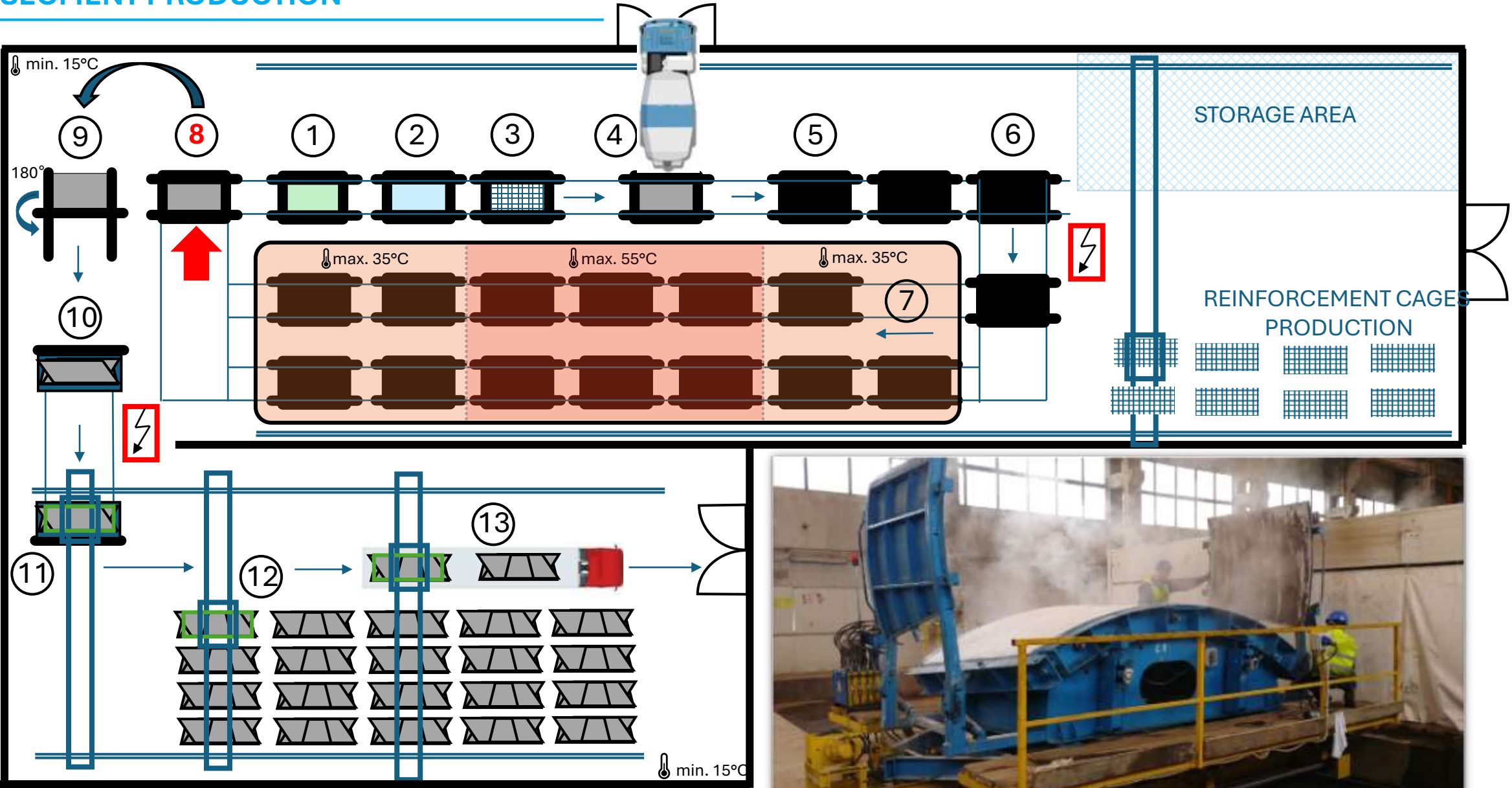


SEGMENT PRODUCTION

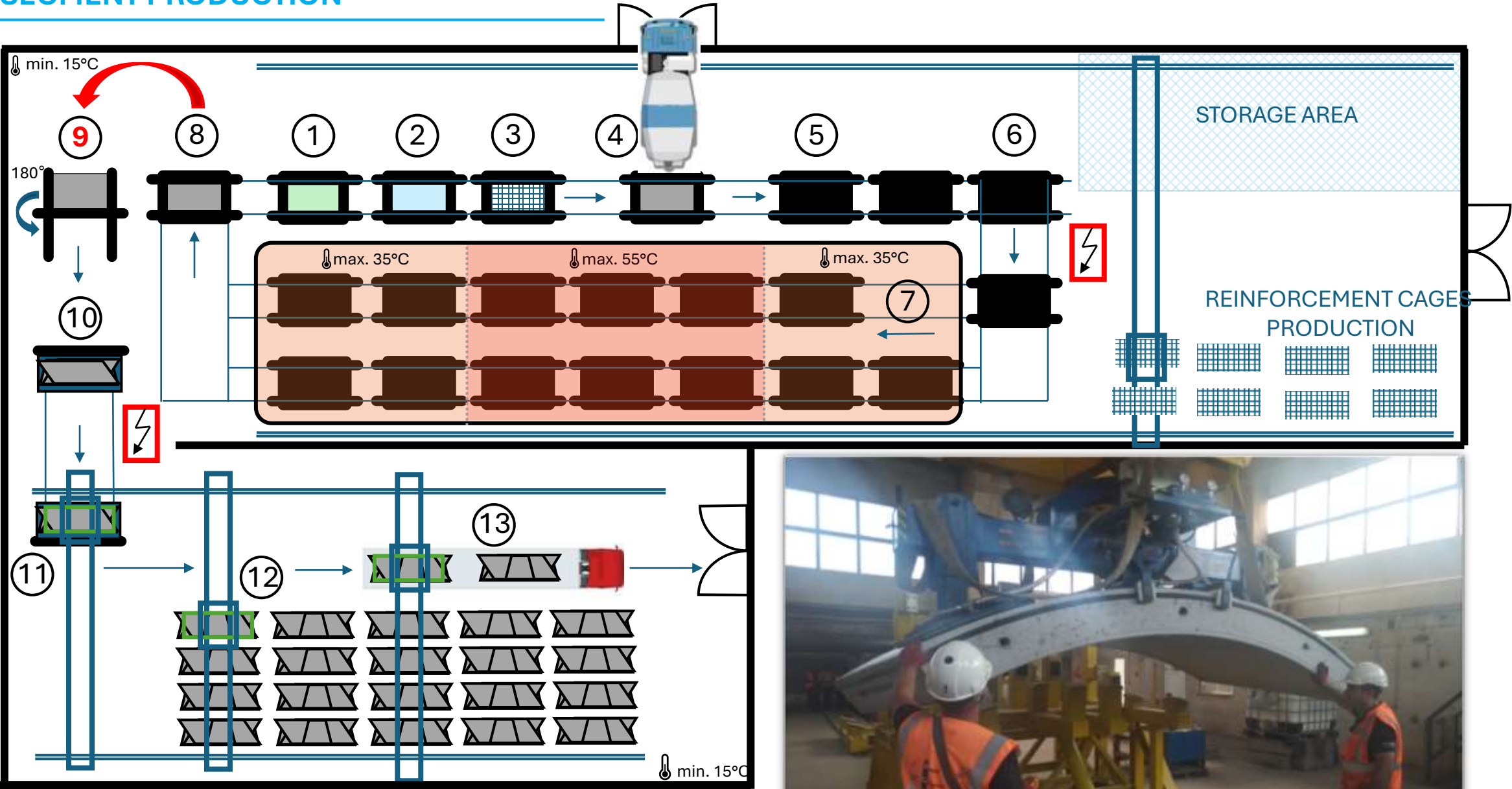




