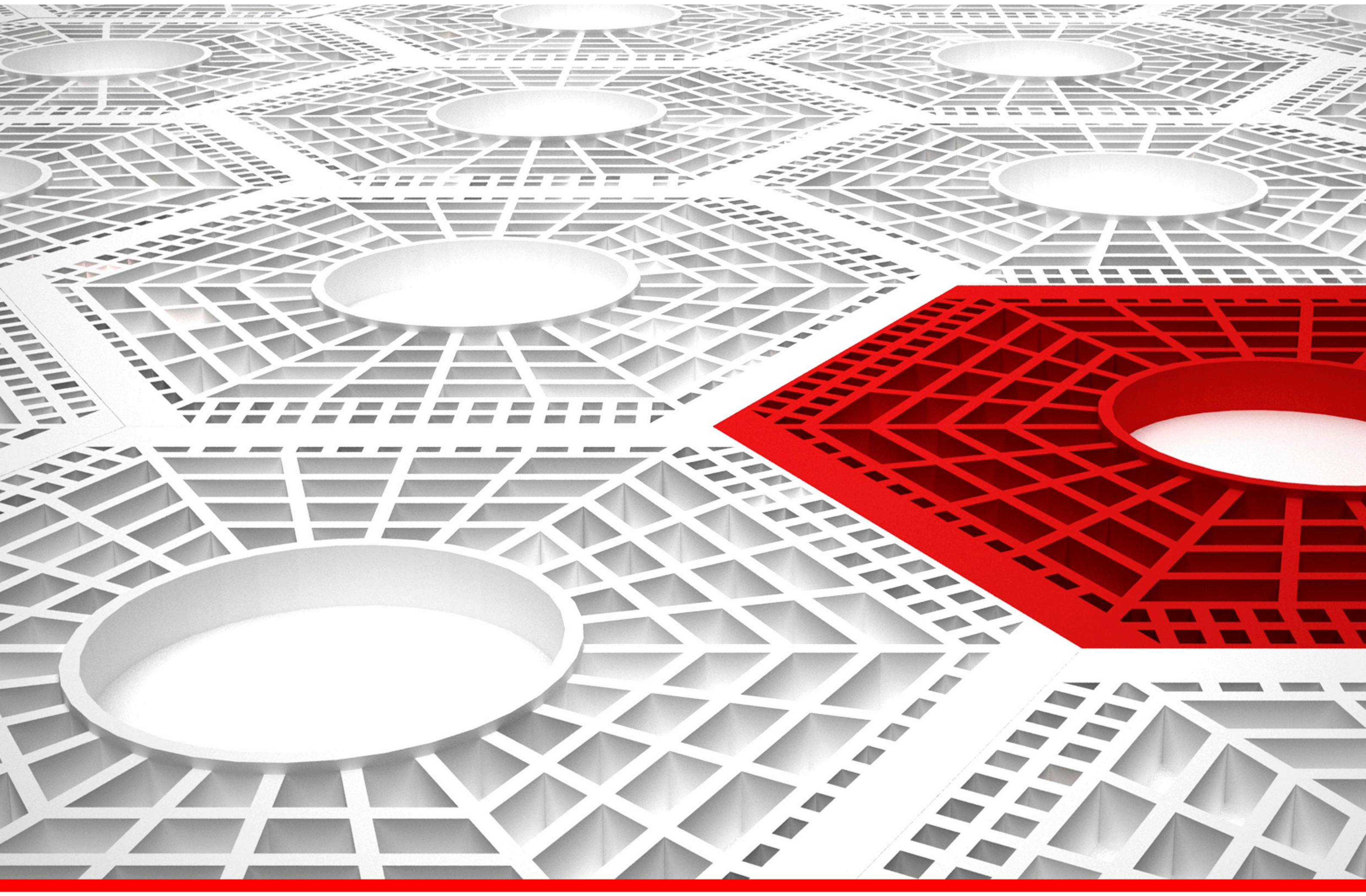
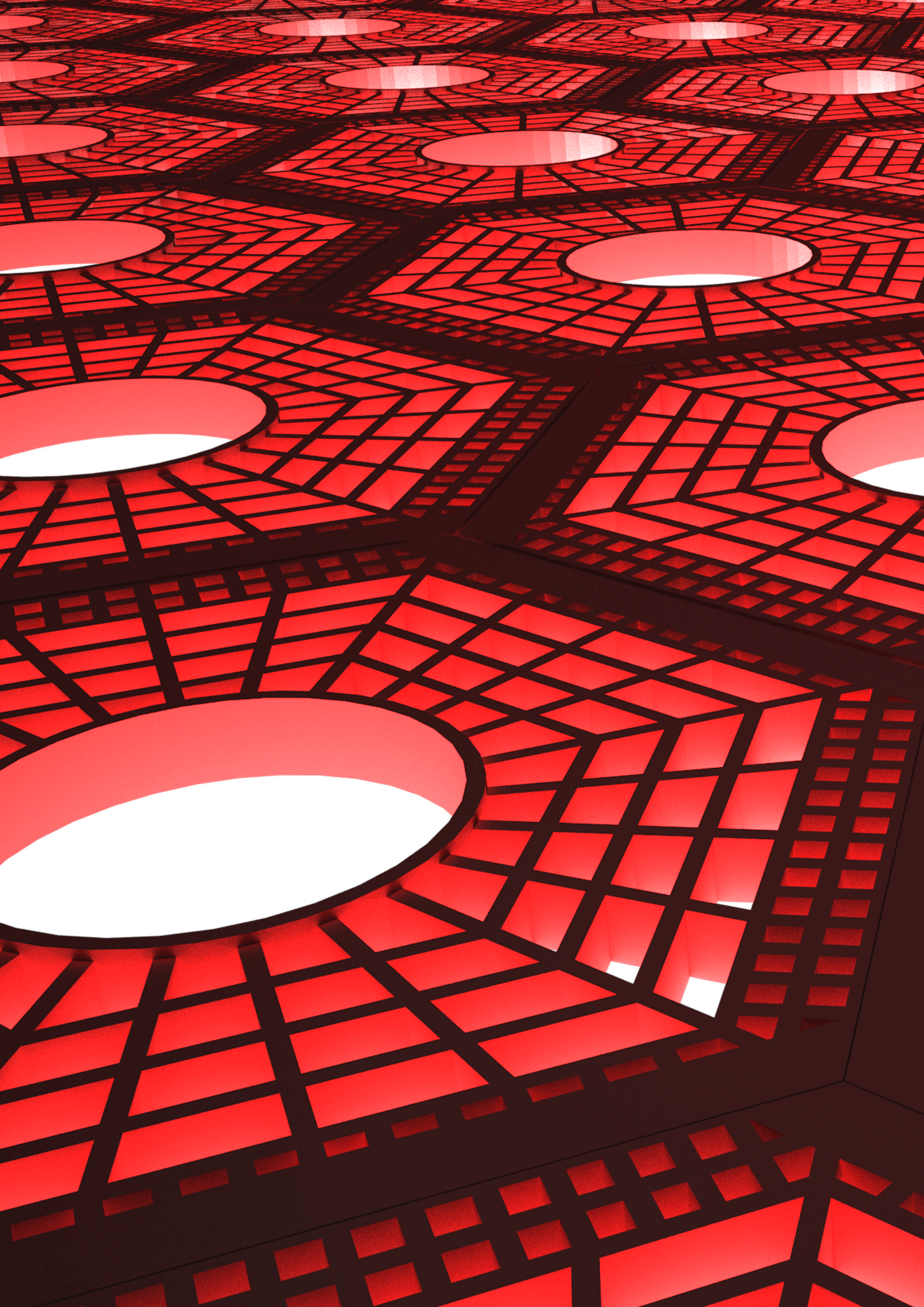


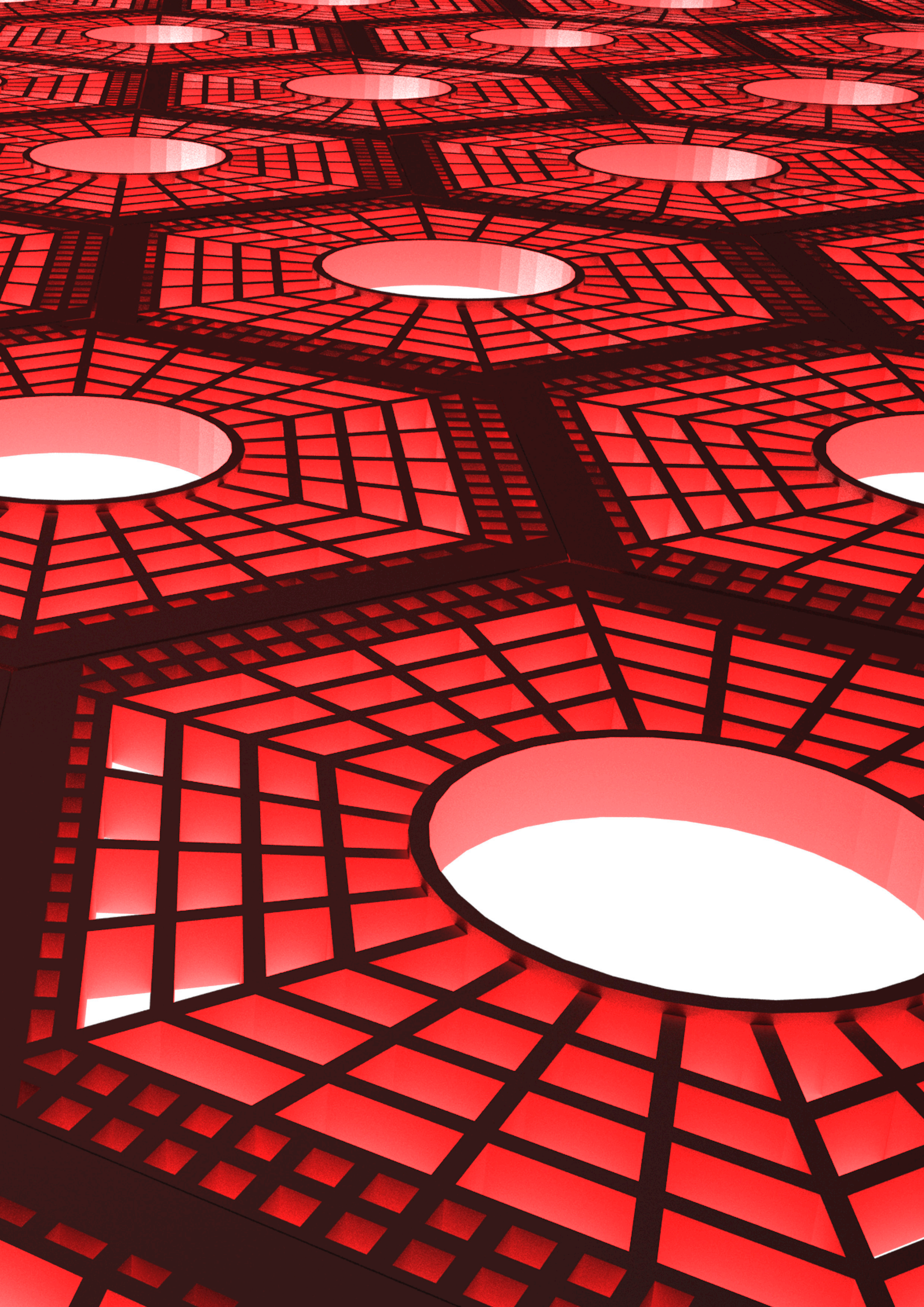
D.S.P.

TECHNOLOGICAL APPLICATION GUIDE

DISCONTINUOUS STRUCTURES AND PAVEMENTS

1ST EDITION · YEAR 2013





DISCONTINUOUS STRUCTURES AND PAVEMENT PROJECT

TECHNOLOGICAL GUIDE OF APPLICATION

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DEDICATIONS

Dedicated to my mother, Remedios Vera Artacho, who has recently passed away, for having instilled into us the fighting and self-improvement spirit.

PRESENTATION

The Technological Guide of Application of Discontinuous Structures and Pavements marks the end to the research project of the same name. It has been twenty-four intense months that finish with an enormous feeling of satisfaction for every participant in the project, since we have defined some solutions which have created a great interest and which have opened a new panorama in the field of infrastructures and pavements.

Along the project, we have always looked for the maximum efficiency in building structures and pavements, **simplifying the building procedures** but guaranteeing a **good structural operation**. The feasibility of these solutions has been also an essential target for the developed innovations and inventions, so attaining **products of great marketing interest with very competitive prices**. Likewise, looking for the advantages on structural behavior allows these solutions to compete with traditional products in the construction market, giving **competitive advantages**.

This Guide provides all the application prescriptions for the different products and describes the methods developed to calculate and justify them.

The Guide is completed by a software including four computer programs ("DPD, Design of Detachable Pavements", "CBS, Solar Tile Calculation", "DFD, Discretization of Discontinuous Slabs", "CMCR, Calculation of caissons walls") which makes it easier to calculate and design those constructions made with our products.

We wish this Guide to arouse the highest interest among the users, so that they feel that applying Discontinuous Structures and Pavements to their projects and civil or architectural constructions is easy.

Salvador Mansilla Vera and team.

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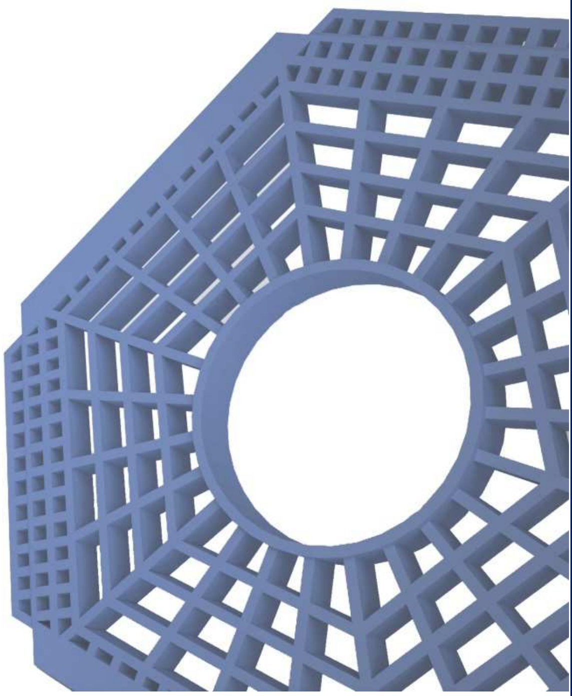
CAP 0. TOWARDS A NEW PANORAMA OF STRUCTURE AND PAVEMENT IN THE WORLD



CAP 0. HACIA UN TOWARDS A NEW PANORAMA OF STRUCTURE AND PAVEMENT IN THE WORLD

Building easier, building better, creating a longer-life structure and pavement must be some of the objectives for main actors and promoters.

The use of new materials in a viable context, together with the traditional ones allows a wide framework of possibilities to improve present solutions.

Pavement able to be disassembled and replaced and capable to generate energy, slab improving the structural behaviour and with no formwork, walls to be built in a very short time and able to be stable and support large land thrusts are, for instance, the result of the research called "Discontinuous Pavement and Structure", and now this Guide appears providing us several products with a clear commercial sense to improve the field of pavement and structure.

This Guide is structured in three parts:

- Detachable pavement
- Solar tiles
- Prefabricated slab with no formwork
- Caisson Walls

Each part provides the user with all the information needed to apply each product in their respective works. Technical features, information, recommendations and methodology to build with these products and technical prescriptions are provided in this Guide.

The scope of this Guide is to serve as a reference in the world of construction. The main focus is on new possibilities and solutions which make easier all the processes for getting better results.

This Guide version 1.0 is not closed and intends to be a start point to provide soon with new solutions and new formats which will be used in pavements and structures.

Currently, we are working in the concept of intelligent pavement, ("pervasive intelligent pavement enhanced reality -PIPER). This concept will open many possibilities and applications for people in urban environment and it is specially focused on useful marketing, mobility and social networking.

On the other hand, we promote the development of new research in discontinuous structure. In particular, we focus on prefabricated solutions that make easier the construction of some elements as building walls and columns, connections, etc.

We also keep studying the use of new materials and solutions of concrete in a feasible context.

All these progresses allow us to believe in a future world where discontinuous pavement and structure will lead the innovation in the field of construction.

CAP 1. DETACHABLE PAVEMENT

CAP 1. DETACHABLE PAVEMENT

PART 1. GENERAL OVERVIEW

1a. Why use detachable pavement?

In urban environments, we are used to see how new pavement with short life is demolished due to new urban utilities, reparations or maybe inadequate structure capacity of pavement.

In some countries, some studies highlight more than 40% of urban pavement is demolished before its expected duration. This brings thousand of euros or dollars in demolition and reconstruction per year.

In some urban places as city centres or shopping centres, luxury pavement has to be demolished in some cases, with an initial investment of more than 60 euros per m^2.

Therefore, a solution which allows the disassembly and later replacement of pavement is suitable to reduce costs in urban environment exploitation.

Moreover, pavement which uses conventional pavers has been proved to be an inadequate solution with heavy traffic. Consequently, improving structure behaviour is essential to allow heavier loads.

1b. Main features

The main features of detachable pavement that make this solution competitive in urban environment are the following:

- It is valid for all levels of heavy traffic.
- General aesthetic, making possible the use of numerous superficial solutions as stone, slurry or coloured silica in prefabricated solutions.Larga vida de servicio.
- Longer service life.
- Prefabricated solutions or in situ solutions are considered.
- Each format can be disassembled and then replaced.
- Competitive price.
- The solution allows the insertion of solar tiles and other devices.
- Conception of Intelligent Pavement (PIPER Project "Pervasive Intelligent Pavement Enhanced Reality") is possible with this solution and makes easier traffic control activities and mobility applications.
- Easy construction, with no specialized team or machinery.
- Best quality control for prefabricated solution before construction.
- It can be built everywhere.
- Less consumption of energy than in other solutions.
- Immediate opening for prefabricated solutions.
- Good behaviour before chemical attack.
- Rehabilitation works are not needed.
- Better drainage.

1c. Advantages of flexible pavement or asphalt pavement

- Longer service life.
- Rehabilitation is not needed.
- Better load distribution in granular layers and less deformation in substructure compared with asphalt solutions with average thickness in urban environment.
- No demolition is needed in reparations.
- CO2 emissions reduction.
- Less energy consumption.
- Better drainage.
- No specialized team or machinery is needed.
- Better behaviour before chemical attack.
- Temperature and rain do not condition the construction of pavement.
- Better aesthetic.

1c. Advantages of rigid pavement or concrete pavement

- Less thickness.
- Steal is not needed.
- Specific machinery is not needed.
- No demolition is needed in reparations.
- Immediate opening to traffic.

Image 1. Prefabricated detachable pavement in two formats.

PART 2. GEOMETRIES AND FORMATS

We have two general groups for construction solutions:

- Prefabricated pavers.
- In situ pavers.

2a. Prefabricated pavers

We are trading three formats: hexagonal 20 cm side; and square 33.3 cm side and 40 cm side.

This pavement consists of three pieces. The first one is in a lower position, in contact with the floor. The second one is an upper piece that provides aesthetic to the pavement, with an upper layer which includes silica and pigments (red, yellow, green, grey, etc.). Finally, the last piece is placed between the lower and the upper layer, which is a technical tongue-jointing made of technical plastic as ABS or polyamide reinforced with fibreglass. Recycled ABS is recommended. This jointing allows the connection between pieces and the distribution of every load to the pavers around the loaded piece. The thickness of the upper and the lower paver is 7 cm, and the thickness of the intermediate tongue-jointing piece is 1.8 cm. The total thickness of this pavement is 15.8 cm.

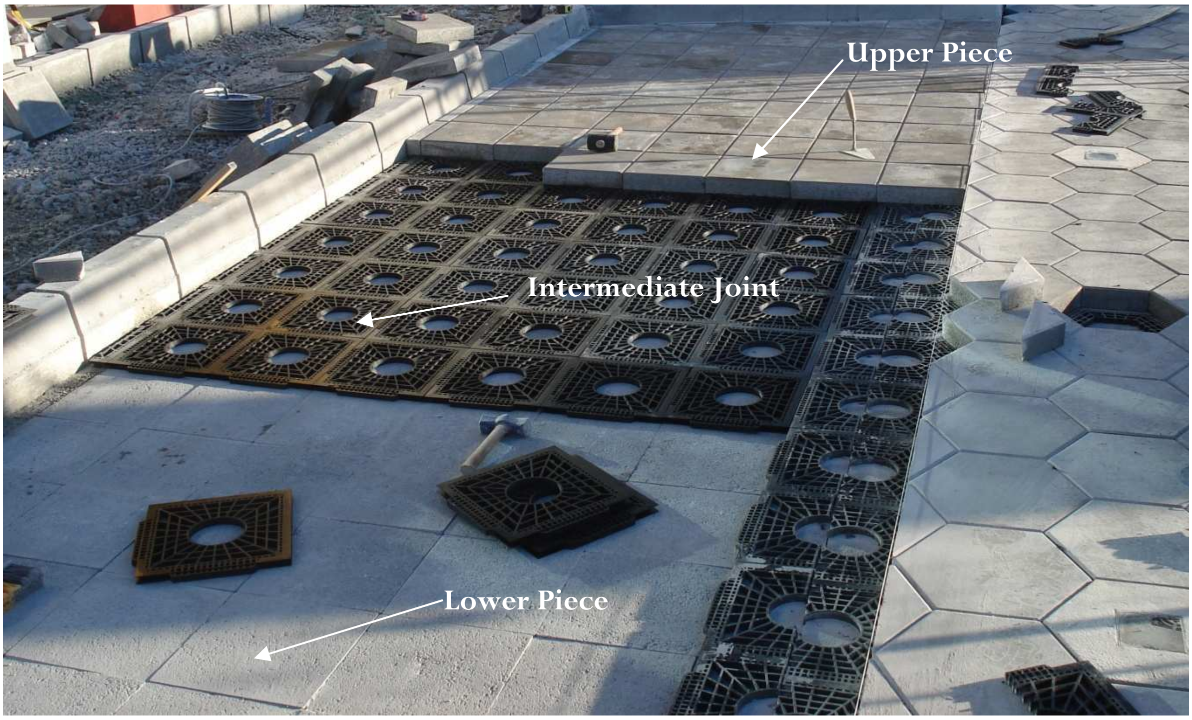


Image 2. Elements of prefabricated detachable pavement.

2b. In situ pavers

In this case, the solution is made in the same place where it is going to be used. This allows a cheaper product even if it needs at least 4 days to ensure the concrete curing. In this case, we use moulds made of recycled ABS. The moulds are filled with concrete and the upper part of the mould is removable to make the forming of the superficial jointing. These moulds have a tongue-jointing shape that allows the connection between pieces and the distribution of loads.

Nowadays, we are trading four formats: hexagonal 15 cm and hexagonal 20 cm side; squared in situ pavement 40 cm side and 33.3 cm side. For hexagonal 15 cm side, the geometry is different to the other three ones since the tongue jointing is made of concrete, while for the rest the tongue jointing is made of technical plastic. The hexagonal 15 cm side is called *hexatrípeto*.

This solution is ideal to use stone pavement as superficial finishing (granite, for example).

The height of each mould is 13.8 cm. The moulds to make the superficial jointing in concrete add 2cm more up to 15.8 cm. These moulds are not used when stone or other materials are used, for example, the superficial finishing materials.

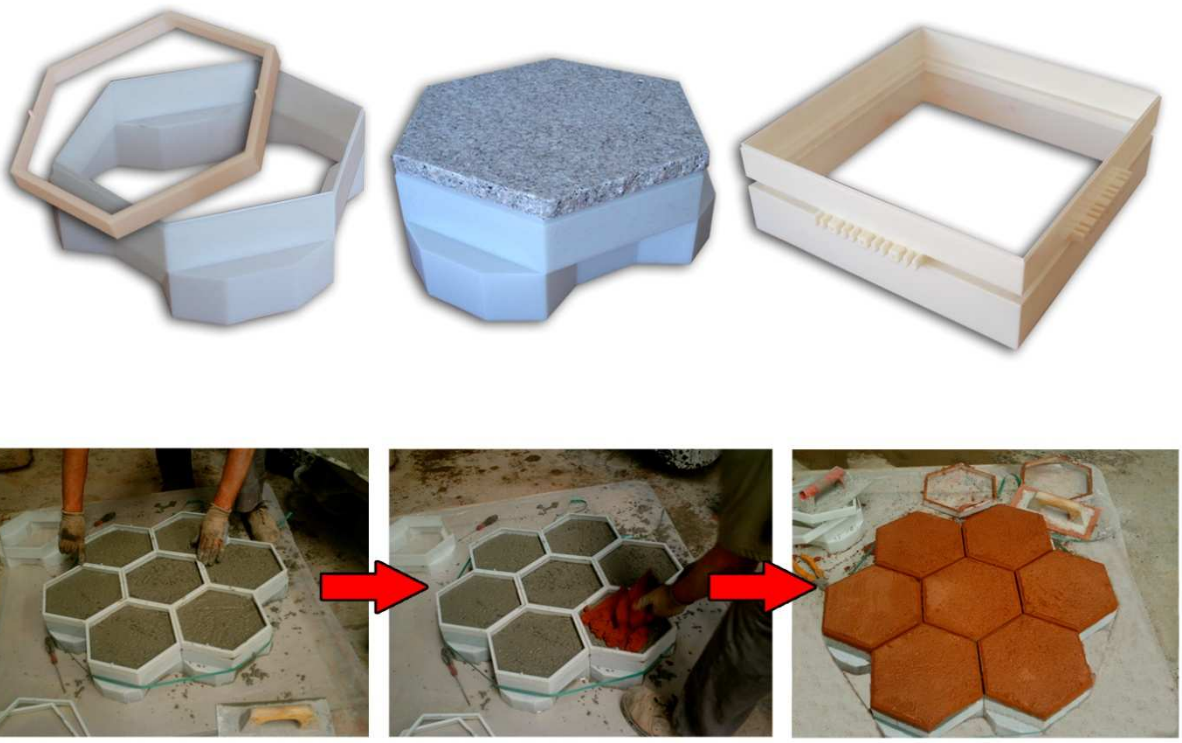


Image 3. In situ detachable pavement.

2c. Disassembly and replacement

For prefabricated solutions, the disassembly of pieces is quite simple. A twenty-kilo sucker is enough to remove the first upper piece, then the intermediate tongue-jointing and finally the lower paver. The replacement can be done manually in the same way as it was built.