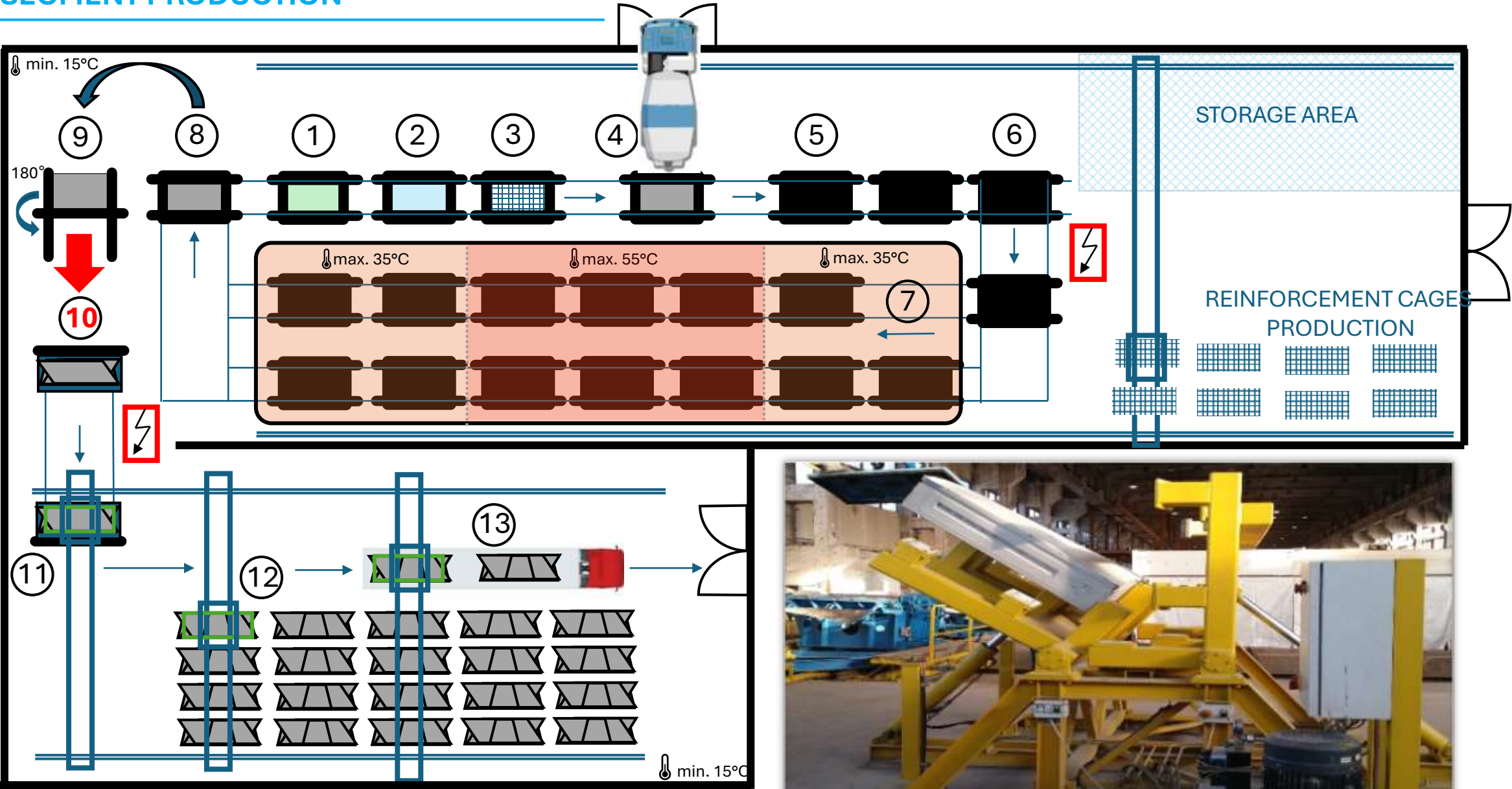
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