For in situ pavement with plastic tongue-jointing, it is necessary to cut first this connection at least in two pieces. A simple radial cutter is enough. Then, these two pieces are removed and, after this, all pieces can be removed. Finally, when the reparation is made, we can rebuild the pavement replacing all the pieces, except the two first ones, which will be rebuild with new moulds filled with concrete. The two pieces whose tongue-jointing were cut can be restored by a steal connector settled in the horizontal hole of the tongue-jointing and used in other pavements. The diameter of this hole is 6 mm.

For in situ *hexatrípeto*, a sucker is used to remove the pieces by a vertical displacement (at least, a hundred kilo sucker is recommended). Safety solutions must be taken into account in this operation.

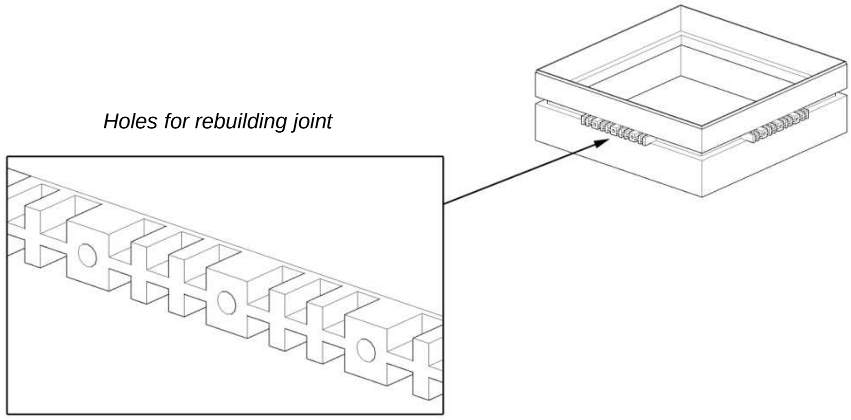


Image 4. Detail of the joint of rectangular in situ detachable pavement.

2d. GEOMETRY FICHES

PDP-SQ333

SQUARED 33.3 CM SIDE PREFABRICATED

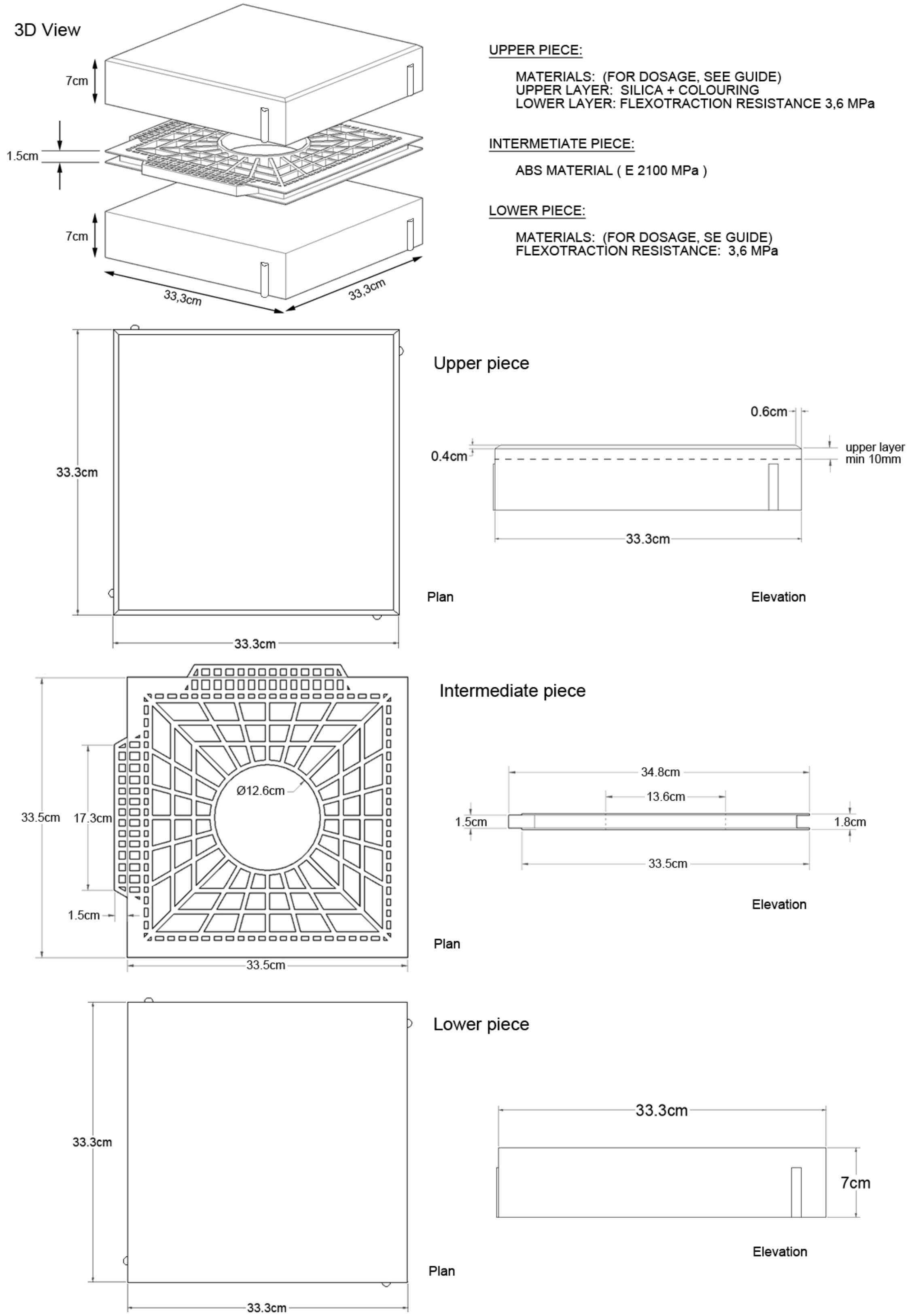


Image 5. Geometry of prefabricated detachable pavement of 33.3 x 33.3 cm..

PDP-HEX200

HEXAGONAL 20 CM SIDE PREFABRICATED

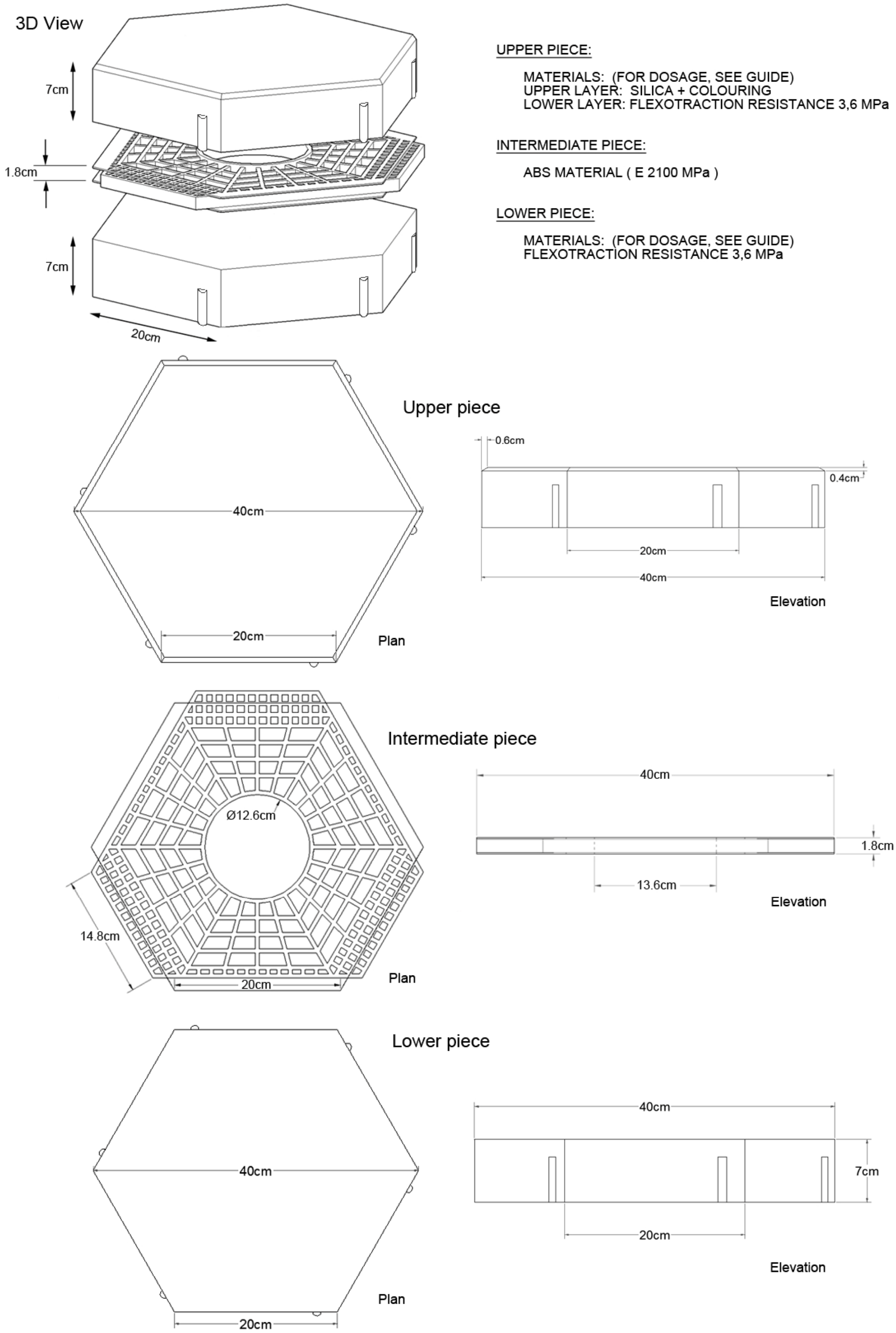


Image 6. Geometry of hexagonal detachable pavement of 20 cm side.

PDI-SQ400

SQUARED 40 CM SITE IN SITU

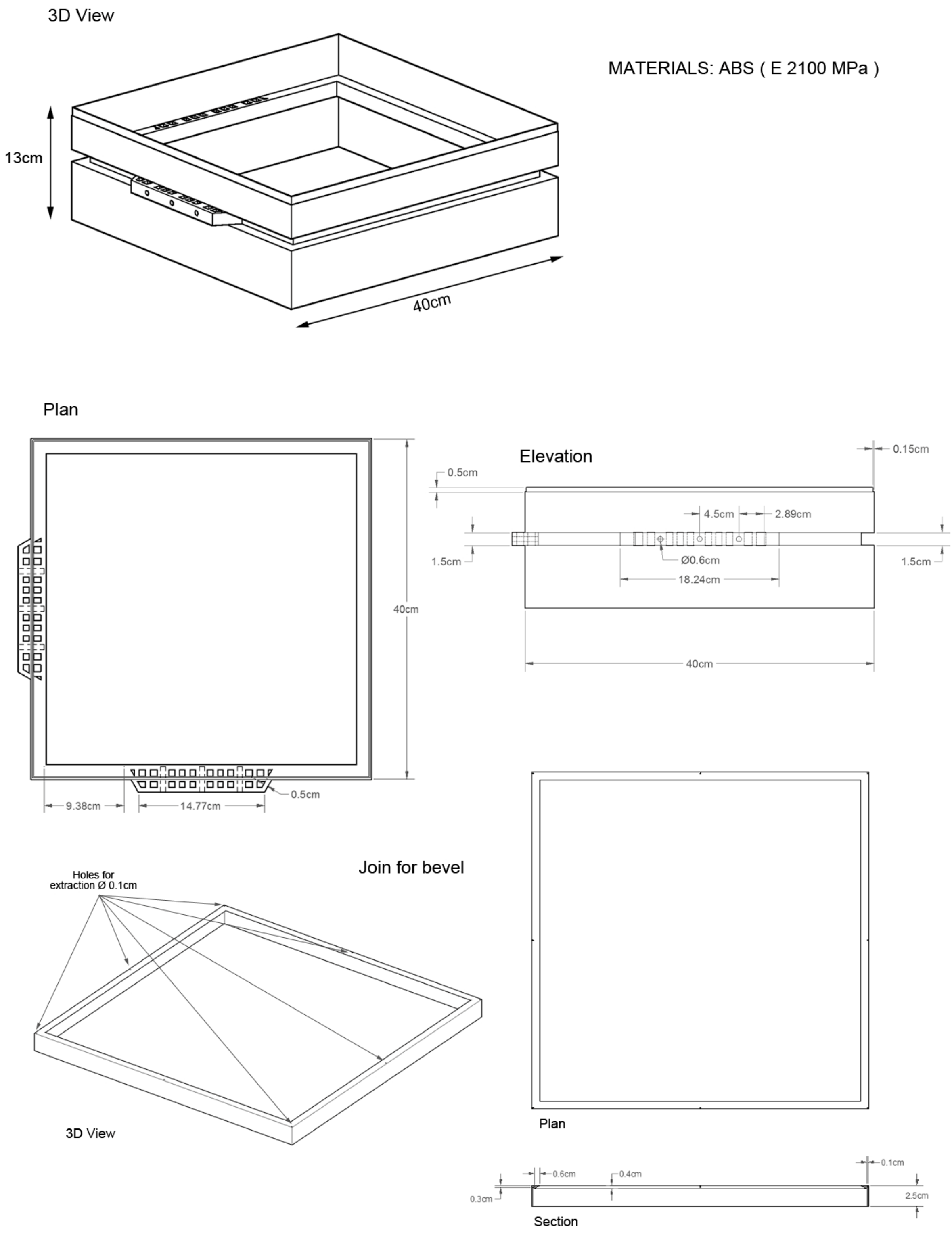


Imagen 7. Geometry of rectangular in situ detachable pavement of 40 cm side.

PDP-HEX150

HEXAGONAL 15 CM SIDE IN SITU, *HEXATRÍPETO*

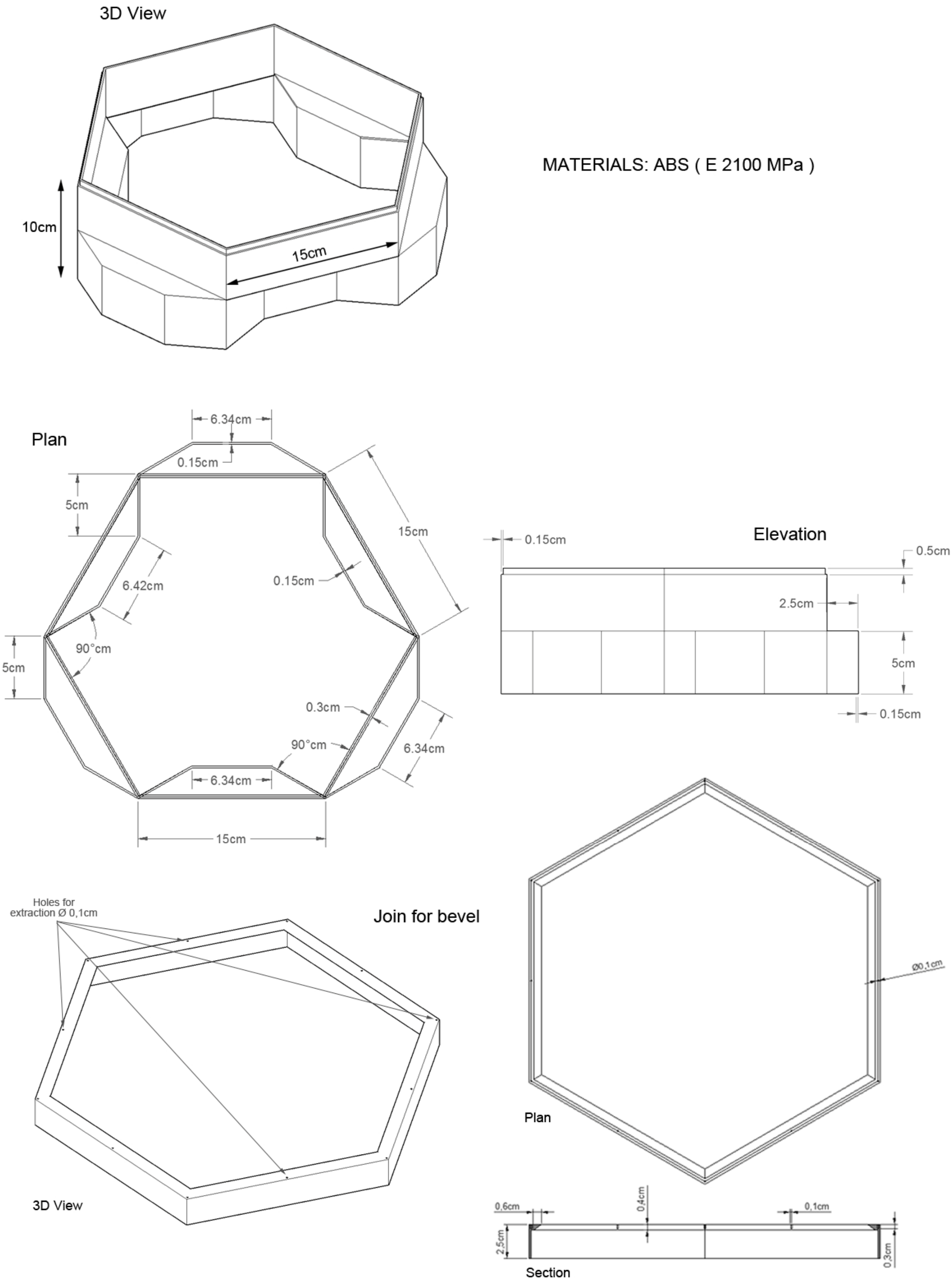


Image 8. Geometry of hexagonal in situ detachable pavement of 20 cm side..

2e. Superficial finishings.

FINISHINGS IN GRANITE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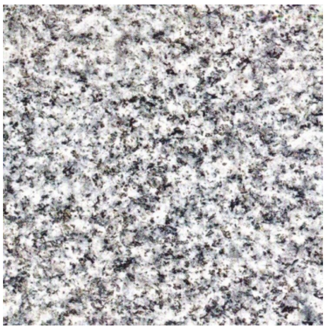
G01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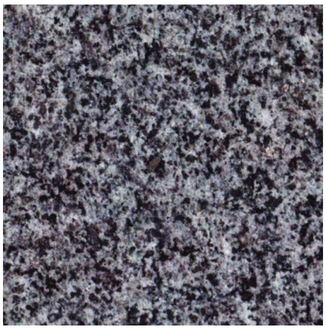
G03


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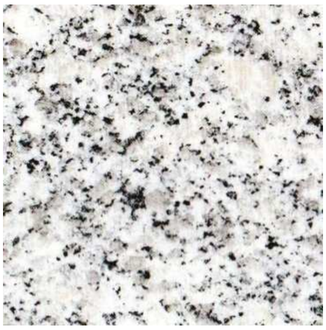

G08

G09 G010 G11



G12 G13 G14



G15 G16 G17



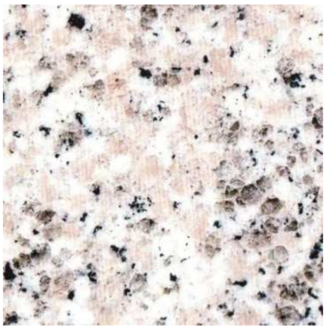
G18 G19 G20



G21 G22 G23

G24

G25



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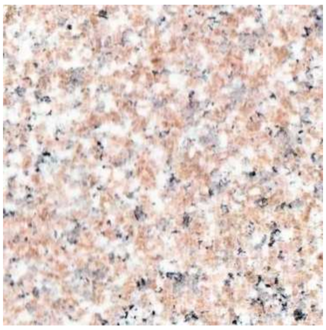

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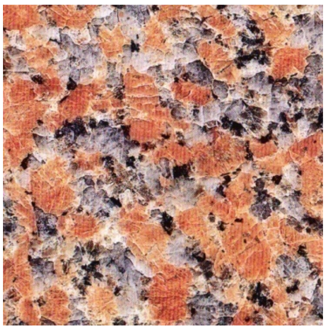

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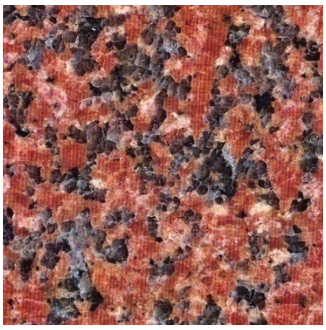

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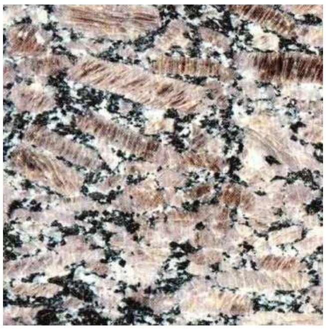

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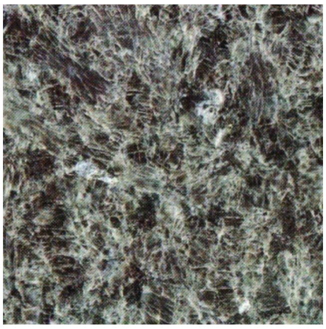
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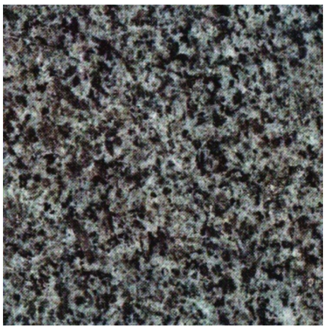
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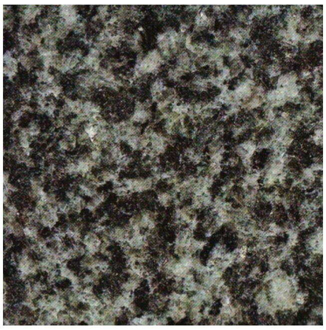
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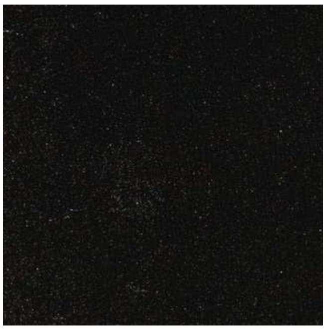
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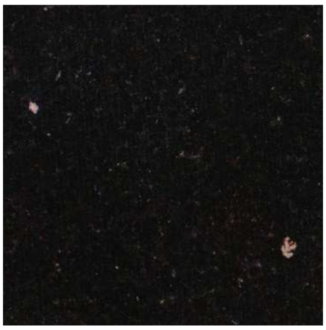
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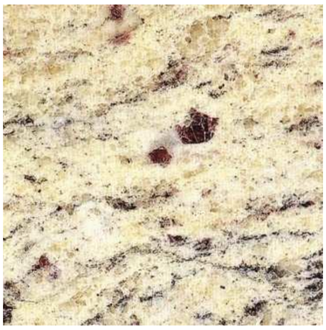
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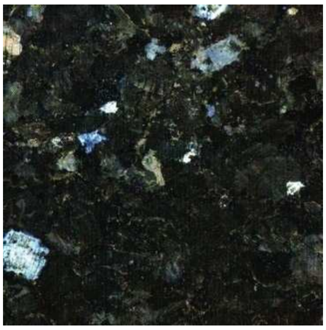
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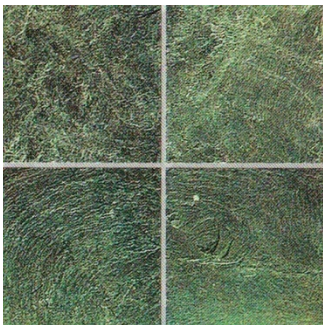
FINISHINGS IN SLATE



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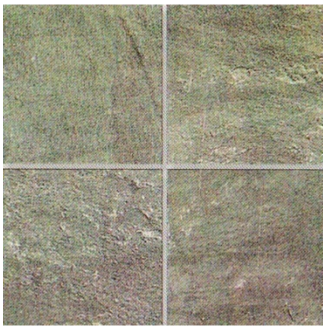

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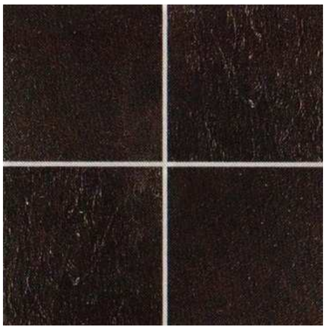

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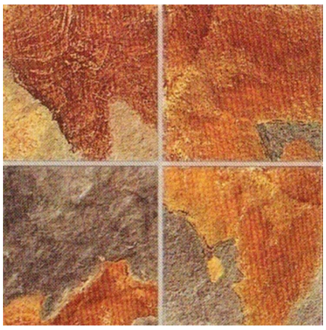

P06

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P08

AVAILABLE COLOURS FOR IN – SITU PAVERS

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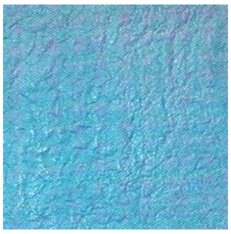
CI02

CI03

CI04

CI05



CI06

CI07

CI08

CI09

CI10

CI11

AVAILABLE COLOURS FOR PREFABRICATED PAVERS


CP01


CP02

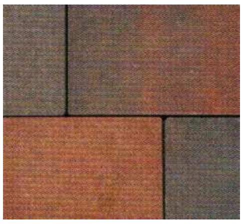

CP03


CP04


CP05


CP06

MIXED COLOURS FOR PREFABRICATED PAVERS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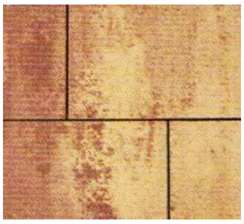
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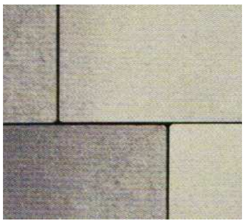
MI03

PART 3. MATERIALS

This part summarizes the main features of materials used in detachable pavement.

3a. ABS in Joints for prefabricated pavers and in moulds for in situ solutions.

Elasticity module, E 2100 MPa and Poisson's ratio n=0.33.