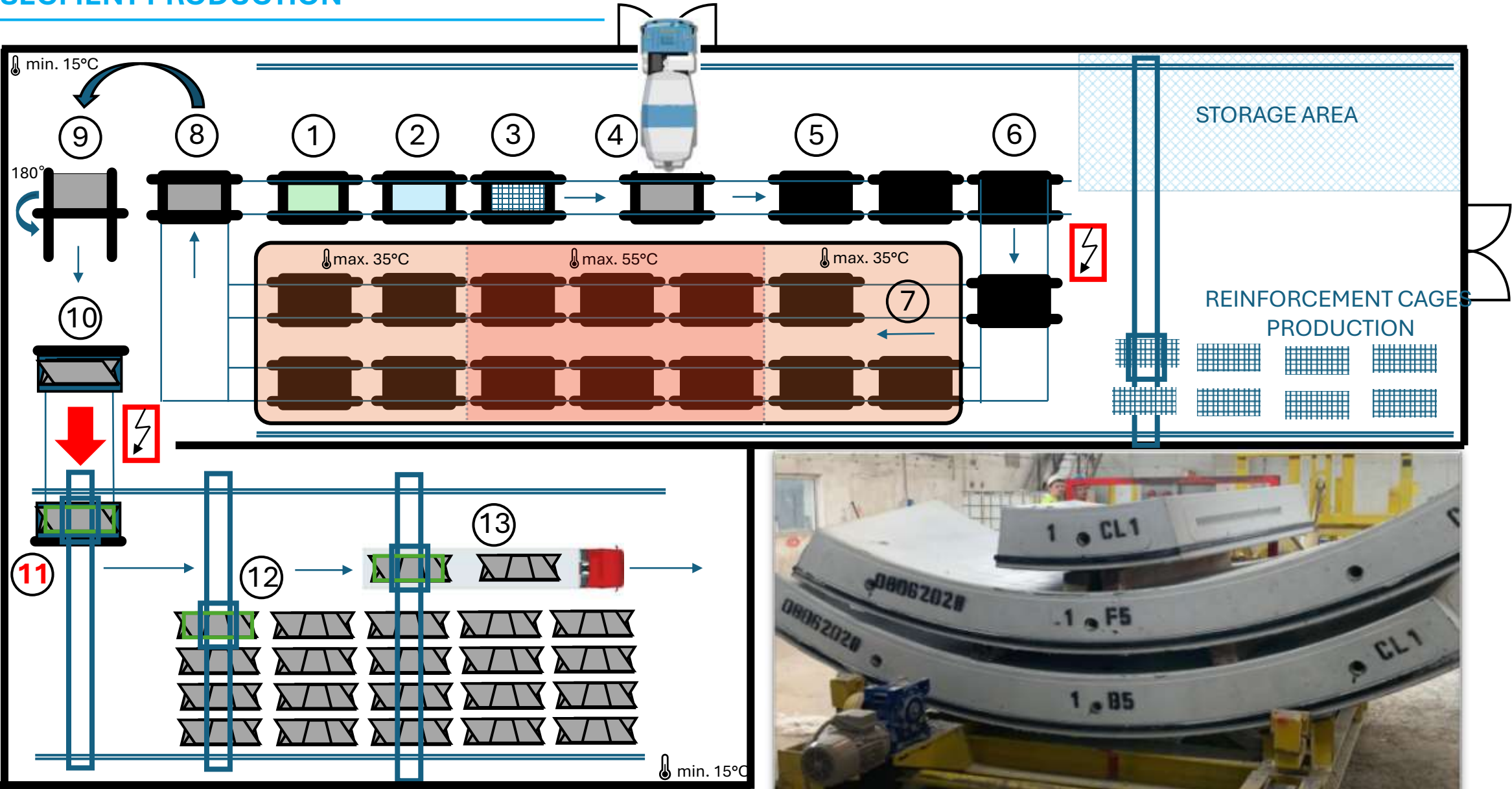
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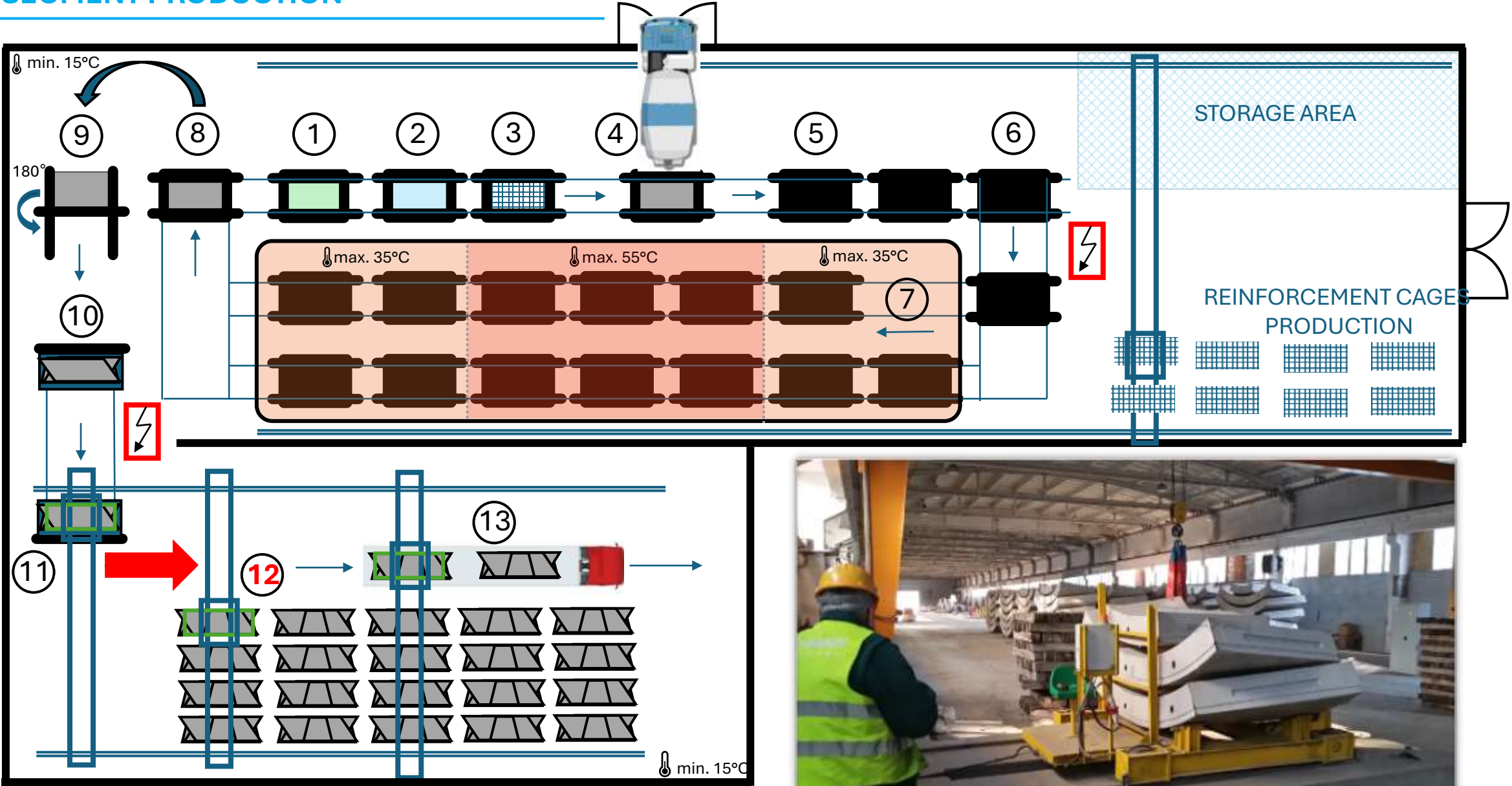