The remaining properties are indicated in the next table:

	Test method	Test Condition	Unit	Value
	Mechanical properties			
Tensile strength at break	ASTM D 638	1/8", 6 mm/min	MPa	40
Elongation at break	ASTM D 638	1/8", 6 mm/min	%	30
Flexural Strength	ASTM D790	1/4", 2.8 mm/min	Kg/cm^2	540
Elasticity module	ASTM D 638	1/8", 6 mm/min	MPa	2.100
Flexural modulus	ASTM D 790	1/4", 2.8 mm/min	MPa	1.900
Rockwell hardness	ASTM D 785	1/2"	ScalE R	R-108
	Impact properties			
IZOD Impact of notched specimens at room temperature	ASTM D 256	1/4", 23º C 1/8", 23º C	Kg-cm/cm Kg-cm/cm	16 25
	Thermal properties			
VICAT 120º C./h	ASTM D 1525	1/8", 50ºC/hr	ºC	104
Annealed, (85ºC,8 hr) Unannealed	ASTM D 648	1/4", 120ºC/hr	ºC	98 87
Melt Flow Index	ASTM1238	200ºC, 5 kg	g/10min	2,7
	Physical properties			
Specific gravity	ASTM D 792		g/cm3	1.05
Foam flammability test	UL 94			1/16" HB

Tabla 1-1. ABS Properties

3b. Concrete for prefabricated paver

The recommended dosage is the next:

Gross concrete, (lower layer in upper paver and lower paver):

Sand, (0-4 mm)	1,100	Kg
Aggregate,(river) (8-10 mm)	330	Kg
Aggregate,(crushed) (4-8 mm)	330	Kg
Cement 42.5 R	245	Kg (minimum content)

Plasticizer	2.5	L
Other additive	0.5	L
Water	50-65	l (according to cement content)

Upper layer in upper paver

Silica	100	Kg
Aggregate, (crushed) (1-2 mm)	75	Kg
Cement 42.5	45	Kg (minimum content)
Additive	0.1	l
Dye	1.5-2.5	Kg (when colour is foreseen)
Water	20-25	l (according to cement content)

3c. Concrete for in situ pavement with heavy traffic

Aggregate	1760	Kg
Cement 42.5 R	360	Kg (minimum content)
Plasticizer	2	l
Fibreglass 36 mm length	18	Kg
Water	180	l (according to cement content)

Aggregate:

Coarse fraction, 8/12 mm: 40%.

Fine fraction, 0/5 mm: 60%.

3d. Concrete for in situ pavement in sidewalks (no traffic is expected)

Aggregate	1,760	Kg
Cement 42.5 R	250	Kg (minimum content)
Plasticizer	2	l
Fibreglass 36 mm length	18	Kg
Water	125	l (according to cement content)

Aggregate:

Coarse fraction, 8/12 mm: 40%.

Fine fraction, 0/5 mm: 60%.

3e. Concrete for in situ pavement for surface finishing

The dosage is the same as in the prefabricated solutions (upper layer in upper paver).

3f. Fiberglass

- Minimum content in ZrO_2 >15%.
- Fibreglass length: 36 mm.
- Loss on ignition = 2%.
- Filaments in roving form.
- Filament diameter = 14 μ
- Linear mass (g/km) = 2,450 Tex
- Density = 2.68 g/cm3
- Elongation at break of the roving = 4.5%
- Young modulus (N/mm2) (MPa) = 72,000 Pa
- Traction resistance of the roving (Nw/mm2) (MPa) >1,700 MPa
- Traction resistance of the Virgin Filament = 3,500 MPa

3g. Cement, aggregate, water, additives and inorganic pigments

In general, they will comply with the EN 1338 Standard for concrete paving blocks as well as the national standards.

3h. Sand for jointing and bedding

On the one hand, the purpose of the base layer is to serve as a support for the lower paving blocks in prefabricated solutions, or as a support for the injection moulds of in situ solutions, which will allow its appropriate compaction and levelling.

On the other hand, the joint layer is going to lock the holes remaining between the paving blocks' joints both for prefabricated and in situ solutions. It should also be noted that unlike the conventional paving blocks, in this case, the joint layer function is to eliminate any movement between the paving blocks since the structural function of conventional ones is already given by the intermediate joint.

The grain size of the base layer (2 mm - 5 mm) is not considered as sand itself but it is normally designated as such.

The base layer thickness will be 2 cm minimum and must be set out above the granular layer, which, in turn, must be set out above the platform.

Sand must not include plastic fines lower than 75 micron. The content limit for organic matter and clay is 3%. As a general rule, if a type of sand is appropriate for making concrete, it will be adequate as sand bed.

Sands should be angular. Limestones are prohibited. Sands should be free from damaging soluble salt or any other contaminants in order to avoid halo efflorescence.

The recommendable grain size for the joint layer is maximum 1.25 mm. The same dosage is allowed for the upper layer when it is already dry, including cement and colorant as well as silica for jointing.

The granulometry of layers will follow the next granulometric interval:

Granulometric interval (mm)	Base layer	Joint layer
5.000	50-100	100
2.500	10-50	100
1.250	0-5	90-100
0.630	--	60-90
0.315	--	30-60
0.160	--	15-30
0.080	--	5-10

Table 1-2. Base layer's granulometry.

PART 4. QUALITY CONTROL.

In this part, the most important aspects for detachable pavement quality criteria are going to be summarized.

4a. Prefabricated paving blocks control:

Nominal sizes

The defined nominal sizes will be indicated in this Guide and will comply with the following requirements.
It should be noted that detachable pavers stand out especially for the geometric accuracy of the manufacturing media. As a result, the geometric tolerance is very strict.

Size tolerance

The paving blocks must meet the nominal sizes established in this Guide. The paving blocks will comply with the size requirements if, for each nominal size tested, the sample average value meets the nominal size stated by the manufacturer, according to the established tolerances.

Paving block thickness: +/- 1 mm.
Paving block base: completely even with no protuberances. A perfect contact with the intermediate joint will be guaranteed if the paving block does not move in relation with the intermediate joint when the later is loaded down.

Paving block side: +/- 0.7 mm.
Inner diagonal: +/- 1 mm.
The superficial layer thickness of the upper paving block will not be lower than 10 mm.

Control of aspect

The paving block surface will have no surface imperfection over 5%. The check will be carried out with a sample of 20 paving blocks once they are dry. If the check results are not satisfactory, the check will be repeated by taking 3 new specimens of 20 paving blocks each until a total of 80 paving blocks.

Colour and texture

If the prefabricated paving blocks have a special texture, it will be described by the manufacturer. Colours can cover the double layer or the paving block as a whole, as the manufacturer prefers.

Natural-coloured paving blocks will have no pigments or pigmented cements.
Paving blocks texture, tonality and colour will be practically uniform in each package unless, due to aesthetic reasons, other thing would be intended.

Mechanical and physical properties

The paving blocks will comply with the following prescriptions:

Water absorption

The paving block will be resistant to frost in a water absorption coefficient lower than 6%.

Tensile strength at break

The same requirements for any conventional paving block will apply. The tensile resistance (Tn) will not be lower than 3.6 MPa and none of the individual results will be lower than 2.9 MPa.

The paving blocks will comply with this requirement if the tensile resistance average value of the sample, according to the method established in the EN 1338 Standard, is not lower than 3.6 MPa and, in addition, values lower than 2.9 MPa have not been obtained.

Abrasive-wear resistance

None of the sample paving blocks will overpass the 23 mm according to the method established in the EN 1338 Standard.

Slipperiness

The following Standards will apply:

UNE ENV 12633	DIN 51130	DIN 51097	ASTM C 1028-07	
Pendulum test	Ramp test Wearing shoes	Ramp test Bare feet	CoF.DRY	Pendulum test
Class 3	R-12	Class C	≥ 0,6	Class 3

Table 1-3. Slipperiness of pavers.

4b. Injection moulds

Nominal sizes

The defined nominal sizes will be indicated in this Guide and will comply with the following requirements.

Size tolerance

The injection moulds must meet the nominal sizes established in this Guide. The injection moulds will comply with the size requirements if, for each nominal size tested, the sample average value meets the nominal size stated by the manufacturer, according to the established tolerances.

Side thickness: +/- 0. 1 mm.

Side height: +/- 0.1 mm
Side length: +/- 0.2 mm
Inner diagonal: +/- 0.25 mm

Straight segments alignment: maximum arrow: +/- 0.3 mm.

Geometric integrity

Faulty injection moulds will not be admitted if they overpass 0.5% where the piece geometry is not completed due to an error in the manufacture process or due to cavities, holes, fissures or drilled holes.

Overlap between pieces

The pieces will have the ability of tongue jointing each one with no need of making pressure or deforming pieces. The accomplishment of the size tolerance will guarantee this aspect.

Edges alignment and contact between pieces

The edges will have no arrows higher than the defined size tolerance, so verifying the correct contact between pieces.

Colour and texture

A non-uniform colour will be admitted for recycled materials.

Mechanical, impact, thermal and physical properties

The injection moulds will comply with the technical prescriptions indicated in Table 1.

4c. In situ paving blocks application control:

Nominal sizes

The in situ paving blocks application will stick to the injection moulds size. Faulty units or units not complying with the tolerance size must not be used.

Aspect control

The paving blocks surface will have no holes or protuberances. The units in situ with such defects will be retired and applied again. It will be especially checked that the superficial layer, once applied, is not stepped on.

Colour and texture

Colours can cover the double layer or the paving block as a whole, as the manufacturer prefers.
Texture, tonality and colour are aimed to be uniform. Therefore, the dosage of the upper layer must be uniform. This layer will not be lower than 20 mm.

Mechanical and physical properties

These paving blocks will comply just with the same prescriptions as the prefabricated blocks except for the maximum strength at failure test, which will be replaced by the flexotraction strength test on prismatic cylinders. To control and make the tests, the specimens will be checked away the pavement with the same filling material.

Water absorption

The paving block will be resistant to frost in a water absorption coefficient lower than 6%.

Flexotraction resistance

At the moment of traffic opening, the flexotraction resistance must be higher than 3.6 MPa and no individual result must be lower than 2.9 MPa.

The paving blocks will comply with this requirement if the rupture resistance average value of the sample, according to the method established in the UNE 83300:1984, UNE 83301:1991, UNE 83305:1986 Standards, is not lower than 3.6 MPa and, in addition, values lower than 2.9 MPa have not been obtained. It is recommended to use cylinders of 15x15x60.

Abrasive-wear resistance

No sample paving blocks will overpass the 23 mm according to the method established in the EN 1338 Standard.

Slipperiness

The following Standards will apply:

UNE ENV 12633	DIN 51130	DIN 51097	ASTM C 1028-07	
Pendulum test	Ramp test Wearing shoes	Bare feet	CoF.DRY	Pendulum test
Class 3	R-12	Class C	≥ 0,6	Class 3

Table 1-4. Slipperiness in detachable pavers.

4d. Control of manufacturing process and supply

In situ or prefabricated paving blocks

The desired dosage will be checked properly. Each component will comply with the prescriptions indicated both in this Guide and in the standards of application.

Both in prefabricated and in situ applications, the mixture has a highly importance in obtaining the best quality levels of the finished product. The mixing of components will be done with a mixer able to guarantee the highest homogeneity. The mixing time, counted since every foreseen component has been added to the mixer, will be enough to guarantee the homogeneity of the mixture.

The vibration of the pieces applied in situ must guarantee the absence of holes or hollows and the complete fill.

If there is vibro-compression, the control of the geometric uniformity of the vibration plant will be very important, avoiding out of tolerance irregularities. Likewise, it will be controlled the regularity of metallic moulds and counter-moulds.

The time of curing will not be lower than 1 week for prefabricated solutions and 7 days for in situ solutions without traffic opening.

Prefabricated solutions will be supplied within pallets of 7-10 m^2 average surface each. When the client requires it, the pallets will be accompanied with a phytosanitary certificate.

Each pallet will include the following information:

- Identification of the brand ACTISA or similar.
- Identification of the manufacturer and the factory.
- Notice of paving block for detachable pavements and typology.
- Nominal sizes.
- Identification of the product with the phrase "PREFABRICATED DETACHABLE PAVER-PAVING BLOCK"
- Identification of the pressing date.

This information will be included in the delivery notice as well as in the packing in at least two labels.

Image 9. Pallet of prefabricated pieces.

<u>Injection moulds parts</u>

During the injection process, the correct operation of the mould, the opening of the moving platens and the expulsion of the cooled unit will be supervised.

The unit will remain in the mould until it solidifies in order to avoid deformities.

The granules or pellets of the injection material will be appropriate for the injection process guaranteeing that the mould has been completely filled and the shape is exactly copied.

The manufacturer will calibrate properly the injection moulding machine (time, pressure, etc.) in order to guarantee the product prescriptions indicated in this Guide.

Each pallet of injected pieces will include the following information:

- Identification of the brand ACTISA or similar.
- Identification of the manufacturer and the factory.
- Notice of the injected piece for detachable pavements and typology.
- Nominal sizes.
- Identification of the product with the word "DETACHABLE PREFABRICATED PAVER-INJECTION JOINT" or with the word "DETACHABLE IN SITU PAVER-ABS MOULD" if it is in situ.
- Identification of the date of injection.


Image 10. Pallet of injections joints.

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4e. Delivery control

Prefabricated paving blocks

When the products are delivered, the quantity, labelled and aspect (surface faults, texture, colour, geometry and base regularity) will be confirmed. Among the paving blocks delivered, some of them (20 paving blocks every 2000 m^2, or fraction, in the same colour and model) will be randomly chosen in order to check the aspect. The prescriptions indicated in this Guide regarding aspect, texture, colour and base regularity apply. A good contact between the intermediate ABS joints will be essential when checking the base regularity. The client will fill out an approval sheet to the carrier, who will deliver it to the manufacturer or the trading company.

If the check results are not satisfactory, the check will be repeated by taking 3 new specimens of 20 paving blocks every 2000m2 each. The new specimens will be chosen among the paving blocks delivered in the same day in the same colour and model. The package will be admitted if there are no more than 4 faulty paving blocks.

Injection moulds parts

Likewise, when the products are delivered, the quantity, the labelled and geometry (geometric integrity, tongue jointing ability, edges alignment and contact between pieces) will be confirmed. Among the delivered paving blocks, some of them (50 paving blocks every 10,000, or fraction, of the same model) will be randomly chosen in order to check them. The prescriptions indicated in this Guide regarding geometric integrity, tongue jointing, edges alignment and contact between pieces apply. The client will fill out an approval sheet to the carrier, who will deliver it to the manufacturer or the trading company.

If the check results are not satisfactory, the check will be repeated by taking 3 new specimens of 50 paving blocks of the same model every 10,000 injected pieces of the same model. The package will be admitted if there are no more than 2 faulty pieces.

4f. Laboratory control

Package size:

Prefabricated paving blocks: 2,000 m^2.
In situ paving blocks: 2,000 m^2.
Injection moulds units: 10,000 units.
Injection moulds materials: 10,000 units.

Sample size: units for making tests

Prefabricated paving blocks 3 x (6 units) Paving blocks admitted in the delivery control. (Triple test)

In situ paving blocks 3 x (6 units) Paving blocks made of the same filling material as in situ pieces. (Triple test)

Injection moulds units: 20 units. Paving blocks admitted in the delivery control.

Injection moulds material: pellets for cylinders (60 kg). Three specimens with the dimensions set in the DIN standards will be injected for each test. The material may also be obtained through grinding the package pieces until reaching 60 kg.

Preservation

The specimens will be duly preserved and kept until the date of each test. Injection moulds parts will be protected from sunshine

Tests

- geometric features
- water absorption
- breaking test
- abrasion resistance
- slipperiness

Prefabricated pieces

The following tests will be carried out by taking 3 specimens:

The pieces used for the size control will be able to be reused for the destructive test.

The age of the pieces will be shown in the test report, but it has to be taken into account that it is not until 28 days after its pressing process when the paving blocks will comply with the specified physical requirements.

The specimens for the tests must be sent 3 weeks after the reception. And the tests must be returned in a maximum period of 4 weeks from that date.

The choice of the laboratory will be agreed upon between the manufacturer and the client. The date of taking specimens and carrying out the tests will be also mutually agreed. In both activities, the manufacturer will be able to be present or represented.

Also, the checks and tests as well as the reception will be able to be carried out in the manufacturer facilities with the client's approval.

The receivers will communicate their agreement or objection to the manufacturer immediately after knowing the test results.

If the paving blocks are set before carrying out the tests, it is deduced that the receiver agrees on the materials that have been already set.

If the test results are satisfactory, the supply is accepted.

If one or more tests have unsatisfactory results, two series of contrast tests, for the cases in doubt, will be carried out unless the manufacturer decides to take the package back. These tests will be also carried out in a laboratory by mutual agreement between the client and the manufacturer. It must have passed a minimum of 28 days from the date of pressing.

If these complementary tests are satisfactory, the package will be accepted and, if not, the package will be re-classified or removed whenever possible and as long as the client agrees.

The test and sample costs will be covered by those who would have ordered the test. If the final results are unsatisfactory, the costs will be covered by the manufacturer.

Pieces applied in situ

The following tests will be carried out by taking 3 specimens:

- water absorption
- flexotraction resistance
- abrasive-wear resistance
- slipperiness

The age of the pieces will be shown in the test report, but it will be taken into account that it is when the traffic is opened (7 days minimum) that the pavement will comply with the specified physical requirements. The test will be admitted 28 days after manufacturing the concrete since only with 7 days the flexotraction resistance is already 75%.

The specimens for the tests must be sent 3 weeks after the reception. And the tests must be returned in a maximum period of 4 weeks from that date.

The choice of the laboratory will be agreed upon between the developer and the construction company. The date of taking specimens and carrying out the tests will be also mutually agreed. In both activities, the construction company will be able to be present or represented.

The developer will communicate their agreement or objection to the construction company immediately after knowing the test results.

If the test results are satisfactory, the application is accepted.

If one or more tests have unsatisfactory results, two series of contrast tests, for the cases in doubt, will be carried out unless the construction company decides to take the package back. These tests will be also carried out in a laboratory by mutual agreement between the developer and the construction company. It must have passed a minimum of 28 days from the date of manufacturing.

If these complementary tests are satisfactory, the application is accepted and, if not, the pavement will be taken back.

The test and sample costs will be covered by those who would have ordered the test. If the final results are unsatisfactory, the costs will be covered by the construction company.

Injected pieces

The following tests will be carried out on the whole number of pieces (20 units per package).

- geometric control and tolerances.
- density: ASTM D 792.

With pellets, 3 specimens will be considered, one for each of the following tests:

- ASTM D638.
- ASTM D790.
- ASTM D785
- ASTM D256.
- ASTM D1525.
- ASTM D648.
- ASTM 1238.
- UL 94.

The specimens for the tests must be sent 1 week after the reception and the tests must start 2 weeks after that reception. On the other hand, the pellets or granules will be picked up by the laboratory on any day during the package manufacturing; if not, the material will be obtained though grinding the corresponding pieces of the package.

The choice of the laboratory will be agreed upon between the developer and the manufacturer. The date of taking specimens and carrying out the tests will be also mutually agreed. In both activities, the manufacturer will be able to be present or represented.

The receivers will communicate their agreement or objection to the manufacturer immediately after knowing the test results.

If the test results are satisfactory, the application is accepted.

If one or more tests have unsatisfactory results, two series of contrast tests, for the cases in doubt, will be carried out unless the manufacturer decides to take the package back. These tests will be also carried out in the laboratory agreed between the developer and the manufacturer. It must have passed a minimum of 28 days from the date of pressing.

If these complementary tests are satisfactory, the application is accepted and, if not, the the injected pieces will be taken back.

The test and sample costs will be covered by those who would have ordered the test. If the final results are unsatisfactory, the costs will be covered by the manufacturer.

PART 5. APPLICATION AND DISASSEMBLING.

5a. Application of detachable prefabricated pavers:

Once the paving blocks have been received in the construction site and validated, this is the application process:

1. Superficial finishing, level and compact the base course and the granular layer or the graded aggregate depending on the case.
2. Spread up the sand over granular layers.
3. Level the sand. The thickness of the sand will overpass 2 cm and a topographer will validate the levelling.
4. Apply the paving blocks on the lower layer. Pieces will be in contact with each other, leaving a space which corresponds to the projecting perpendicular bands.
5. Compacting paving blocks and filling with jointing sand.
6. Edges treatment. Edges will be finished with a rigid element (kerb, rigola or similar); if they have not been foreseen, an edge beam with a minimum width of 20 cm and a minimum height of 12 cm will be applied. Between the rigid element and the lower layer detachable pavers there will be a joint whose minimum thickness will be 1 cm and which will be made with cement mortar.
7. Apply the injection of the intermediate joint following the tongue jointing process.
8. Apply the upper piece. Pieces will be in contact with each other, leaving a space which corresponds to the projecting perpendicular bands.
9. Treat edges just like in the lower layer process.
10. Sand jointing.
11. Open traffic immediately.

Image 11. Different stages in execution of prefabricated detachable pavement.

5b. In situ application with injection moulds

Once the injection moulds have been received and validated, this is the application process for in situ pavers:

1. Superficial finish, level and compact the base course and the granular layer or the graded aggregate depending on the case..
2. Spread up the sand over graded aggregate or granular layer..
3. Level the sand. The thickness of the sand will overpass 2 cm and a topographer will validate the levelling.
4. Optional: Apply a plastic layer (minimum thickness: 200 micron) to improve the regularity of the paving blocks bottom.
5. Apply tongue jointing injection moulds. The moulds will be in perfect contact with no holes between the joints so that the concrete cannot go down.
6. Trim the injection moulds in edges. Edges will be finished with a rigid element (kerb, rigola or similar). If no rigid element has been foreseen, an edge beam with a minimum width of 20 cm and a minimum height of 12 cm will be applied.
7. Apply formwork in particular places such as control boxes, tree gratings, etc.).
8. Delivery of concrete in the injection moulds with a vibrator.
9. Once the concrete has solidified or when the concrete is still wet (wet&wet), apply injection moulds to form the joint.
10. Fill the finished superficial concrete.
11. Remove the superficial joint after 48 hours.
12. Sand jointing.
13. Traffic opening after 7 days.

When superficial prefabricated elements or paving blocks of stone are needed for finishing the in situ pavers, the process from phase 8 will be as follows:

8. Delivery of concrete in the injection moulds with a vibrator leaving 1 cm of the mould free in order to apply the mortar afterwards.
9. Apply the mortar once the concrete has solidified (at least 24 hours after the application). The mortar will overpass the mould height no more than 5 mm.
10. Apply and level the finished pieces.
11. Sand jointing.

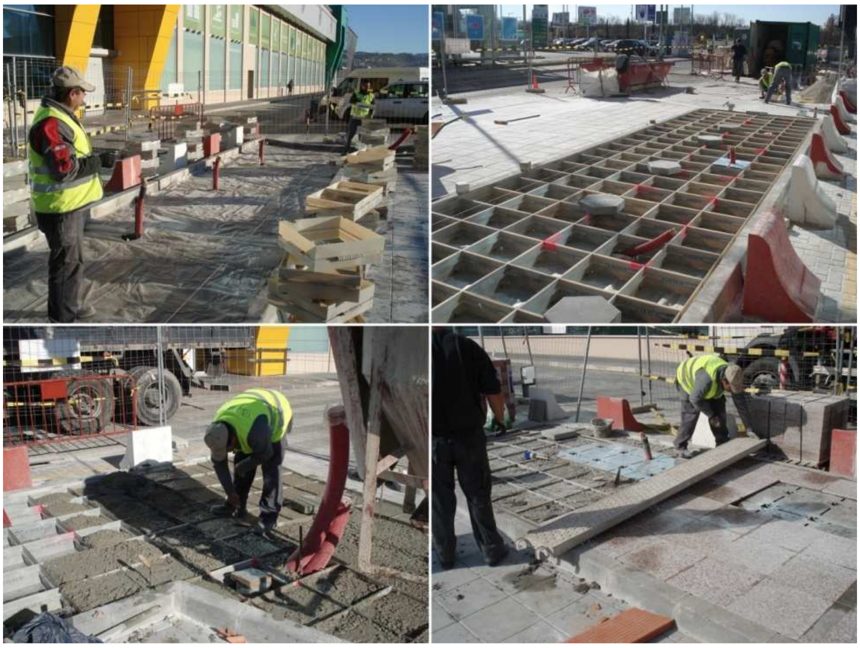


Image 12. Different stages in execution of in situ detachable pavement.

5c. Combining formats

The capacity of combining formats enriches extraordinarily the aesthetic of pavement. However, it is advisable to treat the joints correctly as they become points of structural weakness.

The treatment is different for prefabricated and in situ pavers.

Prefabricated pavers

When, in the edge, pieces in one of the formats cannot be completed, the intermediate joint of said format will be extended until it leans, at least, 1/4 of the surface on the next piece in the other format; the intermediate joint will be cut leaving the necessary space.

When none of the two formats can be completed in the edge, the smaller unit will be extended over the lower pieces of the larger one.

Image 13. Detail of overlapping of intermediate joints

In situ pavers

In this case, the format will be applied with an edge formwork. When the application of these units is finished, the ones in the other formats will be done. Optionally, the joints may be treated or injection plates may be set out in order to avoid adhesions.

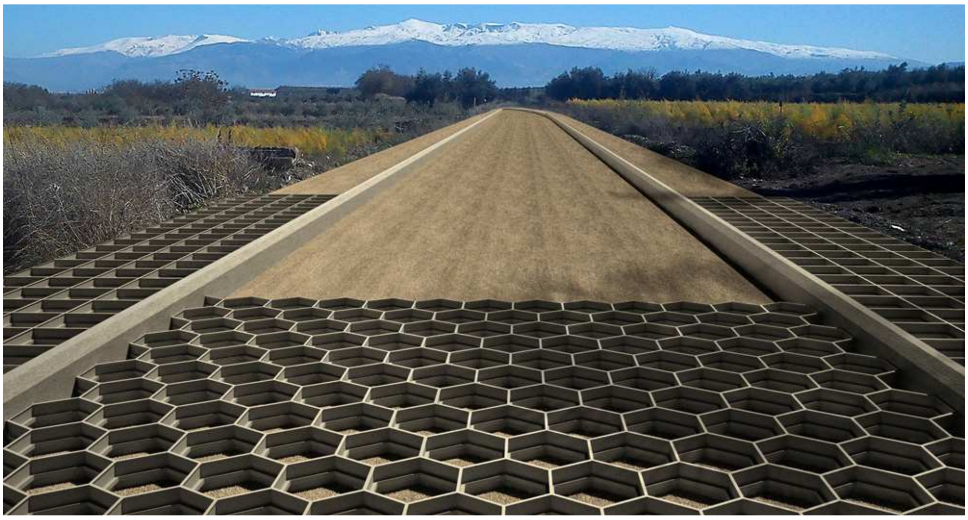


Image 14. Use of two formats of in situ pavement.

PART 6. URBAN SOLUTIONS.

One of the advantages of detachable pavement is the important possibility of combining colours and formats in favour of getting the best aesthetic finishing.

The range of possibilities is huge: from a monochrome solution looking for sobriety until solutions with three or four formats and different colours if looking for more important urban aesthetic.

Architects, engineers and urban designers will choose the best solutions depending on the case. Nonetheless, different possibilities of combining are offered in the following points.

MONOFORMAT AND MONOCHROME SOLUTIONS

In general, they are the simplest solutions as for construction. Their great sobriety makes them advisable for spaces where the architecture of nearby building is expected to be highlighted.