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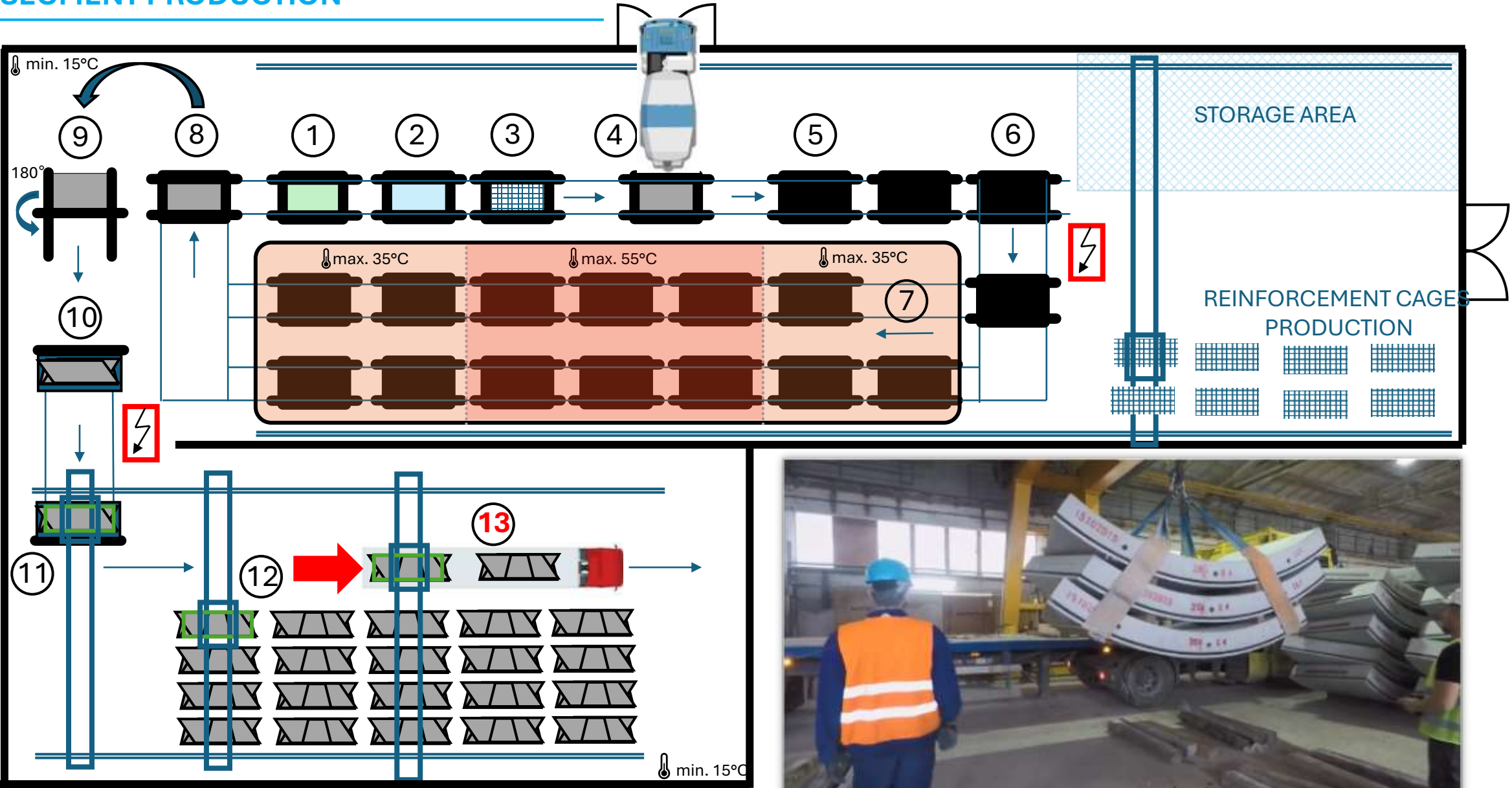
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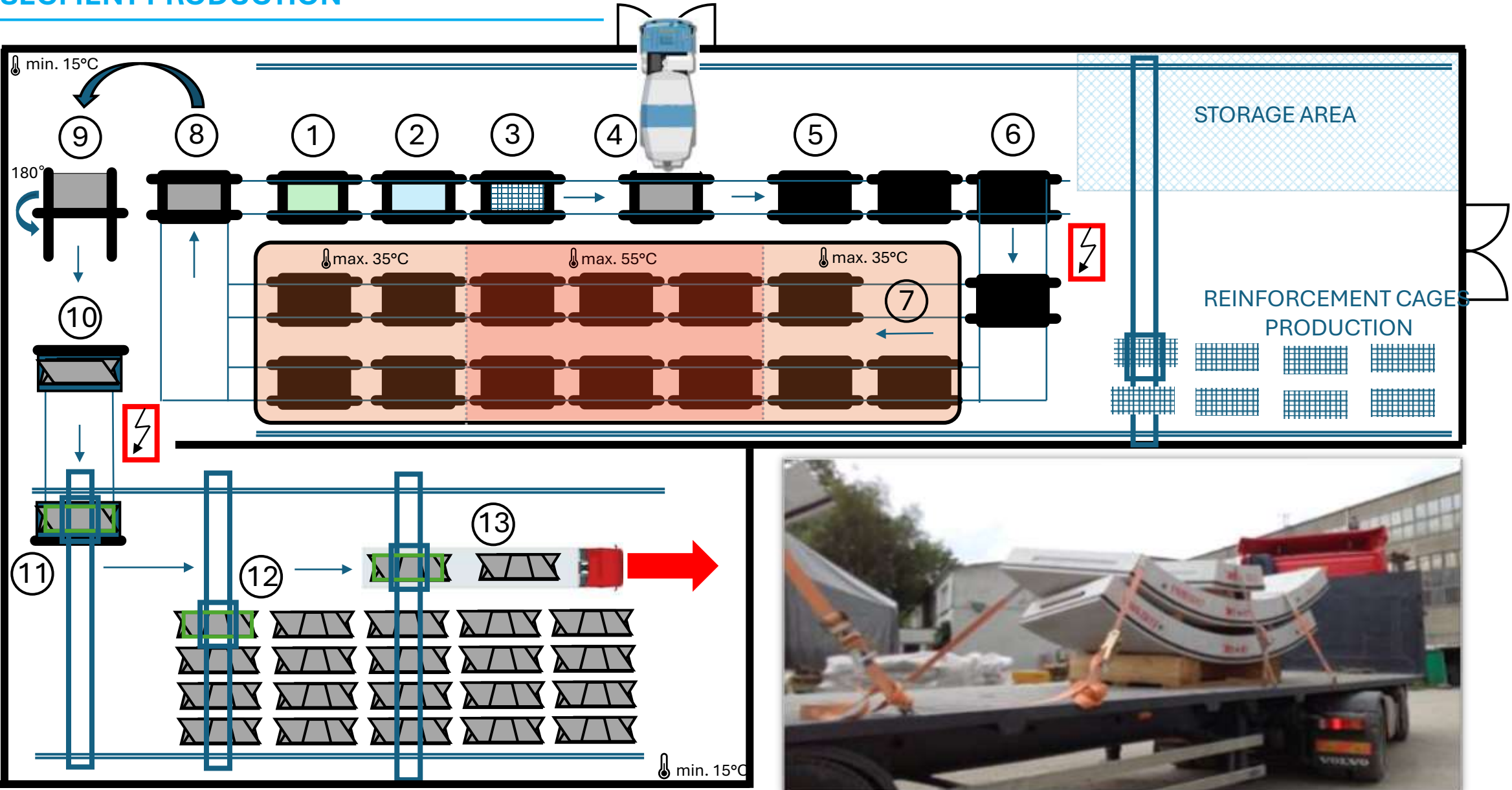
SEGMENT PRODUCTION