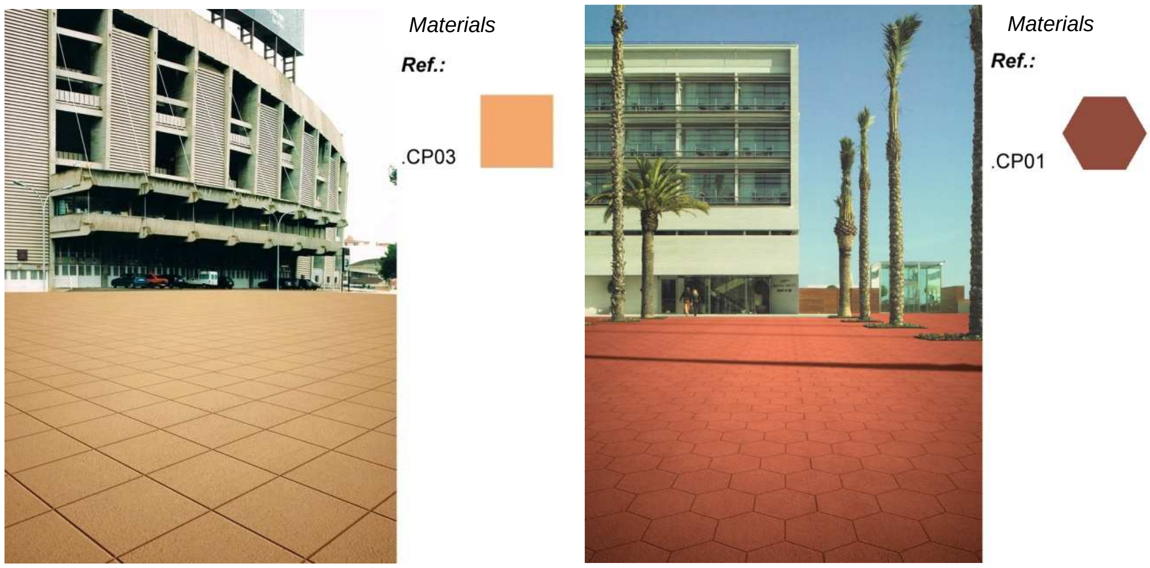
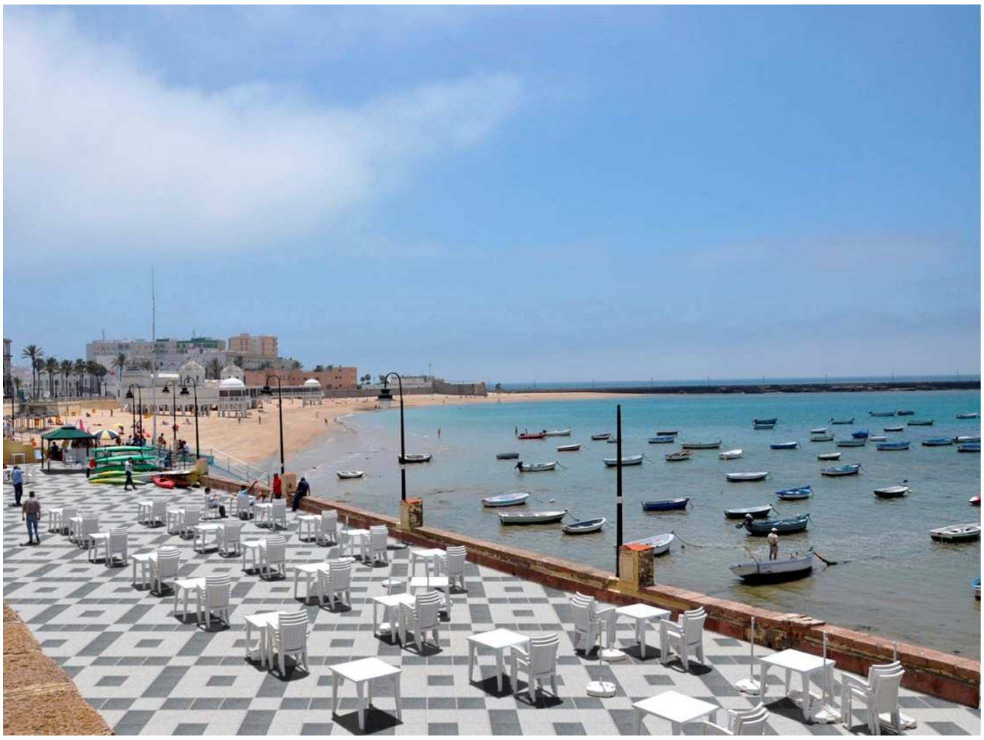


Image 15. Detail of monoformat and monochrome solutions.

MONOFORMAT AND BICOLOUR SOLUTIONS

Prefabricated hexagonal solutions may be set out like a chessboard in two colours through applying half-units in the upper layer. For in situ solutions, it is recommendable to apply sequentially each format and protect the finished pieces in order to avoid projections and damages to the upper layer of the first format finished.



Materials

Ref.:

.CI01

.CI08

Image 16. Detail of monoformat and bicolour solutions.

MONOFORMAT AND MULTI-COLOUR SOLUTIONS

Equal in construction simplicity, it is enough with locating conveniently each one of the relevant colours.

Materials

Ref.:

.CP01

.CP02

.CP03

Image 17. Detail of monoformat and multi-colour solutions.

MULTIFORMAT AND MONOCHROME SOLUTIONS

Although they are more difficult to build, they enable a greater appealing design for differentiating areas according to the use (car parking, road, sidewalk, etc.) In prefabricated solutions, the overlapping of intermediate joints will be carried out suitably.

Image 18. Detail of multi-format and monochrome solutions.

MULTIFORMAT AND BICOLOUR SOLUTIONS

They enhance more effectively the distinction among urban spaces.

Image 19. Detail of biformat and bicolour solutions.

MULTIFORMAT AND MULTI-COLOUR SOLUTIONS

As for urban aesthetic, with this solution, the greatest richness ever is achieved.

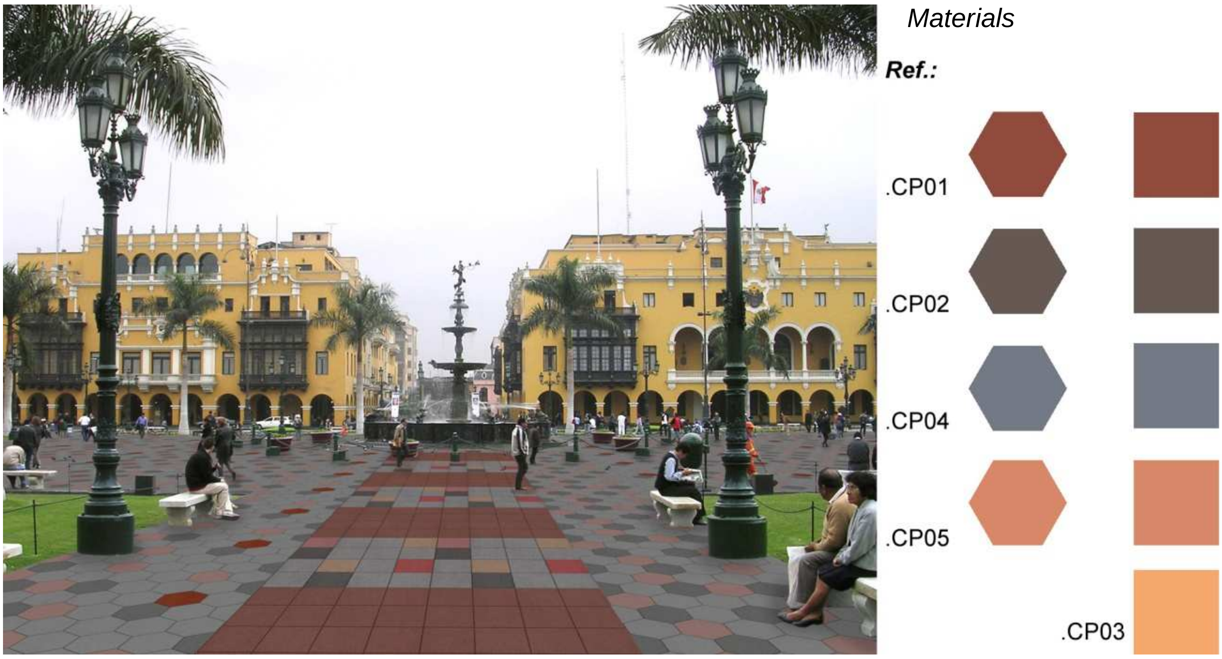


Image 20. Detail of solution in several formats and colours

STONE SOLUTIONS (IN SITU), UNIQUE SUPERFICIAL FINISHING

Stone solutions in only one colour look for sobriety. Stone solutions are also quite appropriate for rural areas, places of cultural interest or historical centres.

Image 21. Detail of solution with stone finishing.

STONE SOLUTIONS (IN SITU), SEVERAL SUPERFICIAL FINISHING

They are solutions of great aesthetic but of higher cost. Detachable pavers enable to reduce considerably stone thickness as well as the price of these types of pavers, which have been applied with paving blocks of thicker stone.

Image 22. Detail of solution with finishings in different types of stone.

SOLUTIONS WITH SOLAR TILE

Solar tiles adapt perfectly to the geometry of detachable pavers.

Combining solar tile and detachable pavers may be carried out through signalling, permanent or intermittent lights in the edges of the road, decorative lights or through energy production from solar tiles.

Image 23. Detail of pavement with solar tiles included.

7a. CLASSIFICATION OF THE UNDERLYING NATURAL SOIL (UNS)

The common classification of soil and material established in the general technical standards will be followed. The symbol, designation of material and complementary prescriptions for their use in core or base courses is described in the following chart.

Symbol	Designation of material	Complementary prescriptions for their use in	
		Core	Base courses
SIN	Inadequate Soil	Cannot be used	Cannot be used
S00	Marginal Soil	Special study Cannot be used in floodable areas	Cannot be used
S0	Tolerable soil	CBR ≥ 3 Swelling (1)< 3% Cannot be used in floodable areas	Cannot be used
S1	Adequate Soil	CBR ≥ 5 Swelling (1)< 3% Except in floodable areas with <1%	CBR ≥ 5 Swelling (1) zero Can only be used in soils SIN,S000 or S0
S2	Selected Soil Type 2	CBR ≥ 10 Swelling < 1%	CBR ≥ 10 Swelling (1) zero
S3	Selected Soil Type 3	CBR ≥ 20 Swelling (1)< 1%	CBR ≥ 20 Swelling (1) zero
S4	Selected Soil Type 4	CBR ≥ 20 Swelling (1)< 1%	CBR ≥ 40 Swelling (1) zero
S-EST1	Soil Stabilised On Site Type 1	Lime or cement ≥ 2% and CBR after 7 days ≥ 6	
S-EST2	Soil Stabilised On Site Type 2	Lime or cement ≥ 3% and CBR after 7 days ≥ 12	
S-EST3	Soil Stabilised On Site Type 3	Compression resistance after 7 days ≥ 1.5 MPa and Cement ≥ 3%	
Z	Graded aggregate	According to Article 510 of the PG-3	
ROCK	Cut sections in rock	-	Regularization with concrete HM-20
P	Rockfill	According to regulations	Cannot be used in base courses
TU	Quarry-run fill	According to regulations	Cannot be used in base courses
(1)	The swelling will be performed in an oedometer according to Norm UNE 103.601		

Table 1-5. Use of materials in core and in base courses.

To make the classification of UNS, for embankment and base courses, the CBR test will be carried out with the optimal moisture from normal Proctor compaction test and with a density of 95% from the normal Proctor test for any type of soil. The classification UNS will be made with specimens located 2 m under the scaling foreseen in cut sections or 2 m under the surface of cut in embankment.

7b. ESPLANADE FEATURES

Three categories of foundation pavement materials are considered:

- LOW with an equivalent modulus Ee of 60 MPa (E1)
- MEDIUM with an equivalent modulus Ee of 100 MPa (E2)
- HIGH with an equivalent modulus Ee of 160 MPa (E3

For S2, S3, S4, Quarry-run fill, Natural Graded aggregate, Artificial Graded aggregate the following elasticity modulus will be considered:

Materials	Maximum E(MPa)	Poisson coefficient
Soil Type S2	150	0.35
Soil Type S3	200	0.35
Soil Type S4 and Quarry-run fill.	250	0.35
Natural Graded Aggregate	350	0.35
Artificial Graded Aggregate	500	0.35

Table 1-6. Elastic parameters of materials used in esplanades.

For soils stabilized in situ the following mechanic features will be considered.

Materials	Maximum E (MPa)	Poisson coefficient
Soil Stabilised Type S-EST1	100	0.35
Soil Stabilised Type S-EST2	200	0.30
Soil Stabilised Type S-EST3	1.000	0.25

Table 1-7. Elastic parameters used in selected soil.

For featuring the base courses elasticity modulus, the following recommendations are considered:

- In cut sections, the supports will be mounted directly by UNS soils, which will have a semi-infinite elastic solid. If necessary, possible scaling and soil replacement will be made.
- In embankments of less than 2 m height, the whole defined by the embankment, its scaling and the semi-infinite elastic solid will be considered.
- In embankments of more than 2 m height, the core soil features will be considered.

The E modulus of the esplanade will be the Ev2 obtained in the plate load test.

7c. PROJECT TRAFFIC

The following usual categories will be considered as for the project traffic:

Category	IMDPA
T00	≥ 4.000
T0	≥ 2.000 y < 4.000
T1	≥ 800 y < 2.000
T2	≥ 200 y < 800
T3A	100 y < 200
T3B	≥ 50 y < 100
T4A	≥ 25 y < 50
T4B	< 25

Table 1-8. Traffic categories.

The number of repetitions of loads foreseen during the service life is obtained with the simplified expression (Crespo et al, 1986):

NT = VP x C x A x 365

NT = Number of repetitions of standard load during calculations.
VP = Number per day of heavy vehicles passing by the lane of the project, during the year of coming into service.
C = Growth factor
A = Equivalence factor of a heavy vehicle with standard axle of value 1.

The growth factor is calculated as follows (Crespo et al., 1986)

$C= [(1+r)^n -1] / r$

Where:

C = Growth factor
n = number of years
r = annual growth rate foreseen

It is highly important that the engineer calculator arranges the pavement materials for the maximum level of traffic to be supported in the lifetime of the project. In particular, for important traffic growth, the traffic category will get increased in one or even two steps..

The annual traffic in the horizon year will be given by:

$NTn = VP \times (1+r)^n \times 365$

The average traffic will be NTn. A maximum value of 5000 heavy vehicles per lane and day is established.

7d. MATERIALS TO CONSTITUTE PIECES

Specifications given in this Guide will be accomplished.

7e. GRADED AGGREGATE OR GRANULAR LAYERS

They are layers that work as a support for detachable pavers to be located over the esplanade. The deformation modulus will overpass 500 MPa. Graded aggregate will be artificial and will comply with the application standards depending on the construction place; when gravel, macadam or other similar material are used, the union with the esplanade will be defined by geotextiles, filter materials, etc. In any case, in the granular package, at least 2 cm at the top in contact with the pavers will be made up of sand with no more than 3% of clay and silt.

7f. CALCULATION MODEL

To model the behaviour of pavement materials, the adherence among soil layers is considered as complete. The contact between the detachable pieces and the soil and also with each other has been established in a model using techniques of contact between solids.

The model features are:

- The base courses are made up of horizontal layers parallel to each other and with constant thickness.
- Each layer is an elastic lineal, homogeneous, isotropic and continuous medium. They are characterised mechanically by the Young modulus (E) and by the Poisson coefficient (ν).
- There is a continuous support among layers of soil adhering them to each other; this adherence is characterised by the roughness of the layers' surfaces, function of inner friction coefficient.
- Inertia forces and thermal effects are negligible. Thermal solicitations are not taken into account.
- The shear is negligible in the contact wheel-pavement,
- The inherent weight of pavers is not considered.
- For the materials to constitute pavement, an elastic lineal behaviour will be considered. Therefore, to define the material relationship stress-deformation, only two parameters are needed:
    - Módulo de Young, (E)
    - Coeficiente de Poisson, (ν).

7g. STRUCTURAL BEHAVIOUR LAWS

For dimensioning, two types of load are considered:

- Load matching an axle of 20T and a wheel track of 60x20cm.
- Load matching an axle of 13T and a wheel track of 60x20cm.

It has to be noted that most of standards calculate the sections of pavement materials for an axle of 13T but, in structures, they consider the car of 60T with 20T per axle.

In our case, the dimensioning of the pieces to be treated both in flexotraction resistance and tangential stress tests is made with loads of 20T, sharing the traditional criteria for structures. But, strength tests on concrete and soil layers are made with loads of 13T.

The calculation of maximum flexotraction and tangential tension with loads of 13T has only been carried out for in situ solutions with opening in 7 days.

For each piece and each type of section of pavement material, laws of flexotraction resistance and tangential tension are obtained according to the function of parameters E, modulus of deformation of the esplanade and the graded aggregate thickness. A modulus of granular layers of 500 MPa has been always considered.

7h. FAILURE CRITERIA AND STRUCTURAL DIMENSIONING

MAXIMUM FLEXOTRACTION STRENGTH

The dosage defined both for prefabricated and in situ pieces enables to obtain safety coefficients of more than 1.5 in the pavement materials solutions described in this point.

This formula considers the traffic opening after 7 days, not being recommendable to open it before unless the construction management indicates otherwise. In this case, it will be justified that 75% of common concrete resistance has been achieved. The foreseen control will be intense or normal according to the prescriptions given in the project or by the construction management.

The check for in situ solutions to be opened after 7 days has been made for loads of 13T and, as mentioned before, for 76% of the common concrete resistance.

TANGENTIAL STRENGTH AT BREAK

In the same way, safety coefficients of 1.5 have been achieved in the tangential strength test for the proposed sections of both prefabricated and in situ solutions.

The check for in situ solutions to be opened after 7 days has been made for loads of 13T and, as mentioned before, for 76% of the common concrete resistance.

FAILURE DUE TO FATIGUE CRACKS

Both for prefabricated and in situ solutions, the common resistance of concrete will comply 100% with the tests:

$$f_{ck} > \sigma_{ct\cdot\ \text{Máx 13T}} \ / \ [0.165\ (1\text{-}0.065 \log N)]$$

Where f_{ck} is common concrete resistance $\sigma_{ct\cdot\ \text{Max 13T}}$ the maximum flexotraction strength expected in the piece according to the section of pavement materials designed for an axle load of 13T and *N* the number of repetitions of load.

The materials defined in this Guide and all the formats are expected to have a lifetime of more than fifty years for traffic of up to two thousand heavy vehicles per lane daily.

FAILURE OF FOUNDATION MATERIALS.

The vertical plain stress in the surface of the foundation is considered as a fundamental parameter. This value is given by the number of repetitions of loads foreseen in the lifetime of the project, as the following expression shows:

$$\varepsilon_z = 0.0216\ N^{-0.28}$$

The necessity of esplanade has been checked for each kind of piece according to the project lifetime and traffic.

When projecting an esplanade E3 is not enough, the following additional measures are projected:

- 50 cm above the esplanade E3 of selected soil S4, (Ev2>250 MPa).
- 40 cm extra of artificial graded aggregate, (Ev2>500 MPa).

In this Guide particular solutions are proposed for each esplanade, for each lifetime and for project traffic.

FAILURE IN GRANULAR LAYERS.

The vertical stress over the granular layer will not overpass 3 kg/cm^2.

PROPOSED SECTIONS OF PAVEMENT MATERIALS. CALCULATION.

The proposed procedure is the following:

1. the **type of esplanade** where pavers will be placed is defined.
2. the **format** (in situ or prefabricated) is selected..
3. the **lifetime**, the type of traffic and its growth are defined.
4. the type of pavement materials is selected following the criteria proposed for **each typology**.
5. requirements of base course are **determined according to the fatigue criteria for lifetime**, project traffic and growth data. For each traffic level the maximum admissible stress will be determined in the base course according to the proposed table. If the value needed for the esplanade is more exigent, the section of the pavement materials will have to be rearranged, starting from step 1.º and selecting an upper level for the esplanade.

SECTIONS OF PAVEMENT MATERIALS PER ESPLANADE AND FORMAT.

Pre-fabricated pavers. RECT 33,3x33,3 y HEXAGONAL 20 SIDE

Esplanade	Graded Aggregate (cm)	Esplanade top	Maximum number of load applications
E1	30		710.425
	40		1.458.907
	50		4.076.030
	50	50 cm S4	71.129.573
	50	50 cm ZA	103.061.343
E2	30		199.452
	40		594.601
	50		1.504.456
	50	50 cm S4	23.885.140
	50	50 cm ZA	29.371.379
E3	30		65.840
	40		192.983
	50		324.118
	50	50 cm S4	5.214.934
	50	50cm ZA	7.455.615

Table 1-9. Maximum number of load applications depending on esplanade and granular layers for prefabricated solutions (hexagonal 20 cm side and rectangular 33.3 x 33.3 cm side).

In situ pavers: HEXATRÍPETO 20 cm SIDE

Esplanade	Graded Aggregate (cm)	Esplanade top	Maximum number of load applications
E1	30		290.971
	40		785.722
	50		2.584.302
	50	50 cm S4	23.873.653
	50	50 cm ZA	29.280.233
E2	30		107.351
	40		272.437
	50		874.203
	50	50 cm S4	7.068.594
	50	50 cm ZA	9.975.803

Esplanade	Graded Aggregate (cm)	Esplanade top	Maximum number of load applications
E3	30		40.280
	40		92.807
	50		317.183
	50	50 cm S4	2.032.558
	50	50cm ZA	3.229.832

Table 1-10. Maximum number of load applications depending on esplanade and granular layers for in situ solutions (hexagonal 15 cm side).

In situ pavers: HEXATRÍPETO 40 cm SIDE

Esplanade	Graded Aggregate (cm)	Esplanade top	Maximum number of load applications
E1	30		408.609
	40		709.468
	50		1.573.421
	50	50 cm S4	7.610.603
	50	50 cm ZA	13.281.117
E2	30		141.025
	40		230.043
	50		537.383
	50	50 cm S4	1.531.733
	50	50 cm ZA	4.298.633
E3	30		44.313
	40		74.488
	50		182.447
	50	50 cm S4	363.395
	50	50cm ZA	1.456.770

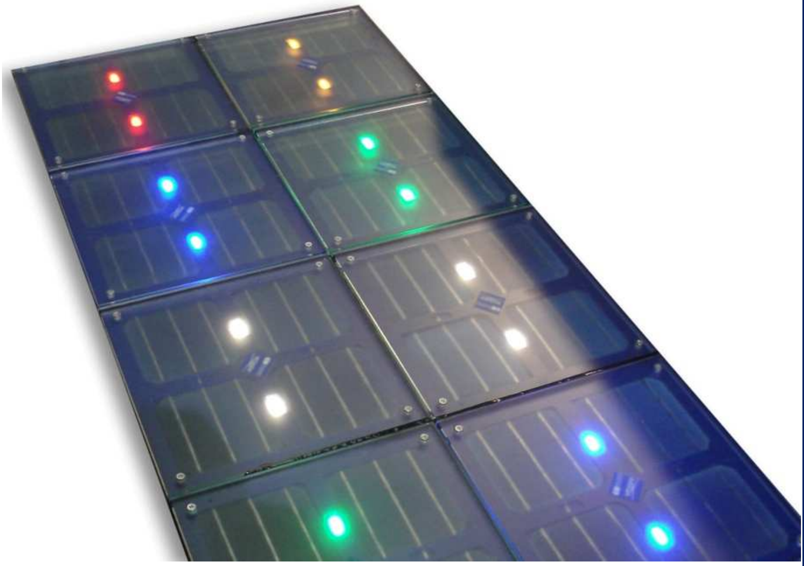
Table 1-11. Maximum number of load applications depending on esplanade and granular layers for in situ solutions (rectangular 40 cm side).

BASE COURSES ACCORDING TO TRAFFIC LEVEL

	UNS	Inadequate or marginal Soil			Tolerable Soil		Adequate Soil		Selected Soil
	Sol	Solution1	Solution2	Solution3	Solution 1	Solution 2	Solution 1	Solution 2	Solution1
Esplanade category	E1	100cm S1	35 cm S2 over 50 cm S1	35 cm S2 over 70 cm S0	60 cm S1	45 cm S2	100 cm UNS		
	E2	100 cm S2	40 cm S3 over 60 cm S1	40 cm S3 over 80 cm S0	75 cm S2	40 cm S2 over 50 cm S1	55 cm S2	35 cm S3	100 cm UNS
	E3	100 cm S3	50 cm S3 over 70 cm S2	80 cm S4	80 cm S3	70 cm S4	60 cm S3	50 cm S4	50 cm S3

Table 1-12. Solutions of esplanade according to UNS

CAP 2. THE SOLAR TILE



CAP 2.

THE SOLAR TILE

PART 1. GENERAL OVERVIEW.

The solar tile gives a qualitative leap towards the traditional concept of pavement as they are able to provide additional qualities to those of floor and aesthetic.

The ability of incorporating power-generating solutions enables to discern a wide-ranging variety of possibilities. Among them:

- Illumination from floor working as signalling.
- Illumination from floor working as decorative elements.
- Power-generating solutions for public lighting.
- Supply to other urban elements as advertising panel or MUPI.
- Supply to station of charger for electric cars.
- Supply to telecommunication equipments such as Wi-Fi, Bluetooth, RDFI, etc.
- Supply for domestic use.

The location of a solar module in the pavement may be less effective than in other locations due to horizontality and dirtiness effects. However, the proximity to the supply point, the autonomy of the net and the use of pavers as a support base have advantages that make the solar tile a useful, feasible and essential element for the modern concept of urban environment.

The solar tile is a milestone for the new concept of modern city, generating new services never imagined for the user. These services are very helpful for the user's daily life.

The concept of intelligent pavement based on the concept PIPER (Pervasive Intelligent Pavement Enhanced Reality) will allow applications which make the user's life easier as they include pervasive applications viable thanks to smart phones, tablets and other devices.

Therefore, mobility applications, useful and interactive marketing and pervasive social networking will be feasible thanks to solar tiles deployed in urban areas.

The manufacture of solar tiles with materials suitable for their deployment in pavement, with resistance for heavy traffic and valid slipperiness for pedestrian… all these features turn the solar tile into elements of great interest for urban areas.

PART 2. GEOMETRIES AND FORMATS.

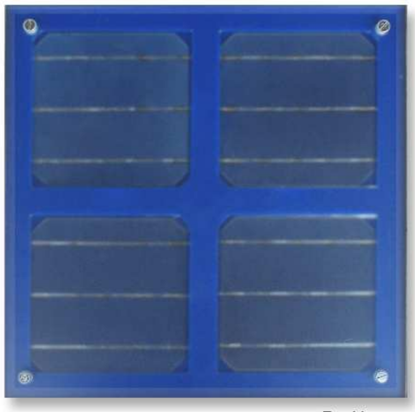
The solar tiles are designed with the appropriate features for their location in pavement.

Their rigidity, the superficial protector's slipperiness and their transparency are essential attributes for guaranteeing the right operation of solar tiles.

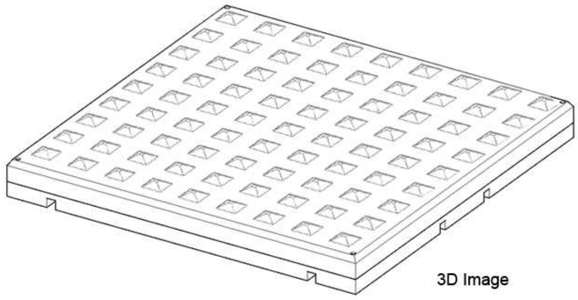
The available formats are the following:

BS-PFV-SQ400

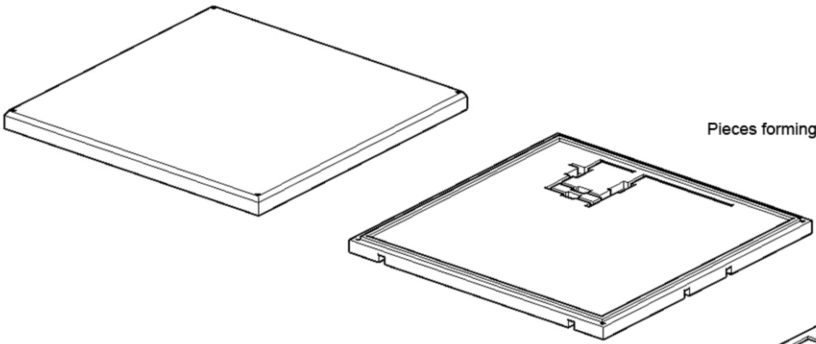
Solar tile 40x40 cm with back-lighting for photovoltaic energy production



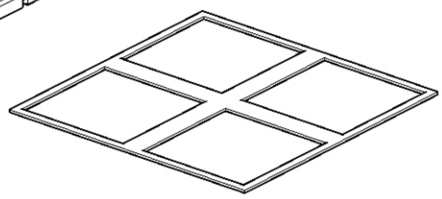
Real image



3D Image



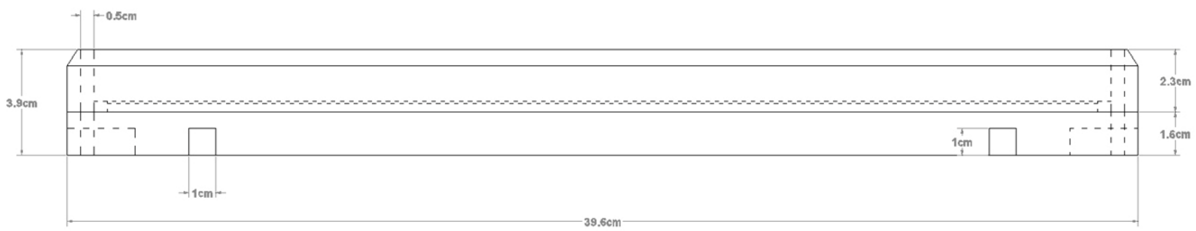
Pieces forming the solar tile



MAXIMUM POWER : **16,08W**
VOLTAGE WITH MAXIMUM POWER: **2,4V**
ELECTRIC CURRENT WITH MAXIMUM POWER: **6,7A**

SIZES: **396 x 396 X 30 mm.**
SOLAR CABLE: **4mm² IP67**

MATERIAL: **INJECTED PMMA**

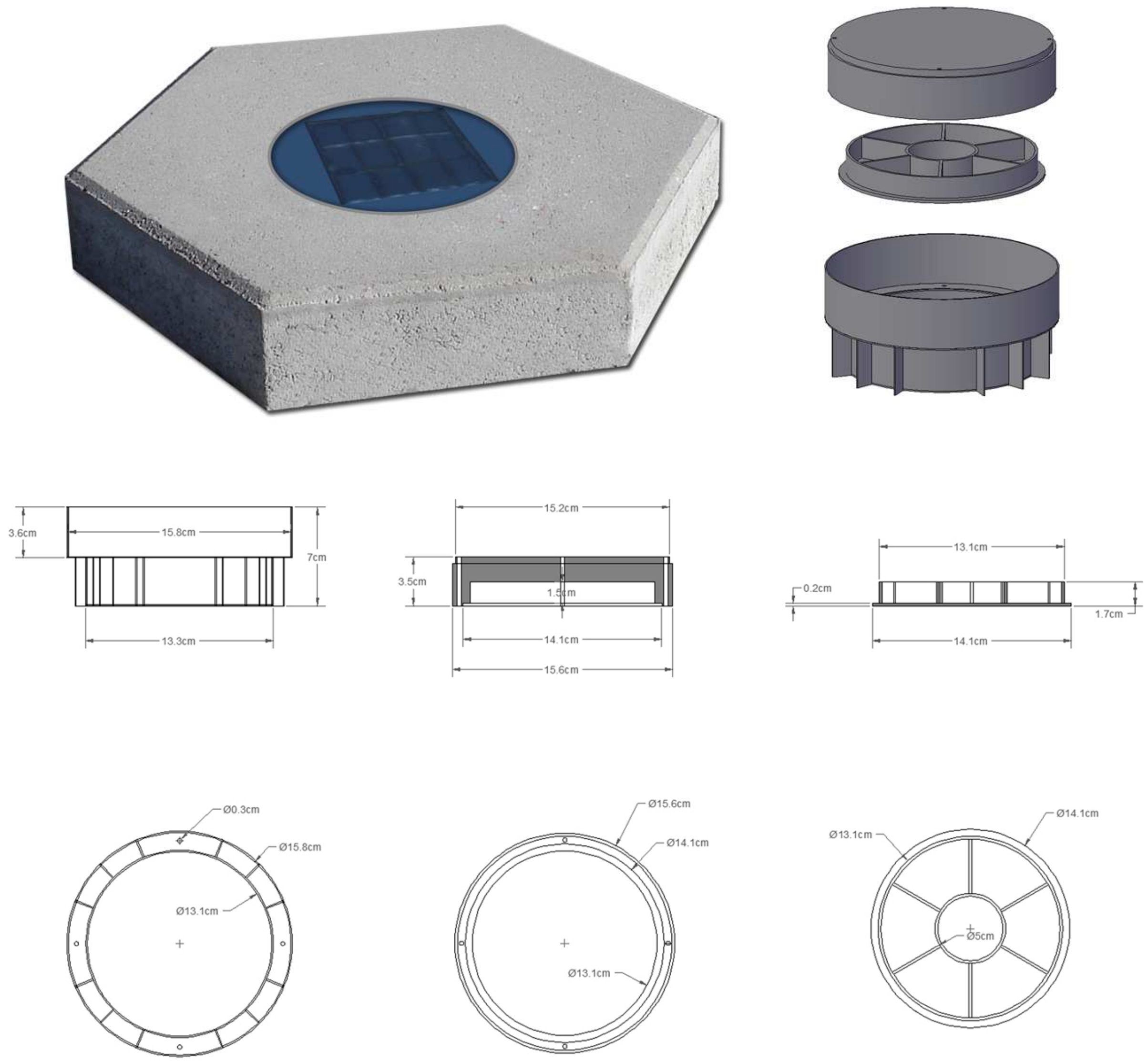


Section detail

Image 24. Geometry of solar tile BS-PFV-SQ400.

BS-PFV-C160

Road solar tile for photovoltaic energy production



MAXIMUM POWER : **1,2W**
VOLTAGE WITH MAXIMUM POWER: **6V**
ELECTRIC CURRENT WITH MAXIMUM POWER: **200mA**

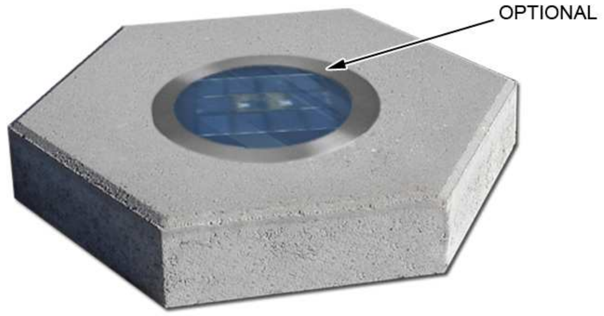
SIZE: **CIRCULAR 160 x 70mm.**
SOLAR CABLE: **4mm^2 IP67**

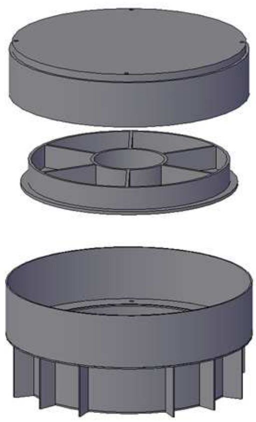
MATERIAL: **INJECTED PMMA**

Image 25. Geometry of solar tile BS-PFV-C160.

BS-DS-C160

Decorative solar tile for guiding





MAXIMUM POWER : **1,2W**
VOLTAGE WITH MAXIMUM POWER: **6V**
ELECTRIC CURRENT WITH MAXIMUM POWER: **200mA**

SIZE: **160 x 70 mm.**
OPERATION: **OFF-LINE**

MATERIAL: **INJECTED PMMA**
2 WHITE LED, 28-4.0V, 20mA, 18500 mcd

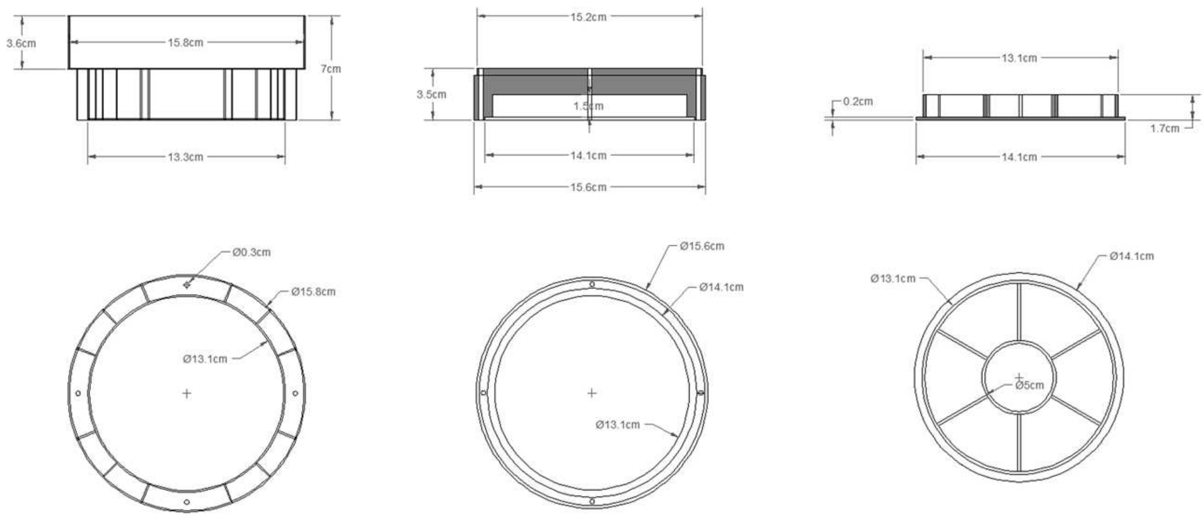
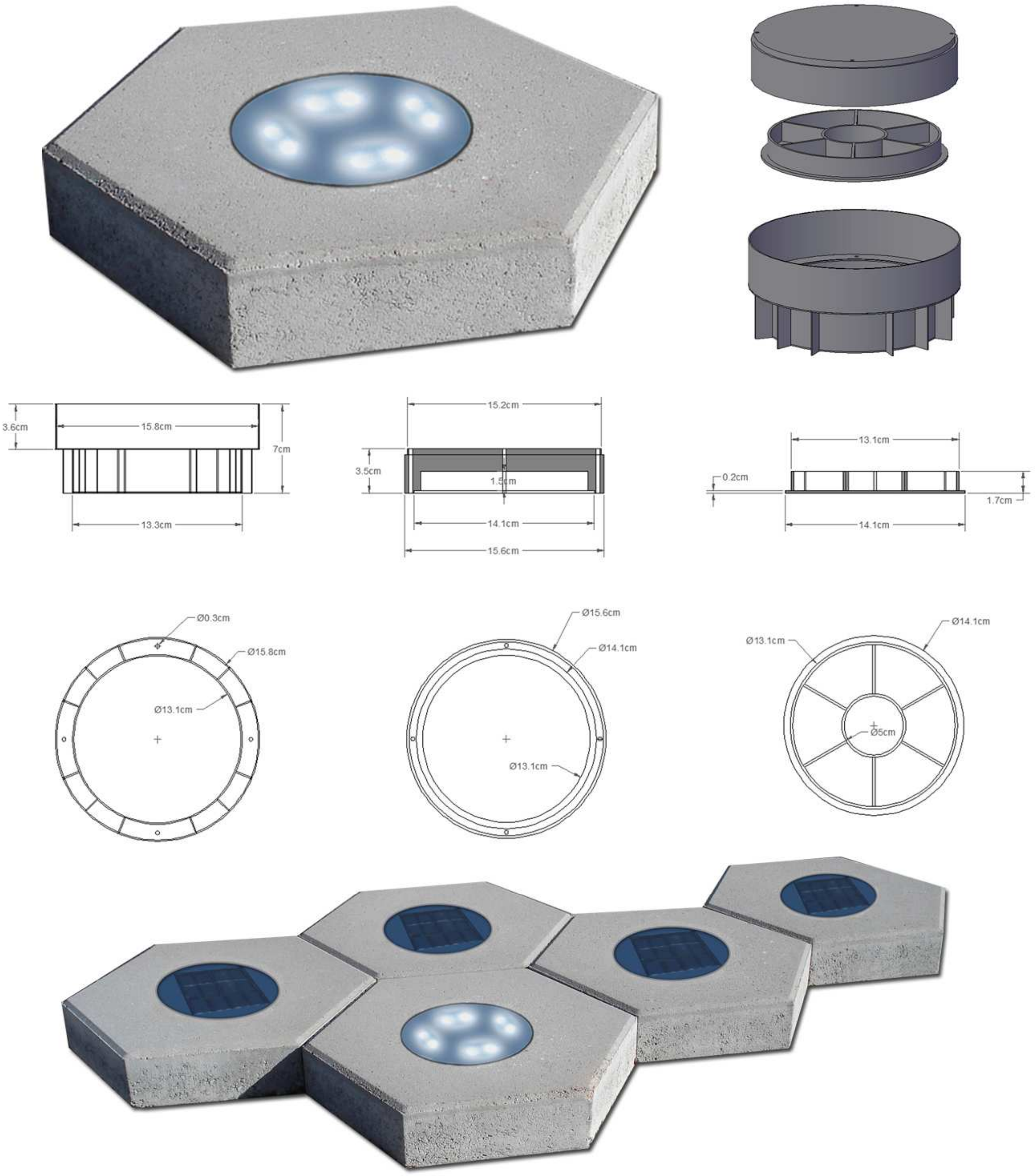


Image 26. Geometry of solar tile BS-DS-C160.

BS-DST-C160

Solar tile for road illumination coming from floor or PIPER devices

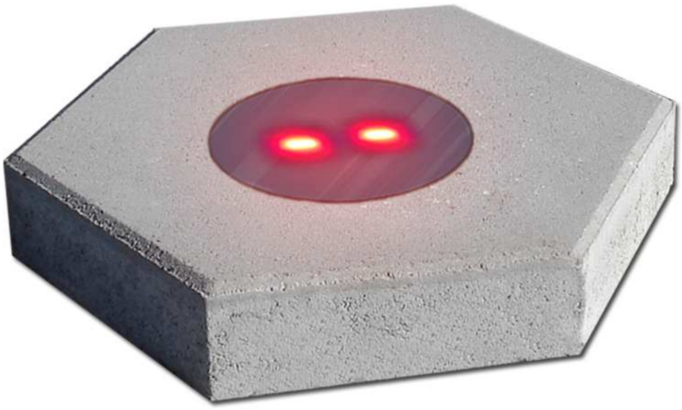


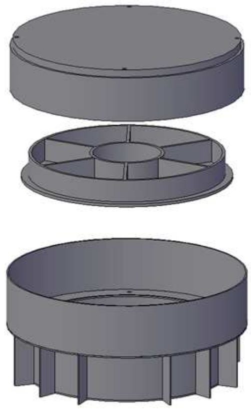
MAXIMUM POWER : **DEPENDING ON THE SERIES OF ATTACHED TILES**
SIZE: **CIRCULAR 160 x 70mm.**
OPERATION: **ENERGY SOURCE OF ATTACHED TILES**
4x4 LED 2.8-4.0V 20mA 18500 mcd. (OPTIONAL WIFI CIRCUIT)
MATERIAL: **INJECTED METHACRYLATE**

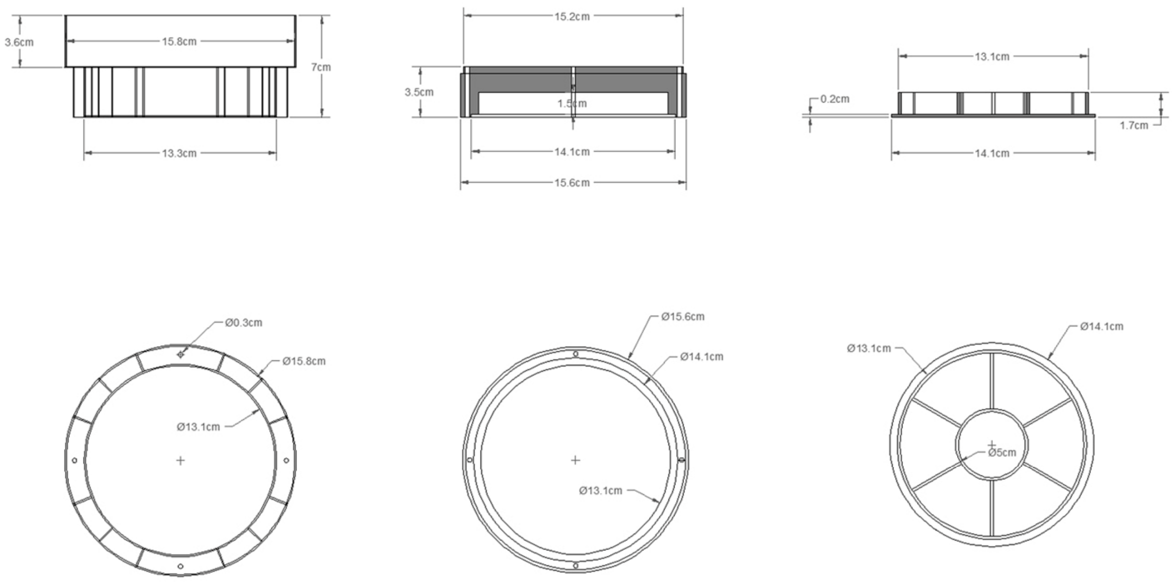
Image 27. Geometry of solar tile BS-DST-C160

BS-S-C160

Road solar tile for guiding







MAXIMUM POWER : **0,8W**
VOLTAGE WITH MAXIMUM POWER: **5V**
ELECTRIC CURRENT WITH MAXIMUM POWER: **160mA**

SIZE: **CIRCULAR 160 x 70mm.**
OPERATION: **OFF-LINE**

2 RED LED 1.8-2.4V 20mA 7000 mcd.
MATERIAL: **INJECTED PMMA**

Image 28. Geometry of solar tile BS-S-C160

The geometric features of each solar tile are described in the following points.

2A. Solar tile of 40x40 cm with back-lighting for photovoltaic energy production.

Cod.: BS-PFV-SQ400

Generation

Maximum power: 16.08 W.

Voltage with maximum power: 2.4 V.

Electric current with maximum power: 6.7 A.

Number and type of cells: four monocrystalline cells

Operating temperature: -30º C to 80º C.

Module efficiency: 18%.

Sizes: 396x396x26 mm.

Capsule and superficial protector.

TIPE **1a y 1b.**

Illumination, (optional)

LED of back-lighting, (optional): 12 V, 20 A, 14 Lumen, 32x13 mm. (RGB, optional).

Circuitry

3 diodes 3 A of by-pass. These diodes enable those solar tiles located in a shadow or dark to by-pass. These diodes will not produce voltage and, moreover, will act as open circuits. This would prevent to charge the battery.

Solar cable 4 mm^2 with a female connector negative and a male connector positive IP67. Bus bar of 1.5 and 4 mm.

Attachments.

Assembling kit 2x8 solar tiles. PRODUCT CODE: BS-SERIES1-400.

Assembling kit 1x3 solar tiles. PRODUCT CODE: BS-SERIES2-400.

Assembling kit 1x8 solar tiles. PRODUCT CODE: BS-SERIES3-400.

Plotting template 2x8 solar tiles: PRODUCT CODE: BS-PLSERIES1-400.

Plotting template 1x3 solar tiles: PRODUCT CODE: BS-PLSERIES2-400.

Plotting template 1x8 solar tiles: PRODUCT CODE: BS-PLSERIES3-400.

Ignition circuit with LED backlight: PRODUCT CODE: BS-Control-RI

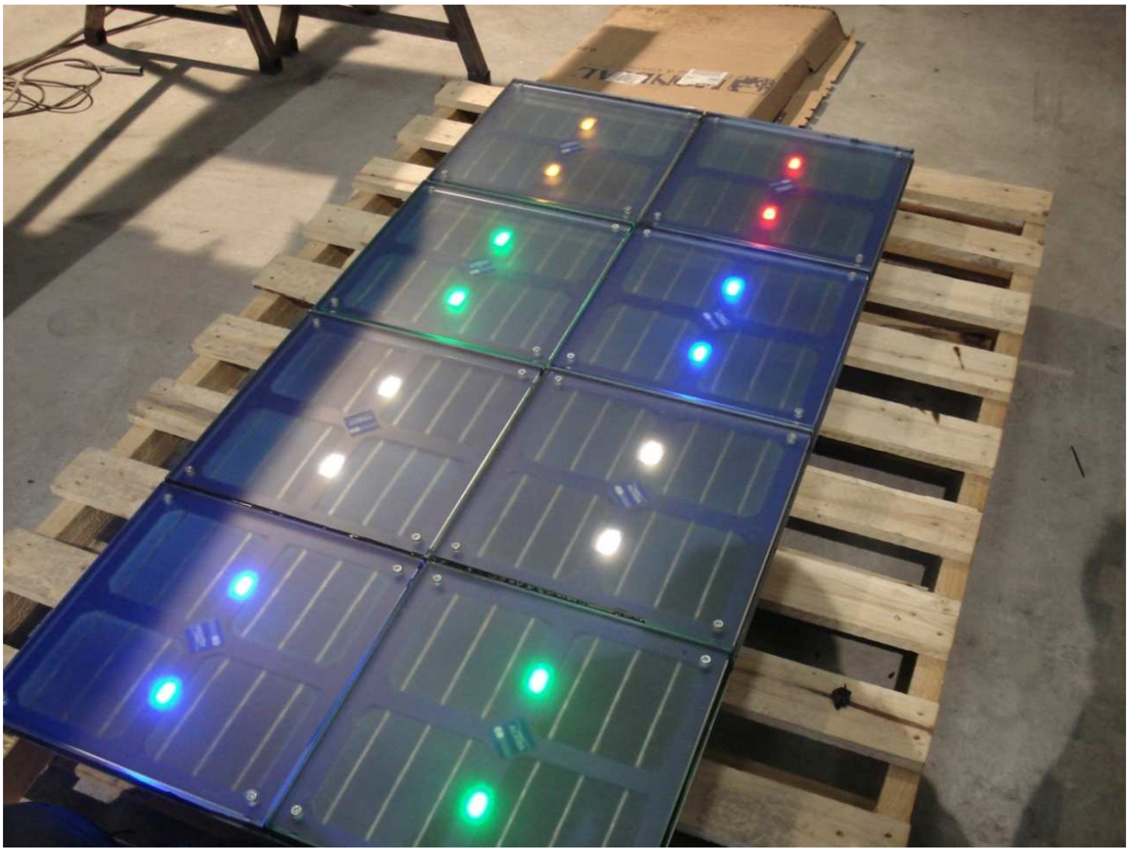


Image 29. Overview of 2x8 tiles

Image 30. Group of tiles arranged on sidewalk.

2B. Road solar tile for photovoltaic energy production.

PRODUCT CODE: BS-PFV-C160

Generation

Maximum power: 1.20 W.

Voltage with maximum power: 6 V.

Electric current with maximum power: 200 mA.

Type of cell: monocrystalline cell.

Operating temperature: -30º C to 80º C.

Module efficiency: 18%.

Capsule and superficial protector

TYPE 2 ó TYPE 3

2C. Decorative solar tile for guiding

PRODUCT CODE: BS-DS-C160

Generation

Maximum power: 1.20 W.

Voltage with maximum power: 6 V.

Electric current with maximum power: 200 mA.

Type of cell: monocrystalline cell.

Capsule and superficial protector

TYPE 2 ó TYPE 3.

Illumination

Type of LED: 2 white-light LEDs, 2.8 - 4.0 V, 20 A, 18,500 mcd.

Battery

Battery: 3.6 V, 2,400 mA.

Circuitry

Circuit controlled by micro-controller with twilight function and control for first ignition, (100x90 mm)

2D. Solar tile for road illumination coming from floor or PIPER devices.

PRODUCT CODE: BS-DST-C160.

Generation

3 solar tiles in series code BS-PFV-SQ400 or several of type BS-PFV-C160.

Iluminación

Type of LED: 16 (4x4) white-light LEDs, 2.8 - 4.0 V, 20 mA, 18,500 mcd (optional for PIPER devices).

Capsule and superficial protector

TYPE 2 ó TYIPE 3.

Battery

Battery: 4x3.6 V, 2,400 mA.

Circuitry

4 circuits with 4 LEDs each and one micro-controller with twilight function and control for first ignition: (45x40 mm).

PIPER devices

Integrated circuit transceiver 2.4 Ghz 802.11 Wi-Fi Sensor Networking. 200 mA. 10mW RF power. Chip antenna. 25x30 mm. Transmission range: 250 m.

(Optional Zigbee and Bluetooth circuit devices)

2E. Road solar tile for guiding.