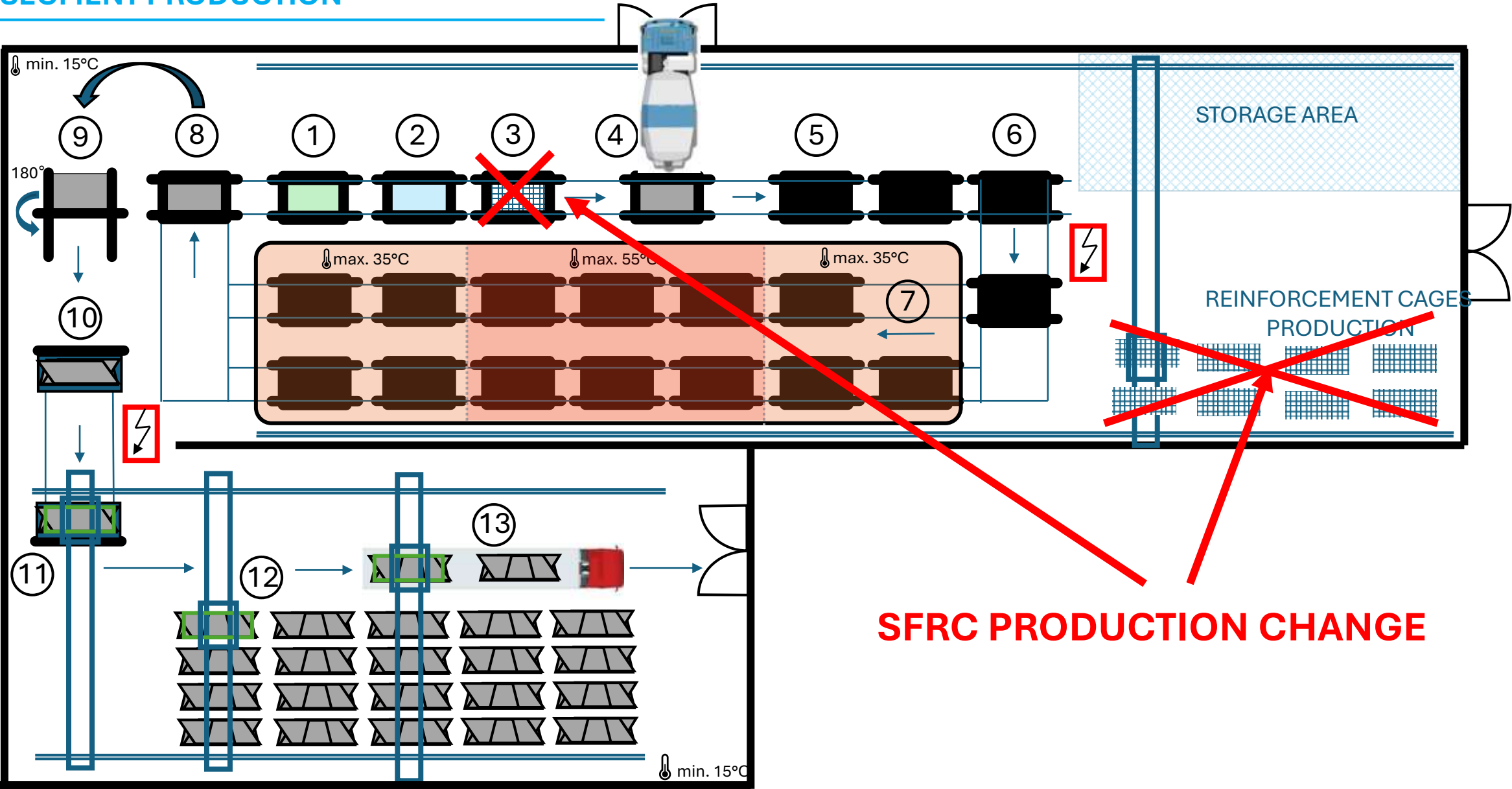
SEGMENT PRODUCTION



SEGMENT PRODUCTION



SEGMENT PRODUCTION



SFRC PRODUCTION CHANGE

Daily production