PRODUCT CODE:: BS-S-C160.

Generation

Maximum power: 0.8 W.

Voltage with maximum power: 5 V.

Electric current with maximum power: 160 mA.

Number and type of cells: monocrystalline cells

Capsule and superficial protector

TYPE 2 ó TYPE 3.

Illumination

Type of LED: 2 red-light LEDs, 1.8 - 2.4 V, 20 A, 7,000 mcd.

Battery

Battery: 2.4 V, 2,400 A.

Circuitry

Circuit controlled by micro-controller with twilight function, control for intermittence and first ignition, (60x35 mm).

2F. COMMON FEATURES

Resistance to heavy traffic: 8,3 kg/cm^2 of load. (20 T per axle).

Slipperiness of class 3

Autonomy in winter: operating the whole night.

Sunshine recommendations:

- devices of permanent light on road with a minimum of 4 hours of direct sunlight;
- devices of intermittent light, 3 hours.

OPERATION MODE OF CIRCUITS

The circuit has 3 operation modes:

Standby mode, Day mode and Night mode.

STANDBY MODE: It is the default mode. Once the solar tile is deployed, this mode will never return. The consumption in this mode is 0.001 mA.

During the first start up of the device, once it has been connected to the power supply, the two LEDs will make three simultaneous flashes to verify the correct operation of the circuit. After that, the Standby mode will be activated, reducing the consumption to 0.001 mA. If batteries capacity is considered, (2,400 mA), their expected lifetime is higher than 200 years.

Due to the low power consumption of the circuit in Standby mode, the on/off switch is not required. Since the circuit is assembled until it is deployed, the circuit will remain packed in darkness and it must not be unpacked until it must be deployed. To make the device operate normally, it is necessary to detect the enough luminosity for 5 minutes without interruption. After that, the device will indicate the abandon of the Standby mode with 5 intermittences alternating each LED.

DAY MODE: To avoid circuit fluctuations between day and night, as it happens during sunset and at evening, the micro-controller compares the voltage delivered by the solar cells so that during day cycle, when the voltage is lower than 0.12 V, the micro-controller interprets that it is getting dark and the night mode is activated. To pass from night cycle to day cycle, the solar cells voltage should overpass 0.22 V. Besides the hysteresis, it has been created, in the micro-controller software, the following condition: before changing the mode, verify it 5 consecutive times during approximately 1 minute. This will avoid the imbalances provoked by clouds or people causing sporadic shadows.

NIGHT MODE: The intermittent LEDs are programmed to be on for 50 ms and to be off for 450 ms, with an average consumption of 4 mA/h.

Although LEDs stay on only 1/10 of the time, due to the persistence of human eye, we will feel that the on-time is longer than the actual time.

As for the LEDs of permanent light, it is important to guarantee that the location of paving blocks allows 5 hours per day of direct sunshine in sunny days.

2G. CAPSULES

TYPE 1.

Types 1a and 1b are available.

Capsule 1a: Superficial protector made up of **PMMA 396x396x20 mm** with slipperiness class 3, 20 mm thickness, with side flap to cover it and with through-screws. U-joint made up of PMMA 3 mm and base with diodes and connections box.

Capsule 1b: Superficial protector made up of laminated glass 396x396x20 mm 10+10 mm with double EVA layer in the middle, treated for acid with slipperiness class 3, inferior extra-clear glass and through-screws. U-joint made up of PMMA 3 mm and base with diodes and connections box.

TYPE 2.

Superficial protector with circular slipperiness 158 mm diameter class 3, 18 mm thickness, through-screws and edged for jointing with polyurethane. Circuit made up of PMMA 2 mm and circular injected aluminium base 2 mm thickness.

TYPE 3.

Superficial protector with circular slipperiness 158 mm diameter class 3, 10 mm thickness, through-screws and edged for jointing with polyurethane. Circuit made up of PMMA 2 mm and circular injected aluminium base 2 mm thickness.

PART 3. MATERIALS.

The following features are obligated for materials constituting the solar tile capsule:

3A. PMMA, (Methacrylate)

Mechanic features

- Density DIN53479: 1.19 g/cm^3
- Charpy impact test ISO179: 15 1/D kJ/m^2
- Izod impact strength test with notch ISO 180: 1.6 1/A kJ/m^2
- Traction resistance (-40 ºC) DIN53455: 100 MPa
- Traction resistance (+23 ºC) DIN53455: 72 MPa
- Traction resistance (+70 ºC) DIN53455: 35 MPa
- Elongation at break DIN53455: 4.5 %.
- Bending test, standard cylinder (80x10x4mm) DIN53452: 105 MPa
- Compression tension DIN53454: 103 MPa
- Maximum safety tension (until +40 ºC) : 5 to 10 MPa
- Elasticity modulus E (long-/short-term), DIN53457: 3300/3200 MPa
- Modulus of rigidity G in 10Hz 1700 MPa
- Fatigue resistance in alternative bending test to 10 cycles (cylinder with notch / without notch) 30/10 MPa
- Brinell hardness H961/30 ISO 2039-1: 190 MPa
- Abrasion resistance with 1,600 gr of abrasive similar to ASTM-D673 44: 98%.
- Friction coefficient plastic over plastic - 0.80
- Friction coefficient plastic over steel - 0.50
- Friction coefficient steel over plastic - 0.45

Optical properties (features)

- Standard illumination D65 DIN 5036 92%
- Loss of reflection in the visible region (for any surface): 4%.
- Total transmission or energy (3 mm thickness) DIN 67567
- Absorption rate in the visible region (3 mm) 0.05%.
- Index of refraction DIN53491 - 1.491

Thermal properties

- Coefficient of linear thermal expansion 0- 50ºC DIN53752-A 1/K: 0.07 mm/m ºC
- Thermal conductivity DIN52612: 0.19 W/mK
- Coefficient of thermal transfer (1mm thickness) DIN 4701: 5.8 W/m^{2}K

- Coefficient of thermal transfer (3mm thickness) DIN 4701: 5.6 W/m^{2}K
- Coefficient of thermal transfer (5mm thickness) DIN 4701: 5.3 W/m^{2}K
- Coefficient of thermal transfer (10 mm thickness) DIN 4701: 4.4 W/m^{2}K
- Specific heat capacity - 1.47 J/g K
- Approximate moulding temperature (furnace temperature) - 150…160 ºC
- Maximum superficial temperature (IR radiator) - 180 ºC
- Maximum permanent application temperature: 70 ºC
- Re-contraction temperature: >80 ºC
- Ignition temperature DIN51794: 430 ºC
- Fire resistance >1.5 mm thickness) DIN4102 - B2
- Vicat index (method B) DIN ISO 306: 102 ºC
- Dimensional stability to heat (Martens Method) DIN53458: 85 ºC
- Thermal resistance ISO 75 bending tension 1.8 MPa DIN53458: 90 ºC
- Thermal resistance ISO 75 bending tension 0.45 MPa DIN53461: 95 ºC

3B. Laminated glass

Mechanic features

Compression resistance > 10.000 kg / cm^2
Traction resistance > 400 kg / cm^2
Bending resistance with momentary load > 170 Kg/cm^2
Bending resistance with permanent load > 60 Kg/cm^2
Density 2.5 g / cm3, 2.5 kg / m^2 by mm thickness.
Hardness > 6.5 in the Mohs scale
Young Modulus E= 7.2 10^{10} Pa, (720.000 Kg/cm^2)
Poisson coefficient μ= 0.22.
Abrasion resistance: P2A, (laminated 10+10 mm)
Pendulum impact resistance. 1B1, (laminated 10+10 mm)
Resistance to abrupt temperature changes: 40 K, (laminated 10+10 mm)
The supplier company will attach a sheet with the aforementioned data indicating the method of standard test used.

Luminosity features 10+10 laminated with extra-clear base and 2 EVA layers.
Transmittance: 81% Tvis
Outside reflectance 7% Rvis1
Inside reflectance 7% Rvis2
Ultraviolet transmittance <1% tUV

Thermal features of 10+10 laminated with extra-clear base and 2 EVA layers.
Solar transmittance: 57% Tsol
Outside solar reflectance 6% Rsol1
Outside solar reflectance 6% Rsol2
Absorbance of glass 37%, (A)

Thermal properties of 10+10 laminated with extra-clear base and 2 EVA layers.
Solar factor: 0.67 g (EN 410)
Coefficient of thermal transfer 5.1 w/m^{2}K U (EN 673)

3C. Location plates and fixing screws

Made up of stainless steel AISI-304.

Mechanic properties	
Elongation (%)	< 60
Brinell hardness	160-190
Izod impact (J*m-1)	20-136
Elasticity modulus (MPa)	190-210
Traction resistance (MPa)	460-1100
Resistance to corrosion	+ 504 hours without change (stainless)
Salt-fog test UNE 112017:92	+ 650 hours without change (stainless coated on titanium)
Physical properties	
Density	7,93 g·cm^3
Thermal properties	
Coefficient of thermal expansion (10-6*K-1))	18
Thermal conductivity with 23ºC	16,3

3D. Aluminium for injections

Traction resistance	160Mpa (N/mm^2)
Elastic limit	110 N/mm^2
Limit at break	150 N/mm^2
Wind shear resistance	117 MPa
Elasticity modulus	69 N/mm^2
Resistance to corrosion	Very good
Density	2.7 g/cm-3
Fire resistance	M0 according to UNE 23-727-90 Non-combustible
Coefficient of linear thermal expansion	23.5 * 10-6 m/mK
Recyclable	Yes

PART 4. QUALITY CONTROL

Quality control includes the following aspects:

- control of materials and certifications.
- control of assembling in the workshop.
- control of assembling in the construction site.

4A. Control of materials

Each solar tile unit includes a guarantee certification, issued by each manufacturer, regarding all the products used for manufacturing the solar tile.

Likewise, the reception of materials is controlled in the workshop following the next steps:

- Materials for capsules (glass and/or methacrylate, stainless steel plates and screws): complete tests carried out each 10,000.00 m^2, including mechanical, physical, thermal, luminosity and energetic. However, transmittance tests will be elaborated when each group of protector layers (methacrylate or glass) is received.
- Solar cells: the control system Cell-by-cell (CBC) is implemented and it verifies the voltage values and the intensity in a lamp of 1,000 w/m^2. Cells not complying with prescriptions are retired and returned to the deliverer.

4B. Control of assembling in the workshop

- Solar tiles: the control system Tile-by-tile (TBT) is implemented and it verifies the expected voltage values and intensity in the same way. Likewise, the tightness of each solar tile is verified by immersing it partially in a bucket.
- Electronic circuits: the control All electronic circuits (AEC) is implemented and it checks all the circuits before they are commercialized, including the activation functions and the charge of battery.
- LED: once all LEDs are in series, the operating system is checked.

4C. Control of assembling in the construction site

Once the power-generating solar tiles are located in the construction site, the input voltage to the regulator will be checked.

As for the guiding and illumination solar tiles, the circuit activation will be checked when the LED flickers three times and, therefore, the protector can be removed.

Faulty solar tiles localization

If, while organizing the solar tiles in series, they do not comply with the expected output voltage, the localizing of the faulty one will be made with a voltmeter, which will measure the voltage in a sunny day covering sequentially each solar tile a time. This verifies that when just one solar tile is covered, voltage falls around 3.1 V (2.7 V of the own tile plus 0.7 V when passing by the diode). The faulty solar tile will be located, then, because this one will not provoke the decrease of the total voltage.

PART 5. CONSTRUCTION, ASSEMBLING, DISASSEMBLING AND MANTEINANCE.

The construction stages of a photovoltaic floor with BS-PFV-SQ400 and BS-PFV-SQ333 format are the following:

- Applying the base of support of the solar tile, (a minimum thickness of 8 cm is recommended), protecting the flow tubes. When detachable pavers are used as base of support, the filling concrete must be levelled with the upper edge of the connection joint.
- Plotting guides of 50 mm width minimum and of 40 mm depth minimum; the plotting plate included in the assembling kit will be used. Solar tiles will be levelled with the continuous pavement avoiding off-levels.
- Placing of fixing plugs once the mortar is dry.
- Deploying solar tiles after elaborating the connection of positive and negative final cables. When backlight is included, LED cable connection will be considered. Plotting and screw fixing
- Operating test.
- Finally, jointing with polyurethane.

Image 31. Solar tiles setting

The disassembling of the solar tiles can be done one by one or disassembling them as a whole if all the fixing screws in the base are removed. Once the plate is removed, it is recommended to clean the polyurethane strip that has remained both in the pavement and in the edge of the in-series solar tiles. When the solar tile is going to be replaced, the polyurethane strip must be re-established.

For maintaining the solar tiles, the following aspects are recommended:

- control of performance at least during the first month measuring five times minimum on different days.

- control of performance measuring once a year.

- periodic cleaning of solar tiles, ideally once every two weeks; once a month minimum. For cleaning, plenty of clear water is recommended. When detergents are used, the compatibility with the protector material must be guaranteed. Pressurized water may be also used for removing incrustations.

If the solar tile used is the format BS-PFV-C160 for detachable paver, the stages are the same as those of detachable paver but with the following differences:

- once the intermediate joint is located, its vertical walls will be drilled to enable the pass of the cable to the solar tile where the battery to be fed is placed.

- once the piece including the battery is placed and the devices are going to be fed and after connecting the solar cables, each BS-PFV-C160 unit is finally placed. The connection may be in series or in parallel depending on the charge of the battery to be fed.

If autonomous solar tiles for back-lighting or guiding are used, the following stages are considered:

- for any pavement: location of the aluminium casing embedded in the concrete basement and, once this step is finished, location of the solar tile, screwing and jointing it.

- for detachable pavement: placing the unit or the detachable paver including the solar tile will be enough.

Maintaining the latter ones will require a control of on- and off- systems during the first month from the deployment. Likewise, cleaning is recommended once every two weeks; once a month is admissible.

6.1 General recommendations for power-generating solar tiles

Before the planner elaborates the corresponding urban project with solar tiles, the following recommendations must be considered:

- The planner must elaborate the corresponding performance calculations for the selected location, guaranteeing the proper profitability of the PV module.
- This study must allow the planner to select the best possible location of the solar tile in order to obtain the best profitability. The planner may establish criteria to enable the best integration in the urban furniture and the right connection to the services receiving its energy.
- The planner will try to choose locations free from shadows provoked by other urban elements or, at least, to reduce them.
- If it is going to be deployed in sidewalks, it is recommended to leave a distance of, at least, 1.2 m between the kerb and the pavement.

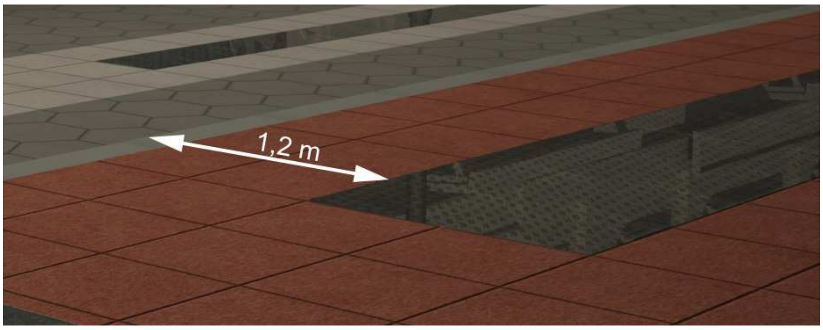


Image 32. Recommended distance to the sidewalk edge.

- If it is going to be deployed on roads, it is recommended to not place it where many vehicles stop (due to traffic lights) or where traffic jams are frequent. In general, the traffic per lane and day must be lower than 1,000 vehicles.

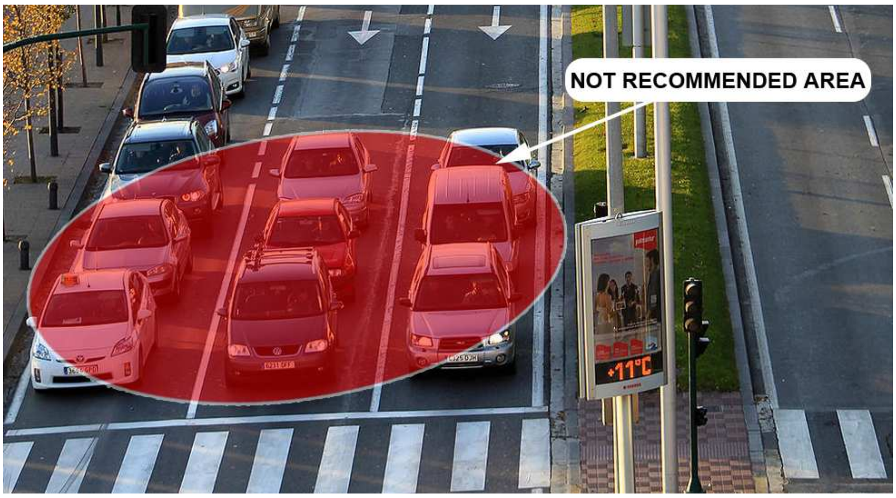


Image 33. Not recommended area on road.

- In roads oriented to E-W, solar tiles are recommended to be located in the northern or southern half depending if it is the northern or the southern hemisphere. They must carry the energy through transversal ducts to the points of supply, (traffic lights, lighting, etc.)

Image 34. Solar tiles location in streets oriented East-West.

6.2 Recommendations for illumination or guiding solar tiles

These solar tiles are recommended to be placed where a minimum of direct solar radiation is available:

- as for intermittent guiding solar tiles, 3 hours will be enough on sunny days.
- as for permanent guiding solar tiles, at least 4 hours will be enough and more than 5 hours would be ideal.

On the other hand, the planner must analyse the level of artificial illumination on the road where solar tiles are going to be placed because more than 90 lx is considered to be too high, which would prevent from an acceptable perception of light and, therefore, this would make them lose their utility. It must be noted that the illumination level on roads is usually between 20 and 40 lx and only in particular environment do they overpass 50 lx.

PART 7. INTELLIGENT PAVEMENTS.

The PIPER Guide, which will be available soon, will compile all the recommendable steps to install the BS-DST-C160 devices, depending on the expected uses:

- interactive marketing.
- mobility solutions.
- connectivity.

These steps will aim to guarantee the best services for users through a right location and distribution of the devices on urban roads.

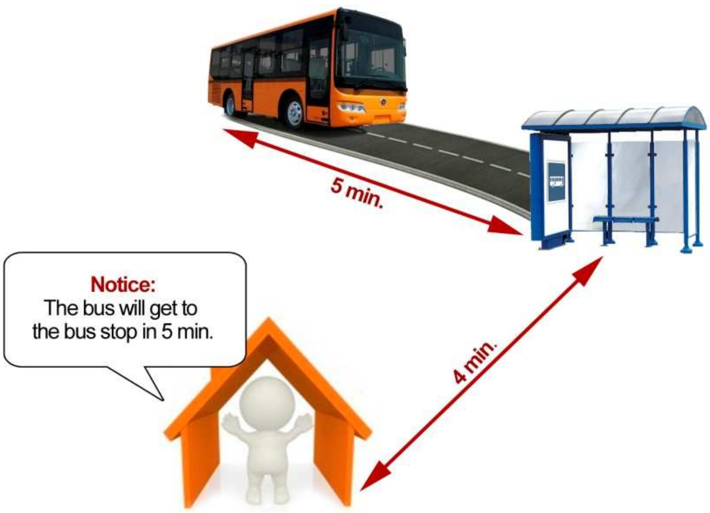


Image 35. Example of applicability of PIPER equipments

PART 8. PERFORMANCE CALCULATION.

The solar tile has a double usage (pavement and PV solution). This incorporates some limitations to the capacity of the solar tile as PV solar module. In particular:

- Solar tile locations must be horizontal.
- Environmental exposure is higher and, consequently, dirt and "aging" will diminish the module's performance.
- The transmissivity will decrease when solar tiles have glass laminated with superficial treatment for non-slip.
- The solar tile is expected to be used in streets with a reduction in hours of direct solar radiation. Therefore, recommendations regarding street orientation, building height, street width and geographic position will be needed.
- These aforementioned effects are analysed in the following points:

8.1. Horizontality effect.

The whole methodology that will allow us to obtain the solar tile performance on any day and in any geographic location is described below:

Initially, the position of the sun (δ), sunrise angle(ω_s), the sun distance to Earth on a determined day (r) and the daily extraterrestrial irradiation on horizontal surface ($B_{Od}(0)$) are calculated for each day of the year (d_n)

If it is supposed Earth to turn around the sun with a constant angular speed, simplified expressions can be used for calculating the following parameters:

1.- Position of the sun in radians (δ)

$$\delta = \frac{23.45 \cdot \pi}{180}\, sen\left(2\pi \cdot \frac{d_n + 284}{365}\right)$$

2.- Correction factor of eccentricity of the Earth's orbit (ε_0):

Rapport between distance from Sun to Earth on a determined day (r) and the average value of that distance during a year (r_0):

$$\varepsilon_0 = \left(\frac{r_0}{r}\right)^2 = 1 + 0.033 \cdot \cos\left(2\pi \cdot \frac{d_n}{365}\right)$$

3.- Sunrise angle in radians (ω_s):

$$\omega_s = -cos^{-1}\,(-tg\delta \cdot tg\,\emptyset)$$

ϕ es la latitud.

4.- Extraterrestrial irradiation during a day ($B_{Od}(0)$):

$$B_{Od}(0) = \frac{24}{\pi} B_0 \cdot \varepsilon_0 \cdot (\cos\emptyset \cos\delta)(\omega_s \cos\omega_s - sen\ \omega_s)$$

d_n is the number of the day of the year in order (1 for the first day of January and 365 for the 31st day of December), ϕ is the latitude of the place in radians and B_0 is a solar constant of value 1.367 W/m^2.

5.- Direct and diffuse radiation over the horizontal surface during a day

The Hottel model (1976) expresses the atmospheric transmittance for direct radiation, τ_b, according to zenith angle, Θ_{zs}, (greater transmittance in vertical than in horizontal direction), to the height over the sea level, A, in kilometres, (the higher, the greater transmittance) and to the type of climate; of the form:

$$\tau_b = a_o + a_1 e^{(-k/\cos\Theta zs)}$$

where a_o, a_1 and k are empirical adapted parameters. For calculating these measures, the following equations are used:

$a_o = r_o\ [0{,}4237-0{,}00821(6-A)^2]$

$a_1 = r_1\ [0{,}5055-0{,}00595(6{,}5-A)^2]$

$K = r_k\ [0{,}2711-0{,}01858(2{,}5-A)^2]$

The values r_0, r_1 y r_k are given in the attached Table, for different types of climate. For estimating the diffuse irradiation over a horizontal surface, the corresponding transmittance is given by a Liu and Jordan's expression (1960) of the form:

$\tau_d = 0{,}2710-0{,}2939\ \tau_b$

$\cos\theta_{ZS} = \sin\delta \sin\emptyset + cos\delta \cos\emptyset \cos\omega$

Climate	r_o	r_1	r_k
1. Tropical	0,95	0,98	1,02
2. Summer, average latitude	0,97	0,99	1,02
3. Summer, sub-artic	0,99	0,99	1,01
4. Winter, average latitude	1,03	1,01	1,00

Table 2-1. Values of r_o, r_1 and r_k according to climate.

Therefore, the direct and diffuse irradiances for a clear day over a horizontal surface at ground level (A height) will be:

Direct radiation: $G_B(0)$

$$G_B(0) = \tau_b\, B_{Od}(0) \cos\Theta_{zs}$$

Diffuse radiation: $G_D(0)$

$$G_D(0) = \tau_d\, B_{Od}(0) \cos\Theta_{zs}$$

and the total irradiation without considering the one of the albedo will be given by:

$$G(0) = G_B(0) + G_D(0)$$

6.- Direct irradiance over any surface.

The direct irradiance over any surface is obtained with the following expression:

$$G_B(\alpha,\beta) = F_T(\theta_S)\frac{G_B(0)}{\cos\theta_{ZS}}\max(0, cos\theta_S)$$

where θ_S is the incident angle of the solar rays over an tilted surface (made up of the normal to the surface and the radio vector Sun-Earth at that point) and θ_{ZS} is the zenith angle to the Sun.

$$\cos\theta_S = \sin\delta\sin\emptyset\cos\beta - sin\delta\cos\emptyset\sin\beta\cos\alpha + \cos\delta\cos\emptyset\cos\beta\cos\omega + \cos\delta\sin\emptyset\sin\beta\cos\alpha\cos\omega +$$
$$+\cos\delta\sin\alpha\sin\beta\sin\omega$$

$$\cos\theta_{zs} = \sin\delta\sin\emptyset + \cos\delta\cos\emptyset\cos\omega$$

where α is the azimuth of the tilted surface and β is the inclination angle with respect to the horizontal surface.

if α and β are 0, then:

$\cos\Theta_{zs} = \cos\Theta_s$

$F_T(\theta_S)$ is a factor of transmittance which quantifies the reduction of direct irradiance over the PV module due to the Fresnel loss, the dirtiness and the low levels of irradiance.

$$F_T(\theta_2) = 1 - 0.0663\theta_2^2 + 0.0882\theta_2^3 - 0.194\theta_2^4$$

7. Diffuse radiation over any surface.

For estimating the diffuse component, the model proposed by Pérez is developed: This model considers three sky zones as diffuse radiation sources: the *circumsolar zone* (G_{DC}), where all the radiation is supposed to come from one only point; the *horizon zone* (G_{DH}), where all the radiation comes from the horizon and *the rest of the sky hemisphere* (G_{DR}).

$$G_{DC}(\alpha,\beta) = G_D(0)\left[F_1 \frac{\max(0, cos\theta_S)}{\cos\theta_{ZS}}\right]$$

$$G_{DH}(\alpha,\beta) = G_D(0)[F_2 \sin\beta]$$

$$G_{DR}(\alpha,\beta) = G_D(0)\left[(1-F_1)\frac{(1+\cos\beta)}{2}\right]$$

where F_1 y F_2 are non-dimensional parameters defining the relative contribution of circumsolar zones and horizon zones to the diffuse irradiance.

$$F_1 = F_{11}(\varepsilon) + F_{12}(\varepsilon)\Delta + F_{13}(\varepsilon)\theta_{ZS}$$

$$F_2 = F_{21}(\varepsilon) + F_{22}(\varepsilon)\Delta + F_{23}(\varepsilon)\theta_{ZS}$$

For calculating them, a relation with Δ, θ_{zs} and the coefficients shown in the following table are used. These coefficients experimentally obtained are selected according to the value of ε.

$$\Delta = \frac{G_D(0)}{B_0 \cos\theta_{ZS}}$$

$$\varepsilon = \frac{G_D(0) + \frac{G_B(0)}{\cos\theta_{ZS}}}{G_D(0)}$$

Interval of ε			F_{11}	F_{12}	F_{13}	F_{21}	F_{22}	F_{23}
1,000	-	1,056	-0,042	0,550	-0,044	-0,120	0,138	-0,034
1,056	-	1,253	0,261	0,559	-0,243	-0,019	0,083	-0,081
1,253	-	1,586	0,481	0,460	-0,354	0,077	0,006	-0,116
1,586	-	2,134	0,825	0,187	-0,532	0,172	-0,050	-0,151
2,134	-	3,230	1,102	-0,299	-0,586	0,350	-0,398	-0,171
3,230	-	5,980	1,226	-0,451	-0,617	0,444	-0,949	-0,073
5,980	-	10,080	1,367	-0,838	-0,655	0,431	-1,750	0,094
10,080	-	∞	0,978	-0,812	-0,393	0,335	-2,160	0,186

Table 2-2. Pérez coefficients.

The diffuse irradiance is the addition of the circumsolar zone, the horizon zone and the rest of the sky hemisphere. The first one is multiplied by the transmittance factor $F_T(\theta_s)$ and the others by 0.856 to correct the effects provoked by the Fresnel loss, the dirtiness and the low levels of irradiance.

$$G_D(\alpha,\beta) = F_T(\theta_S)G_{DC}(\alpha,\beta) + 0{,}856G_{DH}(\alpha,\beta) + 0{,}856G_{DR}(\alpha,\beta)$$

In a conservative way, the value of 0.856 can be replaced by the Fresnel loss, being the calculation safer. In this case, over a horizontal surface, the expression will result as follows:

$G_D(\alpha, 0) = G_D(0)\, F_T(\Theta_s)$

8. The albedo's irradiance over any surface.

For calculating the irradiance coming from the albedo, the ground is considered as a horizontal and infinite surface that reflects isotropically the radiation that it receives. Grounds are supposed to have a reflectivity (ρ) of value 0.2 and a transmittance factor equal to 0.856.

$$G_R(\beta,\alpha) = 0{,}856G(0)\cdot\ (1-\cos\beta)\cdot\frac{\rho}{2}$$

9. Global irradiance.

The global irradiance is defined as the addition of the three aforementioned components: direct, diffuse and albedo.

$$G(\alpha,\beta) = G_B(\alpha,\beta) + G_D(\alpha,\beta) + G_R(\alpha,\beta)$$

For calculating the global irradiance value, the value of albedo may be discounted.

10. Calculation of the operation values of a PV generator fotovoltaico.

The first step is to calculate the evolution of temperatures during the day. The model used for describing the variation of ambient temperature (T_a) during a day based on the highest and lowest temperature that day considers that:

a. The highest ambient temperature (T_{aM}) always happens two hours after the solar noon (ω = p/6).

b. The lowest ambient temperature (T_{aM}) always happens during sunrise ($\omega = \omega_S$).

c. Between these two moments, the ambient temperature evolves according to two semi-cycles of two cosine functions, depending on the solar time (ω):

-For $\omega < \omega_S$

it is used : $T_a = T_{aM} - \frac{T_{aM}-T_{am}}{2}[1+\cos(a\omega+b)]$

where: $a = \frac{\pi}{\frac{\pi}{6}-\omega_2-2\pi}$ and $b = -a\omega_S$

- Para $\omega_S < \omega < \frac{\pi}{6}$

-For: $\omega_S < \omega_S < \frac{\pi}{6}$

It is used: $T_a = T_{am} + \frac{T_{aM} - T_{am}}{2}[1 + \cos(a\omega + b)]$

where: $a = \frac{\pi}{\omega_2 - \pi/6}$ and $b = -a\,\frac{\pi}{6}$

- for $\omega > \frac{\pi}{6}$

It is used: $T_a = T_{aM} - \frac{T_{aM} - T_{am}}{2}[1 + \cos(a\omega + b)]$

where: $a = \frac{\pi}{2\pi + \omega_2 - \frac{\pi}{6}}$ and $b = -\left(\pi + a\frac{\pi}{6}\right)$

This process will be used for calculating the temporal evolution of the ambient temperature (T_a).

As for the operation values of a PV generator, the following expression can be considered to define its element I-V:

$$I_G = N_{mp} N_{cp} I_{SC} \left[1 - \exp\left(\frac{V_G/\,(N_{CS} N_{ms}) - V_{OC} + I_G R_S/\left(N_{cp} N_{mp}\right)}{V_t}\right)\right]$$

Where:

I_G is the PV generator's current (A).
V_G is the PV generator's voltage (V).
N_{cp} is the number of cells in parallel of the PV module.
N_{cs} is the number of cells in series of the PV module.
N_{mp} is the number of modules in parallel of the PV generator.
N_{ms} is the number of modules in series of the PV generator.
I_{sc} is the current of short circuit of a cell of the PV module (A).
V_{sc} is the voltage of open circuit of a cell of the PV module (V).
R_s is the series resistance of a cell of the PV module (Ω).
V_t is the thermal voltage (V).

The goal is to obtain the highest power value that the generator may reach for a couple of determined values of irradiance and ambient temperature. For each point of the curve I x V, the product of the current and the voltage represent the output power of these operation conditions. The highest output power of the cell is obtained for:

$$\frac{d(IV)}{dV} = 0$$

The *Fill Factor* (FF) provides with the evaluation of the performance and series resistance of the cell. It is the ratio between maximum power point and the short circuit current by the open circuit voltage.

Ideally, the FF depends only on the circuit's standardized voltage, defined as the ratio between the open circuit voltage and kT/q, being both parameters in related with the following empirical expression:

$$FF = \frac{v_{oc} - \ln(v_{oc}+0.72)}{v_{oc}+1}$$

The method used for calculating the voltage and the current of the point with the highest power is described hereafter. The method follows some particular conditions of radiation and temperature based on the calculation of the FF and on the following values:

- Short circuit current of a cell in standard conditions ($I_{SC,stc}$).
- Short circuit voltage of a cell in standard conditions ($V_{OC,stc}$).
- Highest power current of a cell in standard conditions ($I_{MAX,stc}$).
- Highest power voltage of a cell in standard conditions ($V_{MAX,stc}$).
- Nominal operation temperature of the cell (T_{ONC}).
- Fill factor in standard conditions (FF_{stc}).

The calculation process sequentially uses the following eight relations to obtain the cells' operation values::

a. *Cell's short circuit:*

$$I_{SC} = G(W/m^2)\frac{I_{SC,stc}}{1000W\ /\ m^2}$$

b. *Cell's temperature:*

$$T_c = (\ ^0C) = T_a(\ ^0C) + \left(\frac{TONC(\ ^0C)-20}{800W\ /\ m^2}\right)G(W/m^2)$$

c. *Cell's open circuit voltage:*

$$V_{OC}(V) = V_{OC,atc}(V) - 0{,}0023\big(T_C(\ ^0C) - 25\big)$$

d. *Standardised cell's voltage:*

$$v_{OC} = \frac{V_{OC}}{V_t}$$

where V_t is the thermal voltage:

$$V_t(V) = 0{,}025\frac{T_C(\ ^0C) + 273}{300}$$

e. *Fill factor for an ideal cell without considering the series resistance:*

$$FF_0 = \frac{v_{oc} - ln(v_{oc} + 0.72)}{v_{oc} + 1}$$

f. *Standardised resistance:*

$$r_s = 1 - \frac{FF_{stc}}{FF_0}$$

g. *Cell's voltage and current in the point of highest power:*

$$V_{MAX} = V_{oc} \cdot \left[1 - \frac{b}{v_{oc}} \cdot \ln a - r_2 \cdot \left(1 - a^{-b}\right)\right]$$

$$I_{MAX} = I_{SC} \cdot \left(1 - a^{-b}\right)$$

where: $a = v_{oc} + 1 - 1 \cdot v_{oc} \cdot r_s$ y $b = \frac{a}{1+a}$

h. *Cell's highest power (P_{MAX}):*

$$P_{MAX} = V_{MAX} I_{MAX}$$

From the calculated values for the generator's cells, the following operation values are considered for the generator:

$$I_{MAXG} = I_{MAX} \cdot N_{mp} \cdot N_{cp}$$

$$V_{MAXG} = V_{MAX} \cdot N_{ms} \cdot N_{cs}$$

$$P_{MAXG} = P_{MAX} \cdot N_{mp} \cdot N_{cp} \cdot N_{m2} \cdot N_{c2}$$

If the previous equations are compiled, we obtain the following table:

1.- Current of the cell's short circuit $I_{SC} = G(W/m^2)\frac{I_{SC,stc}}{1000W\ /\ m^2}$ (4)	**2.- Cell's temperature** $T_c = (\,^0C) = T_a(\,^0C) + \left(\frac{TONC(\,^0C)-20}{800W\ /\ m^2}\right)G(W/m^2)$ (5)
3.- Cell's open circuit voltage: $V_{OC}(V) = V_{OC,atc}(V) - 0{,}0023\left(T_C(\,^0C) - 25\right)$ (6)	**4.- Standardised cell's voltage:** $V_{OC} = \frac{V_{OC}}{V_t}$ where V_t is the thermal voltage (7) $V_t(V) = 0{,}025\frac{T_C(\,^0C)+273}{300}$ (8)
5.- Fill factor for an ideal cell without considering the series resistance $FF_0 = \frac{v_{oc} - ln(v_{oc}+0.72)}{v_{oc}+1}$ (9)	**6.- Standardised resistance** $r_s = 1 - \frac{FF_{stc}}{FF_0}$ (10)
7.- Cell's voltage and current in the point of highest power $V_{MAX} = V_{oc}\cdot\left[1 - \frac{b}{v_{oc}}\cdot\ln a - r_2\cdot(1-a^{-b})\right]$ (11) $I_{MAX} = I_{SC}\cdot\left(1 - a^{-b}\right)$ (12)	$a = v_{OC} + 1 - 1\cdot v_{OC}\cdot r_s$ (13) $b = \frac{a}{1+a}$ (14)
8.- Cell's highest power (P_{MAX}) $P_{MAX} = V_{MAX}I_{MAX}$ (15)	**9.- From the calculated values for the generator's cells, the following operation values are considered for the generator**: $V_{MAXG} = V_{MAX}\cdot N_{ms}\cdot N_{cs}$ (16) $I_{MAXG} = I_{MAX}\cdot N_{mp}\cdot N_{cp}$ (17) $P_{MAXG} = P_{MAX}\cdot N_{mp}\cdot N_{cp}\cdot N_{m2}\cdot N_{c2}$

Table 2-3. Operation values of a PV generator

11. Calculation of the power of the solar tile.

If we apply the aforementioned steps 1-10, we will obtain the highest power of the cell and the solar tile at any time of the day. This Guide attaches specific software that, in addition, takes into account aspects described hereafter, (transparency, degradation, etc.).

In general, the horizontal placement of the solar tile involves an important reduction of solar radiation over it, which can fluctuate between 30 to 70 % according to the day of the year and the geographic location.

In the following steps, the effect of transparency, dirtiness, degradation of the protector and the "aging" of the solar module are, in addition, considered, highlighting the limit of direct illumination due to the solar module's placement on a city road.

8.2. Protector's transparency effect.

As indicated previously, for a laminated extra-clear glass with superficial treatment for non-slip, the transmissivity does not overpass 85%, (90% for PMMA).

For the calculations carried out in this study, the value 0.85 will be the considered; i.e. the calculated power will be reduced by 15%.
In any case, in the second stage of this research study, tests verifying previous data will be carried out.

8.3. Dirtiness effect.

As a general rule, in normal conditions of pavement maintenance, the Fresnel method will be enough to consider this kind of loss.

$$F_T = (\theta_2) = 1 - 0.0663\theta_2^2 + 0.0882\theta_2^3 - 0.194\theta_2^4$$

It should be noted that the values obtained from the Fresnel method involve power reduction of between around 50 and 5% depending on the moment of the day. Therefore, it can be considered a very conservative value.

8.4. Protector's degradation effect.

The protector's degradation will be given by the superficial scratches; as mentioned before, it will be indispensable to require values of hardness 6 in the Mohs scale. The degradation provoked by scratches will involve a loss of transmittance.
This loss may vary between 5 and 7% for very busy areas.

8.5. Solar module's "aging" effect.

In general, companies commercialising crystalline solar cells usually certify a lifetime of around 25-30 year, with a loss in the time horizon of around 20-25% (an average of around 8.0% per year).

It is recommended to consider performance losses of 1% per year.

8.6. Climate effect.

Depending on the climate, there will be more or less sunny days a year; the more cloudy days, the lower solar irradiance over the surface. This aspect is very variable up and down the length and breadth of the Earth.

The reduction of sunny days involves a decrease in the annual PV power generation of a module in a determined percentage with regard to the values obtained in a sunny day.

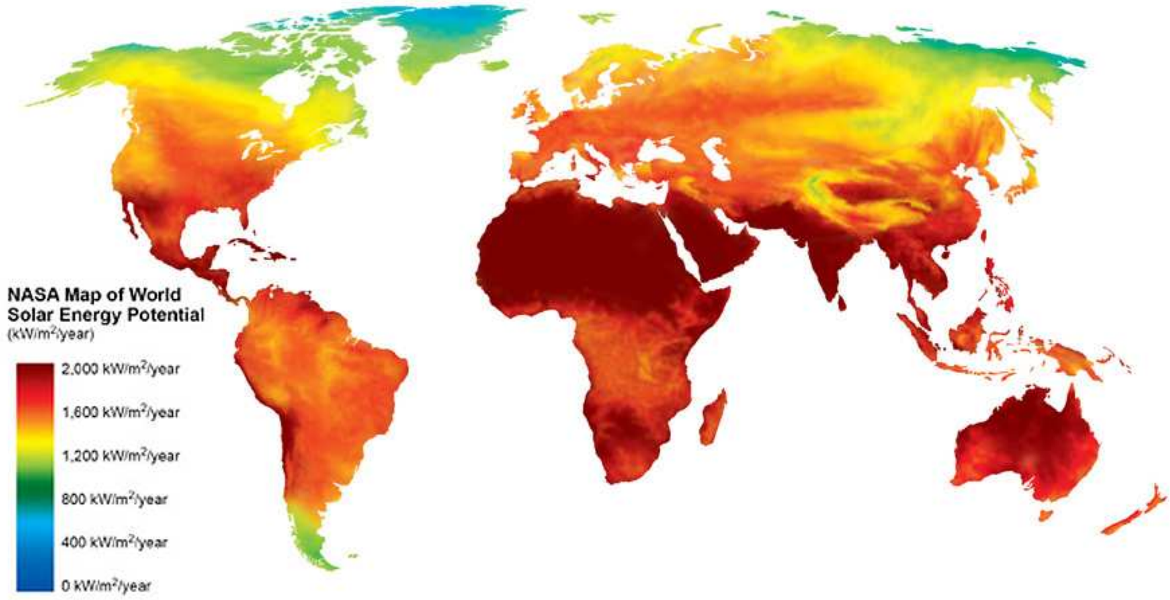


Image 36. Average values of solar irradiance in the world.

The reductions in PV solar production due to climate with regard to sunny days constitute a piece of information to be determined specifically for each geographical area.

8.7. Effect relating to placement in the shadow.

This is the most important effect considered until now as the building height is going to impose a reduction of direct illumination hours.

The length of the shadow projected by a building with h_{build} height will be given by the following equation:

$L_{shadow} = h_{edif} / tg\ h$

where h is the solar height: $h = 90^o - \Theta_s$

For different moments for particular solar azimuths, (A_{sol}), the shadow projected by a vertical axis forms an angle, (α_{shadow}), with the transverse to a street with azimuth A_{street} and with a width of a_{street}, given by the equation:

$\alpha_{shadow} = A_{street} - 90^o - A_{sol}$, the azimuths being measured from the South.

The pavement of a street will be completely in the shadow when the following equation is fulfilled:

$L_{shadow} \cos \alpha_{shadow} > a_{street}$, or when the following equation is fulfilled:

$[h_{build} / tg\ h] \cos \alpha_{shadow} > a_{street} \Rightarrow [h_{build} / tg\ h] \cos (A_{street} - 90^o - A_{sol}) > a_{street}$

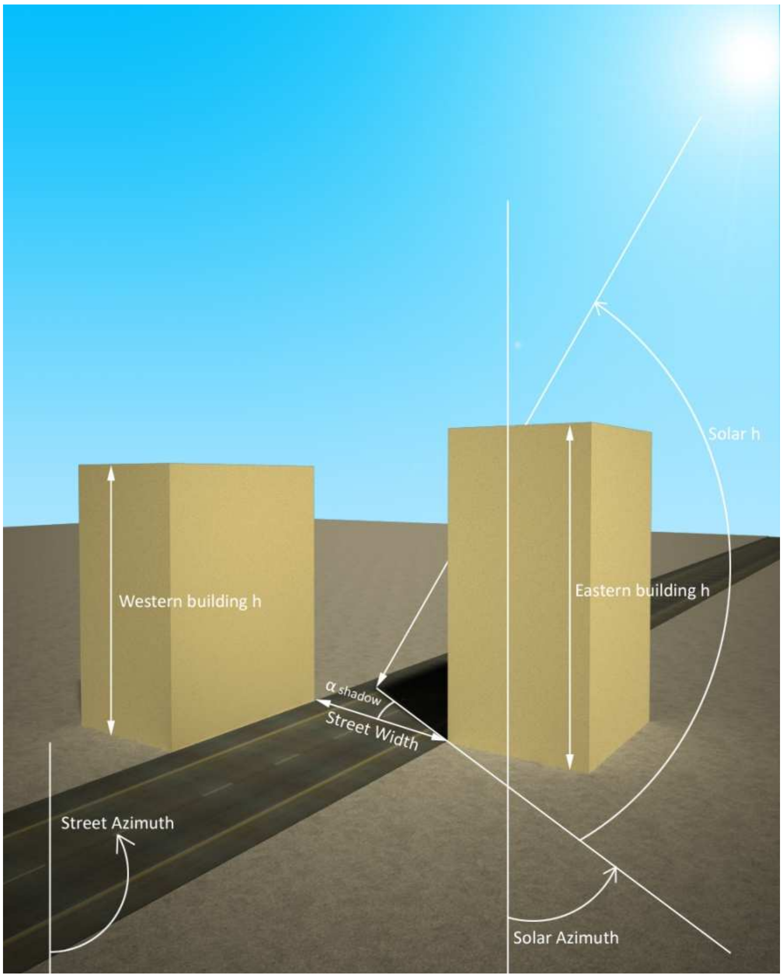


Image 37. Criteria for building projecting shadows over the street.

The whole street will be illuminated when the azimuth of the A_{street} matches with the solar azimuth A_{sol}.
As can be seen, the orientation of the street plays a fundamental role in its own illumination; therefore, the following situations are considered:

- <u>Street approximately E-W oriented:</u>

In this street, when the azimuth A_{street} is higher than the azimuth in the sunrise, ($A_{sunrise}$) and, in addition, lower than the azimuth in the sunset minus 180º (A_{sunset}-180º), the southern sidewalk will be always in the shadow.
$A_{sunrise} < A_{street} < A_{sunset} - 180º$ => in this case, the southern sidewalk will be always in the shadow.

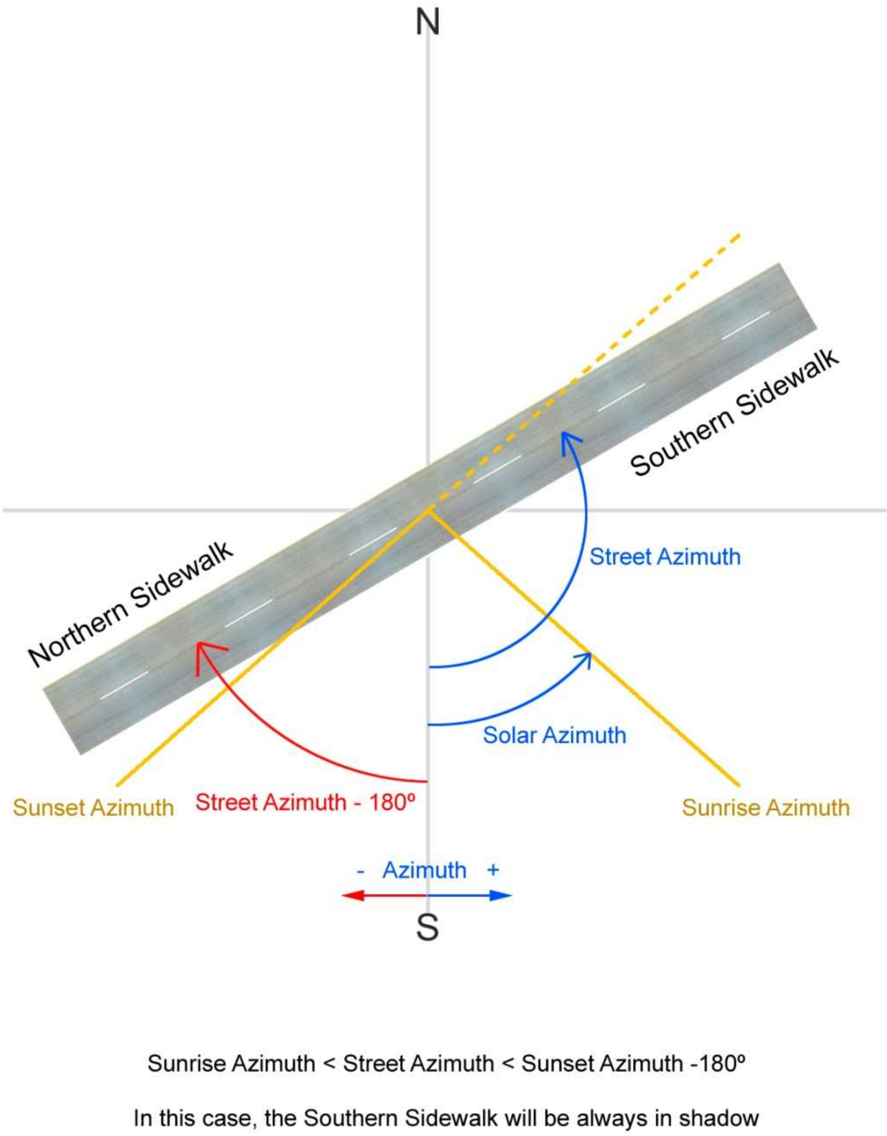
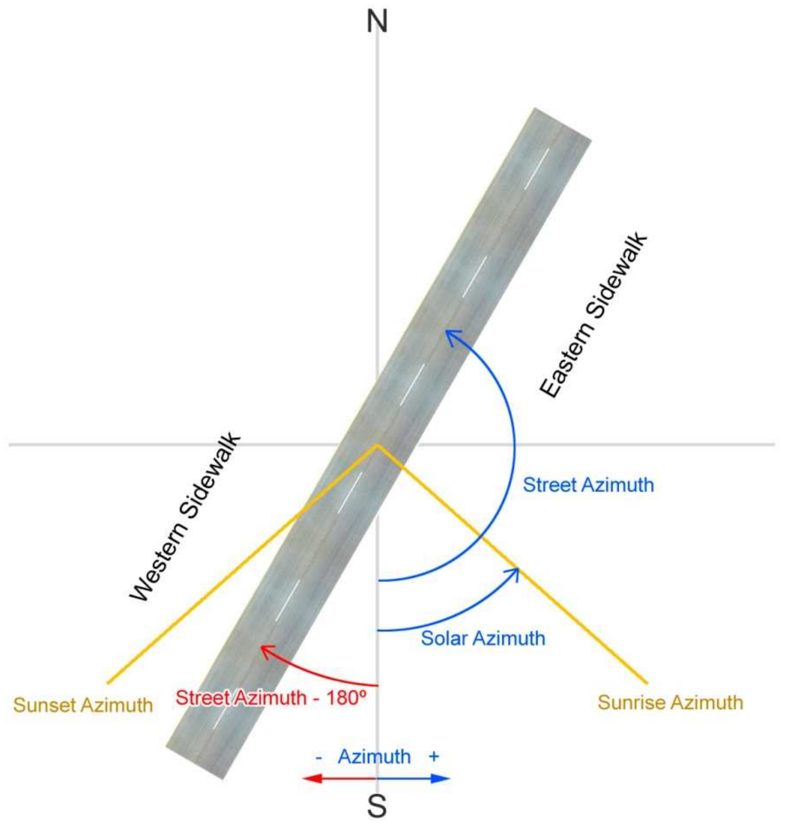


Image 38. Example of road without illumination of the southern sidewalk.

In each moment, for the remaining streets there will be an illuminated and a shaded sidewalk once the street azimuth matches the solar azimuth, when both edges are illuminated.
For these streets, a western sidewalk and an eastern sidewalk will be differentiated; first, we will divide the street following a line in E-W direction; then, the sidewalk divided by the eastern edge of the line will be the "eastern sidewalk" and the opposite, the "western sidewalk".

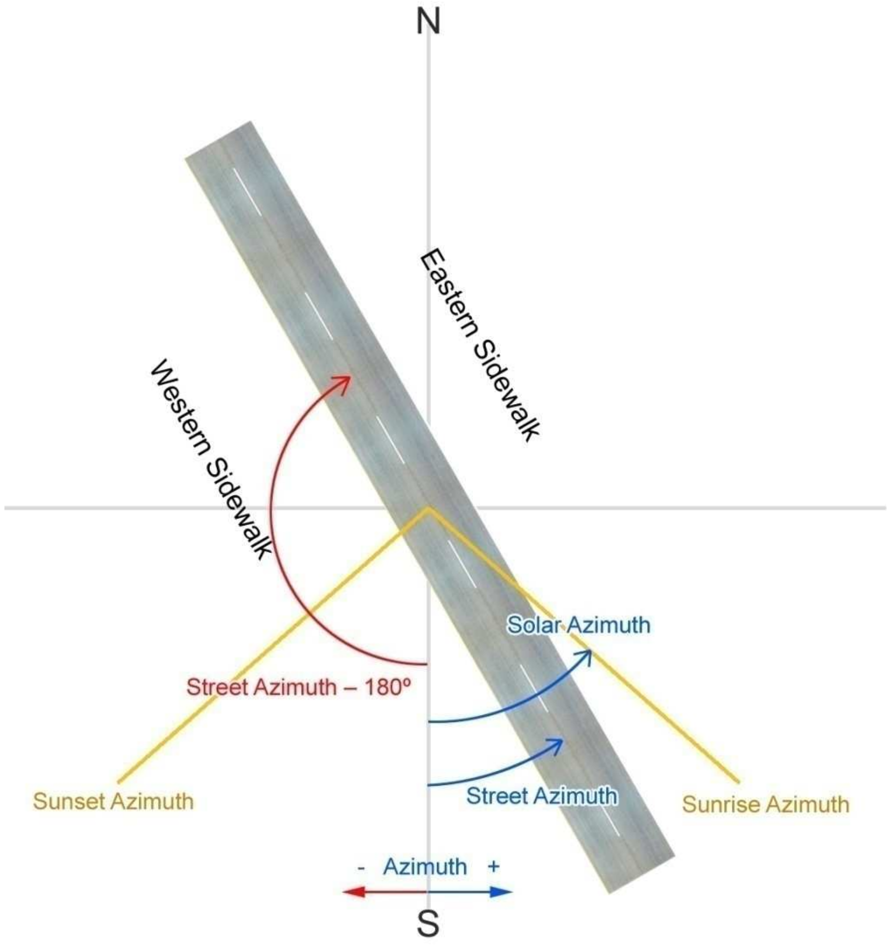
If a street of infinite width is considered, in order to know which sidewalk is illuminated, it will be considered if the street azimuth A_{street} is higher than the solar azimuth $A_{sunrise}$ in the sunrise.
Situation 1: $A_{street} > A_{sunrise}$



Street Azimuth > Sunrise Azimuth	Solar Azimuth > 0	Solar Azimuth<Street Azimuth
Western Sidewalk Illumination	Solar Azimuth < 0	Solar Azimuth>Street Azimuth - 180º

Image 39. Illumination conditions of the western sidewalk with $A_{street} > A_{sunset}$ for a street of infinite width.