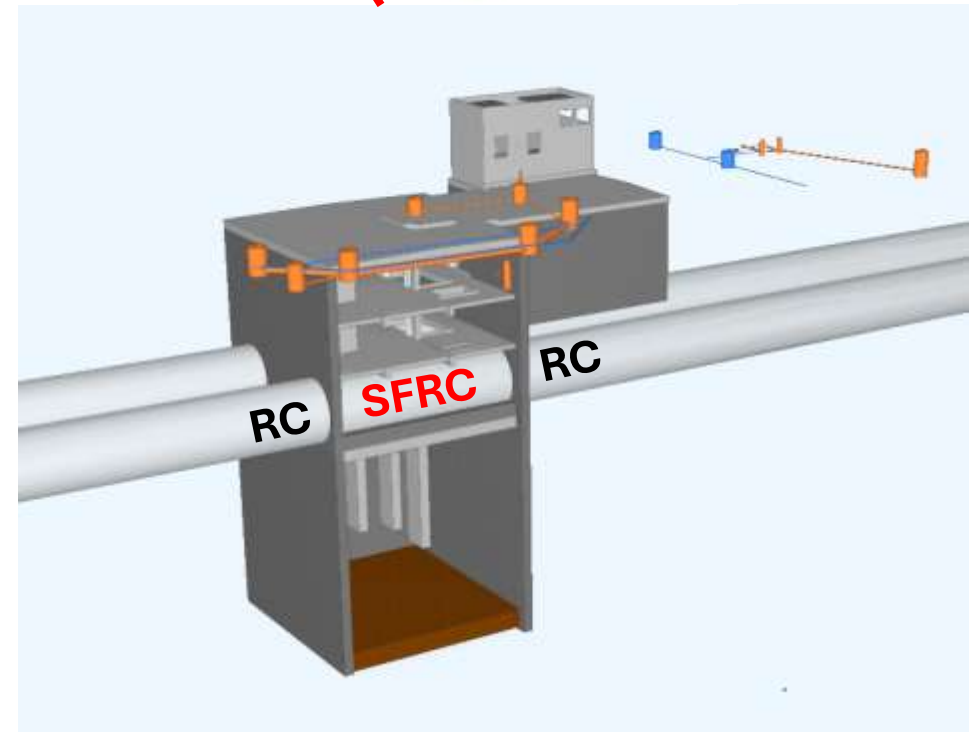
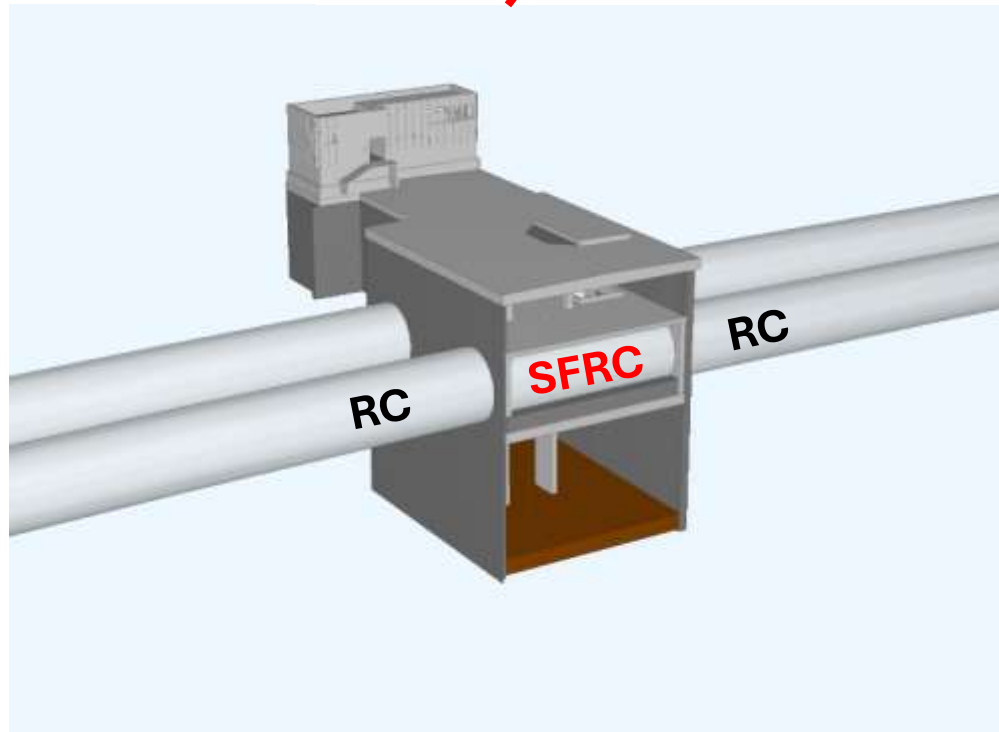
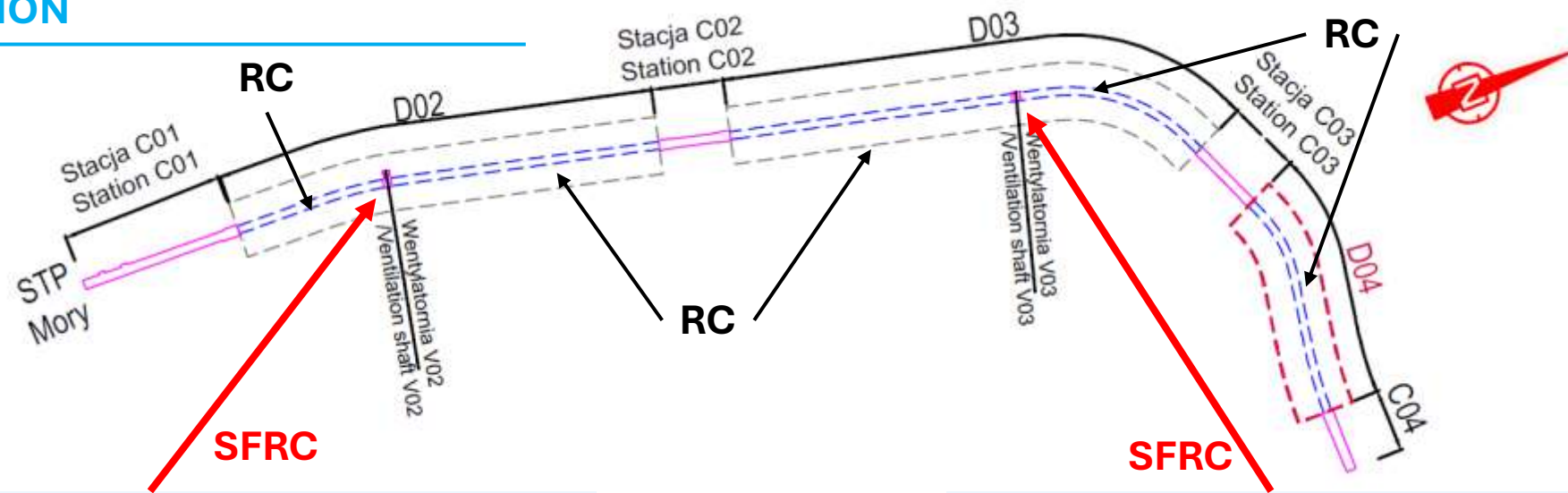
Total production

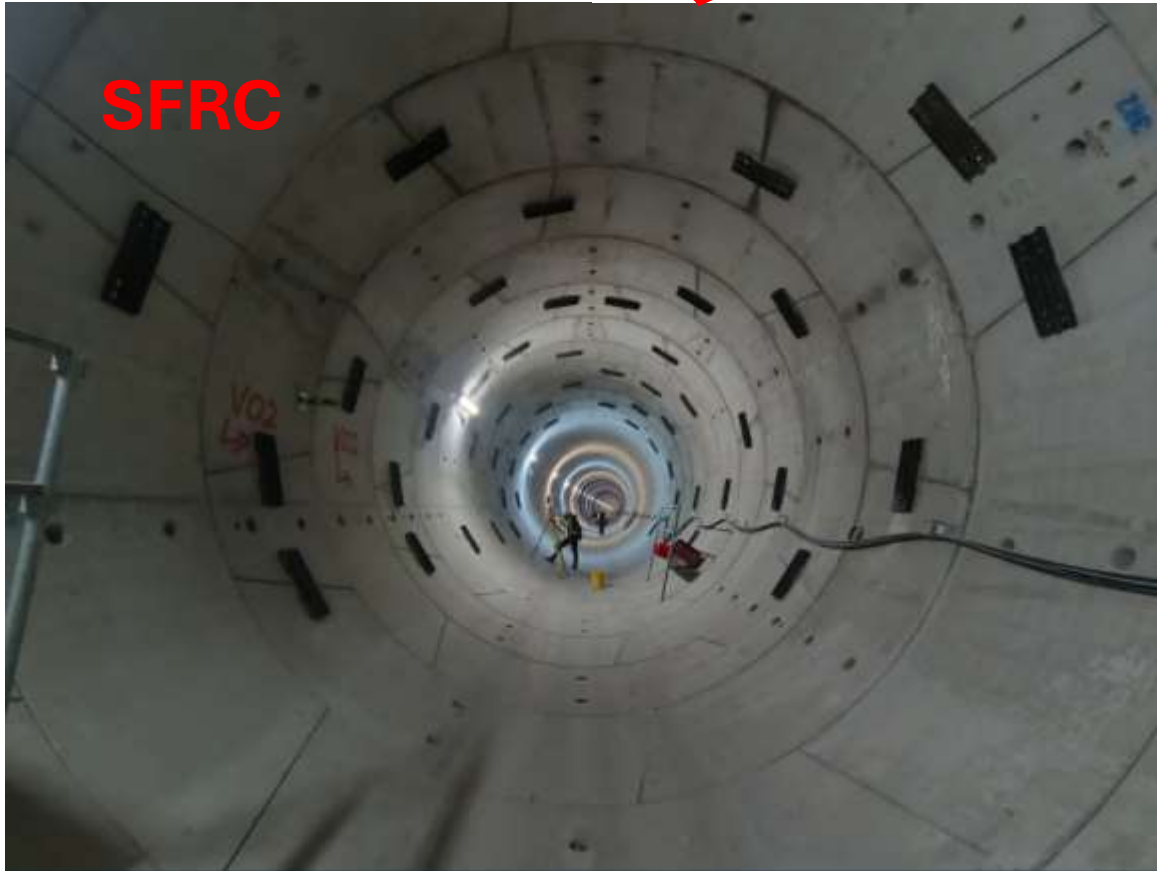
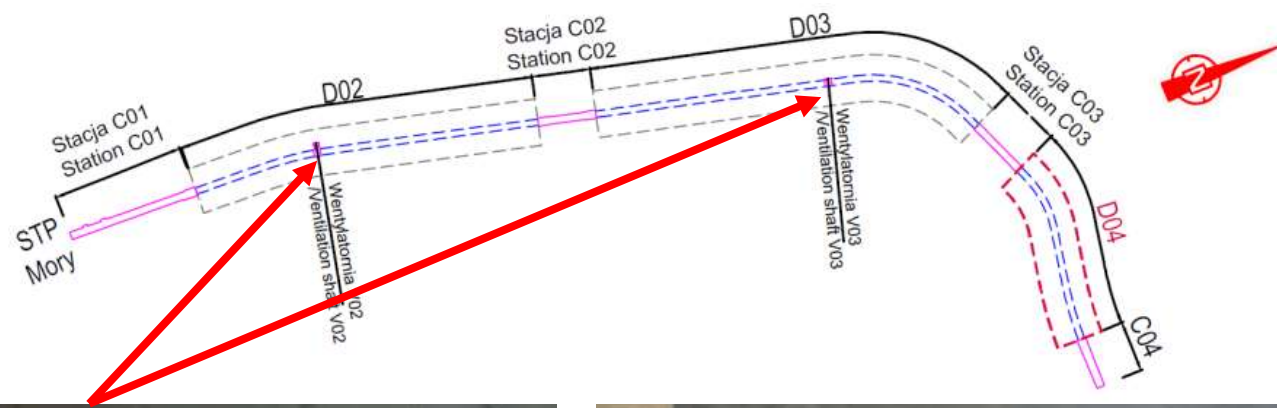
max. 22 rings (132 segments)

3872 rings



# SFRC APPLICATION





# Questions & Answers

**Contact info:**

**Bartłomiej Dziuban**

[b.dziuban@gulermak.pl](mailto:b.dziuban@gulermak.pl)

+ 48 726 005 154