Situation 2: $A_{street} < A_{sunrise}$



Street Azimuth < Sunrise Azimuth	Solar Azimuth > 0 Solar Azimuth>Street Azimuth
Western Sidewalk Illumination	Solar Azimuth < 0 Solar Azimuth<Street Azimuth – 180º

Image 40. Illumination conditions of the western sidewalk with $A_{street} < A_{sunset}$ for a street of infinite width.

When the aforementioned criteria are not achieved in both situations, the eastern sidewalk will be illuminated.
For a street of finite width a_{street}, each sidewalk will be illuminated when, in addition to the previous criteria, the following equation is fulfilled:
$[h_{build} / tg\ h] \cos a_{shadow} < a_{street} \Rightarrow [h_{build} / tg\ h] \cos (A_{street} - 90^\circ - A_{sol}) < a_{street}$
With the previous equations given for each moment of the day, it will be possible to know which sidewalk is illuminated, the length of the shadow and the most important thing: the hours of direct illumination for the solar tile.
Therefore, using the aforementioned method, taking into account the loss due to transmissivity and "aging", and knowing the hours of direct illumination in each street according to its geometry for the western and the eastern sidewalk, the PV performance of the solar tile can be determined.
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CAP 3. DISCONTINUOUS SLABS WITH NO FORMWORK

CAPÍTULO 3.

DISCONTINUOUS SLABS WITH NO FORMWORK

PART 1. GENERAL OVERVIEW

The need to develop structural prefabricated solutions aimed to shorten construction times, to improve the structural behaviour and to reduce the complexity of constructive methods has led to the technological development of discontinuous slabs with no formwork.

The discontinuous slabs with no formwork are mainly characterized by the following advantages:

- They allow the construction of slabs with no formwork. The prefabricated units can be just supported on props located in the ribs.

- The solution is characterized by the perimeter stiffening system of the structure. This solution shares both the advantages from unidirectional slabs (whose efforts are taken to the pillars through the beams) and from the waffle slabs (whose efforts are transmitted in both directions). As a result, the inertia of beams and bands increases considerably and the vertical deformations diminish.

The panels of prefabricated slabs are made up using reinforced concrete (HRMFV fibreglass). This reduces reinforcement and guarantees the absence of cracking with loads of standard level.

These slabs can be applied in two formats: with exposed waffle holes or with holes covered by blocks. In the second case, filigree slabs will be used for covering the holes before applying the concrete compression layer.

Image 41. Detail of discontinuous slab with no formwork.

PART 2. GEOMETRIES AND FORMATS

The available formats are:

- Discontinuous slab with no formwork of 30 cm waffle edge.
  PRODUCT CODE: FDSC-30-R.

Image 42. Detail of discontinuous slab of 30 cm side.

- Discontinuous slab with no formwork of 35 cm waffle edge.
  PRODUCT CODE: FDSC-35-R.

Image 43. Detail of discontinuous slab of 35 cm side.

The blocks and filigree for each previous solution have the following codes:

- Waffle blocks FDSC-30-R: C-30-R.

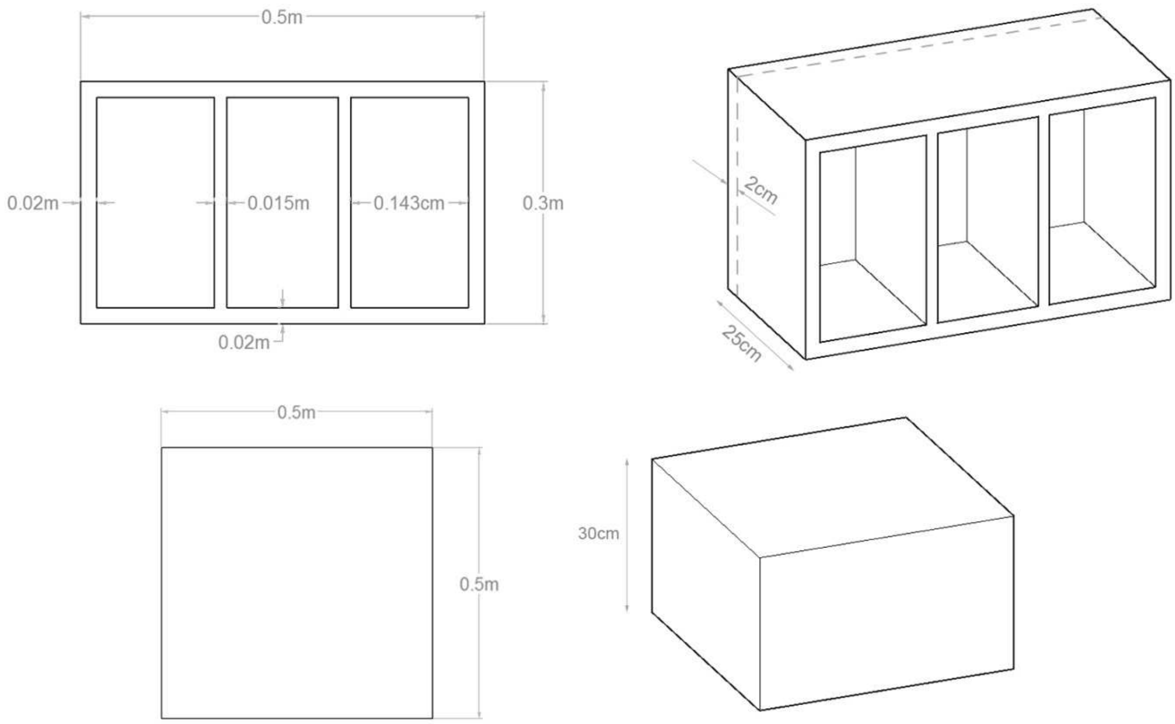


Image 44. Concrete caisson for executing with exposed waffle's holes. To be incorporated in the prefabrication.

- Waffle blocks FDSC-35-R: C-35-R.

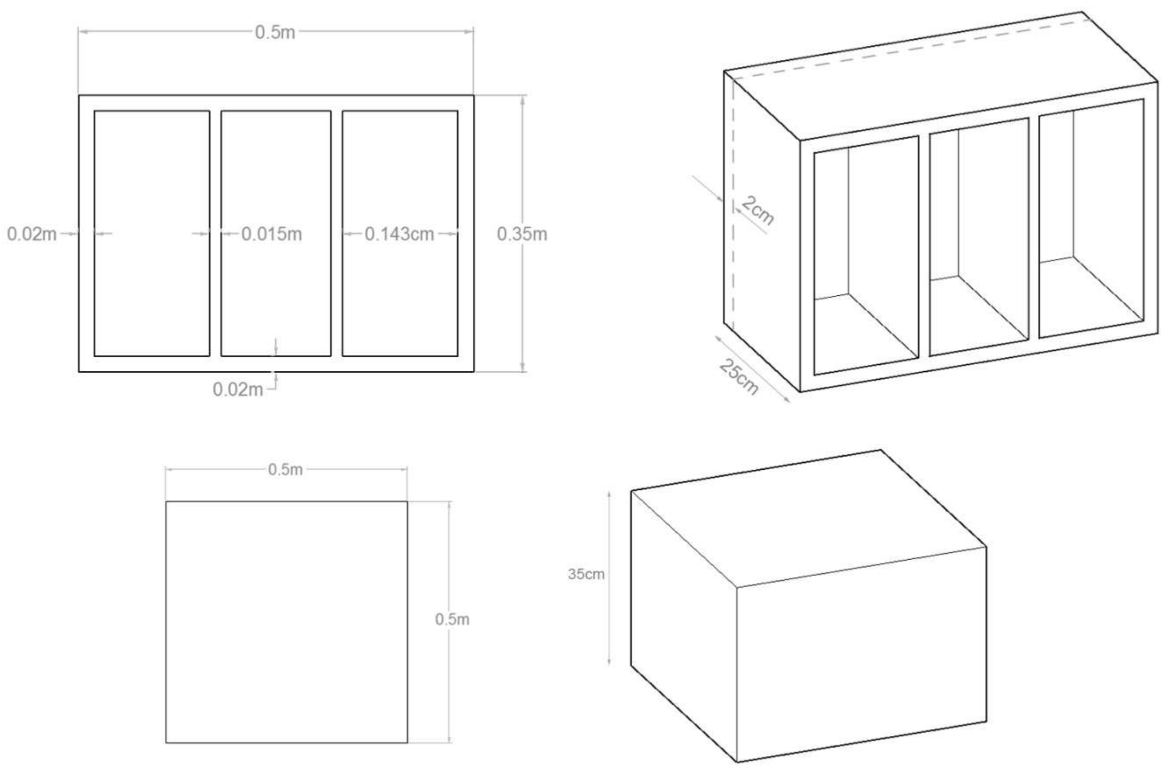


Image 45. Detail of concrete caissons and EPS.

- Filigree slab 50x50x4 cm: P-R.

Image 46. Detail filigree slab.

The lightened area considered for each case is as follows:

- Slab FDSC-30-R: 6 m.
- Slab FDSC-35-R: 8 m.

The waffles dimension in both cases is 50x50 cm and the ribs dimension varies between 8 cm at the bottom and 8,5 cm at the top, when waffle blocks are not arranged. For the latter, ribs will have 8 cm in the whole height.

For FDSC-30-R slabs, the maximum size will be 3x9 waffles. Therefore, any other sized under the previous one is applicable (2x8, 3x9, 3x7, etc.).

For FDSC-35-R slabs, the maximum size will be 3x13 waffles.

If the developer so requests, the incomplete waffle could be made in some cases (in general, mid-waffles).

The lateral jutting wings will have 30 cm length maximum. The conventional value is 25 cm. For intermediate bands, it will be recommended to limit the lateral wing to 12.5 or 15 cm.

In the following graphics the sizes for the different formats of slabs as well as the filigree slabs and blocks are described.

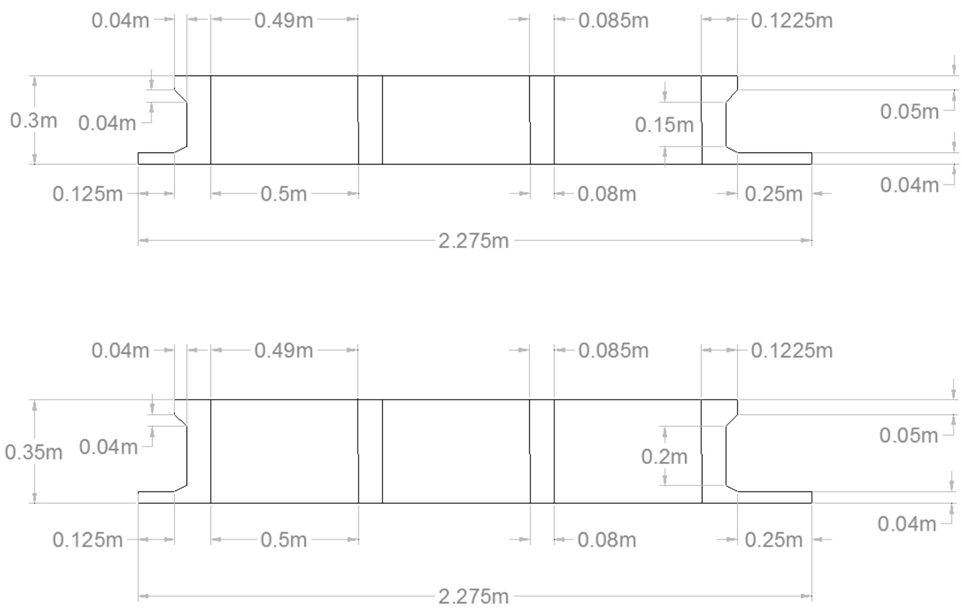


Image 47. Sections Slabs of 30 and 35 cm without caissons.

Image 48. Sections Slabs of 30 and 35 cm with caissons.

Image 49. Sections Slabs with filigree slabs incorporated.

Image 50. Sections Slabs of 30 and 35 cm with compression slab executed during prefabrication.

PART 3. MATERIALS.

Los hormigones a emplear cumplirán la siguiente dosificación:

Aggregate	1700	Kg
Cement 42.5 R	400	Kg (minimum content)
Plasticizer	2.4	l
Fibreglass 36 mm length	15	Kg
Fibreglass 12 mm length	4	Kg
Water	200	l (according to cement content)

Aggregate:

Coarse fraction, 8/12 mm: 40%.

Fine fraction, 0/5 mm: 60%.

The tests must guarantee a minimum characteristic resistance of 35 MPa and a flexotraction strength of 5.5 MPa.

Fibreglass will comply with the following prescriptions:

Fibreglass

- Minimum content in ZrO_2 >15%.
- Fibreglass length: 36 mm
- Loss on ignition = 2%.
- Filaments in roving form.
- Filament diameter = 14 μ
- Linear mass (g/km) = 2,450 Tex
- Density = 2.68 g/cm3
- Ultimate elongation of the roving = 4.5%
- Young modulus (N/mm2) (MPa) = 72,000 Pa
- Traction resistance of the roving (Nw/mm2) (MPa) >1,700 MPa
- Traction resistance of the Virgin Filament = 3,500 MPa

Finally, steel will be certified of type B500S.

PART 4. QUALITY CONTROL.

The corresponding tests will be carried out at the manufacturing place for controlling steel and concrete according to the national standards.

Each package will include the test verifying the characteristic resistance of concrete and the flexotraction strength as well as any other prescribed in the corresponding instructions.

The concrete packages will not overpass the following limits:

Built panel surface: 300 m^2.
Delivery of concrete time: 2 weeks
Steel and fibreglass will include the quality certification.

The steel and fibreglass packages will not overpass the following limits:
Built panel surface: 5,000 m^2 per delivered package.
Per delivered package
The manufacturer will deliver the control planning and the corresponding tests carried out for controlling the delivered panels.

PART 5. ARCHITECTURAL AND STRUCTURAL SOLUTIONS.

In general, for discontinuous slabs, the architect will be able to design with wide freedom, adapting the size of panels to the spaces between pillars afterwards.

The compression slab will be 6 cm thick.

Taking into account the constructive convenience, it is recommended that beams and bands do not overpass 30 cm width. As a general rule this size is enough as their edges will be 33 cm.

When the beams are considered to be wider, it is recommended not to apply the wing of the panel. So, it will be necessary to apply formwork at the bottom.

Likewise, it is recommended to use rectangular pillars adapted to the wing format (25 or 30 cm). If the pillar is bigger, the rib at the corner will be adapted to that size in the manufacturing process, as it appears in the attached graphic.

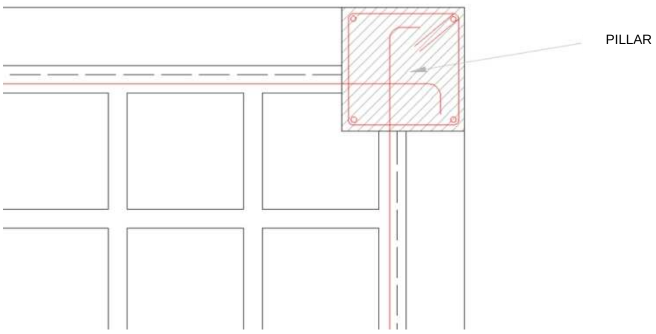


Image 51. Execution of the union between pillars which are wider than beams.

PART 6. CONSTRUCTION AND ASSEMBLING

Once the pillars are deployed, the props will be implemented on the sides of the prefabricated panels. These props will be placed over an edge supported on the pillars.

Alternatively, when panels are deployed in pairs, the number of props will be optimized by applying three lines of props with their corresponding edges:

- one line of props in the middle, cross to the joint line between the two panels.
- two parallel lines to the previous one placed in the edges of each panel.

The previous process can be seen in the attached picture.

Image 52. Setting of prefabricated units.

After seven days, props can be removed. If the arrangement of loads is foreseeable during the construction time, it will be advisable to leave the props which have been used for the lower slab and work, meanwhile, in the higher part, which will clearly reduce the construction times.

Image 53. Setting filigree slabs, formwork, concrete filling and final **uncasing**

PART 7. STRUCTURAL CALCULATION.

For the structural calculation of discontinuous slabs with no formwork, the planner may choose the most suitable method for dimensioning the structure.

This Guide provides a simplified method which enables an easy modelling using any structural calculation software. This method is known as the method of equivalent slab. It consists on considering one slab of equivalent inertia placed between the beams and bands which are located between the panels of slab with no formwork. At the same time, beams and bands will be dimensioned with the lower possible width between the edge and the panel (for external beams) or between the two continuous panels (for internal beams and bands). The edge of beams and bands is specified next:

The equivalent slab will have the following characteristics:

- Slab FDSC-30-R
  Concrete: HA-35.
  Equivalent slab edge: 28 cm. (Compression slab 6 cm)
  Equivalent slab weight: according to geometric adjust. See attached software.

- Slab FDSC-35-R
  Concrete: HA-35.
  Equivalent slab edge: 31 cm. (Compression slab 6 cm)
  Equivalent slab weight: according to geometric adjust. See attached software.

In both cases it will be applied a reduction coefficient of the torsional inertia for the equivalent slab equal to 0.2.

For modelling the equivalent slab, the joint between beams and bands, and slab is considered to be rigid. The concrete used for beams and bands will be determined by the planner. The recommended concrete is HA-35.

When the slab weight is to be inserted in the programme, the engineer calculator may introduce no slab weight and, later, apply a superficial permanent load with the right weight, or may introduce a load per low volume for obtaining the same load per square meter per own weight.

The models developed by finite elements show that this method gives tension values between 5% - 10% higher than the actual model of discontinuous slab with no formwork. Likewise, the arrows are situated around 10%, hence the method is safe and the slabs calculations are highly simplified.

The following sheets provide the maximum values of traction and tangential tension expected for every dimension of discontinuous slab with no formwork panels and for every defined load.

The engineer calculator must compare that in the equivalent slab the solicitations are lower than previous values.

This will guarantee the absence of cracking in the units of the slabs with no formwork.

The engineer calculator must distinguish the solicitations in the perimeter ribs and those in the inner ribs.

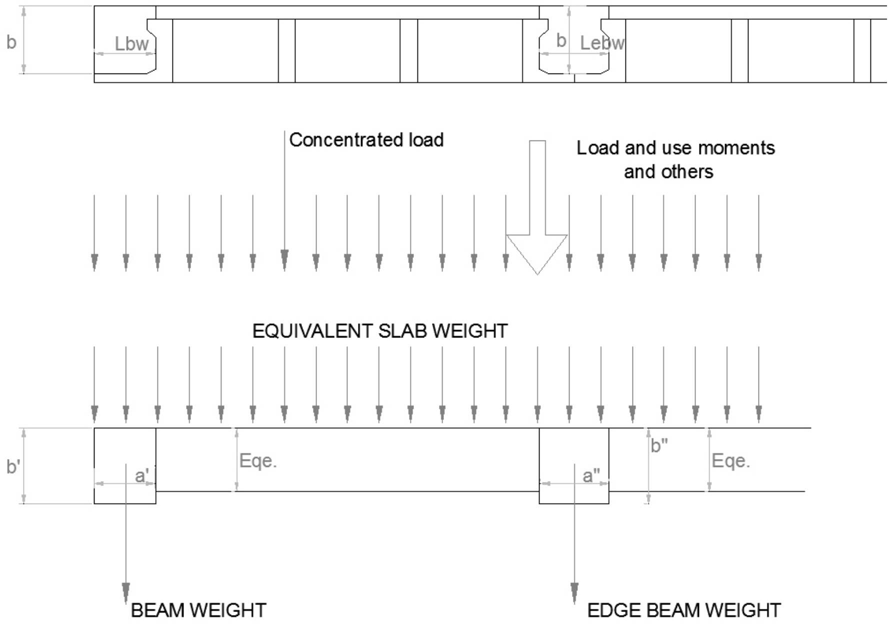


Image 54. Assignment of loads on the equivalent slab.

FDSC-30-R (30cm)	b’ = b+1 cm a’ = a_L – 2 cm	b” = b+1 cm a” = a_C – 3 cm	Eqb. = 28 cm (1) Weight: according to geometry.
FDSC-35-R (35cm)	b’ = b a’ = a_L – 1 cm	b” = b a” = a_C - 1,5 cm	Eqb. = 31 cm (1) Weight: according to geometry.

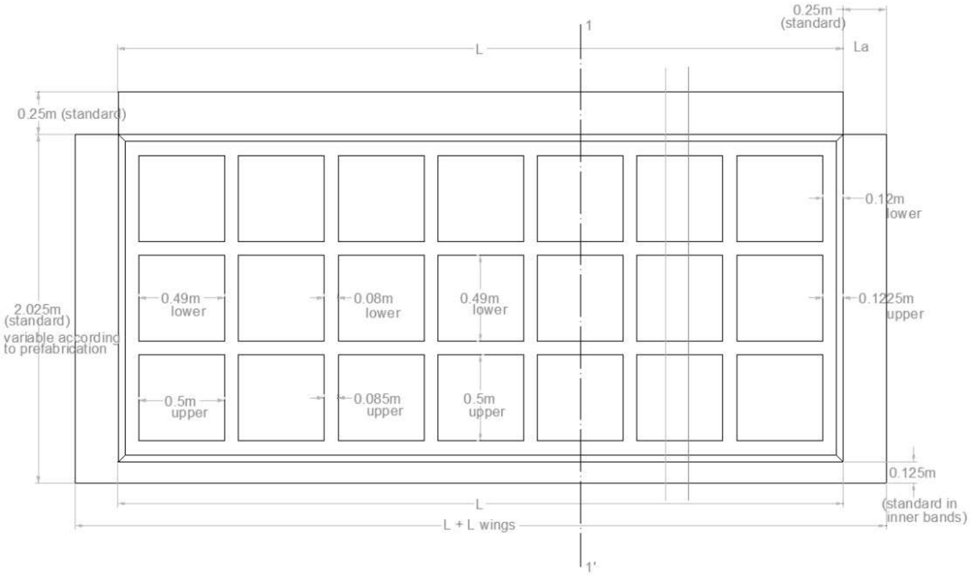
(1) with filigree slabs, enlarge 2 cm the equivalent bord.

Table 3-1. Geometry of the equivalent slab, and inner beams and bands.

Slab FDSC-30-R

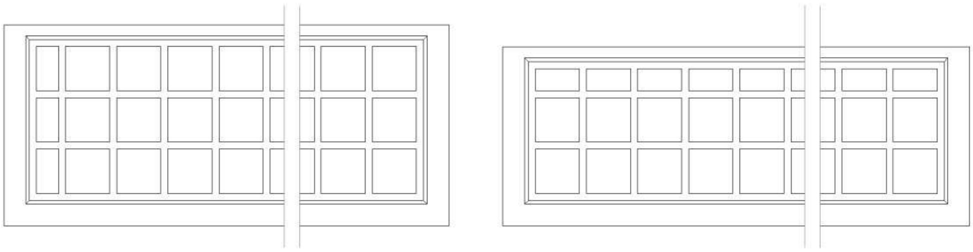
1.- GEOMETRY

Plan

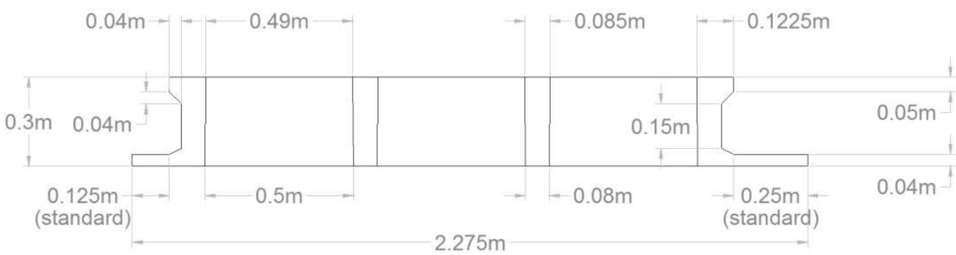


The wings size can be adjusted to the perimeter size required by the slab

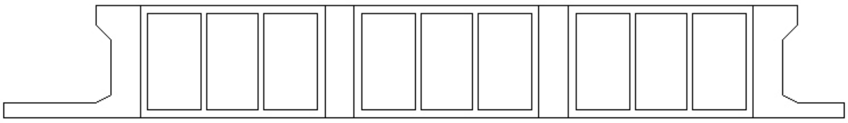
Solutions with mid-blocks



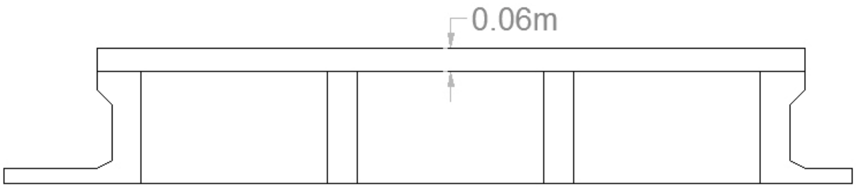
Section 1-1'



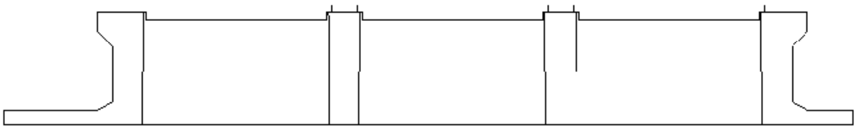
Option with waffle blocks incorporated during prefabrication:



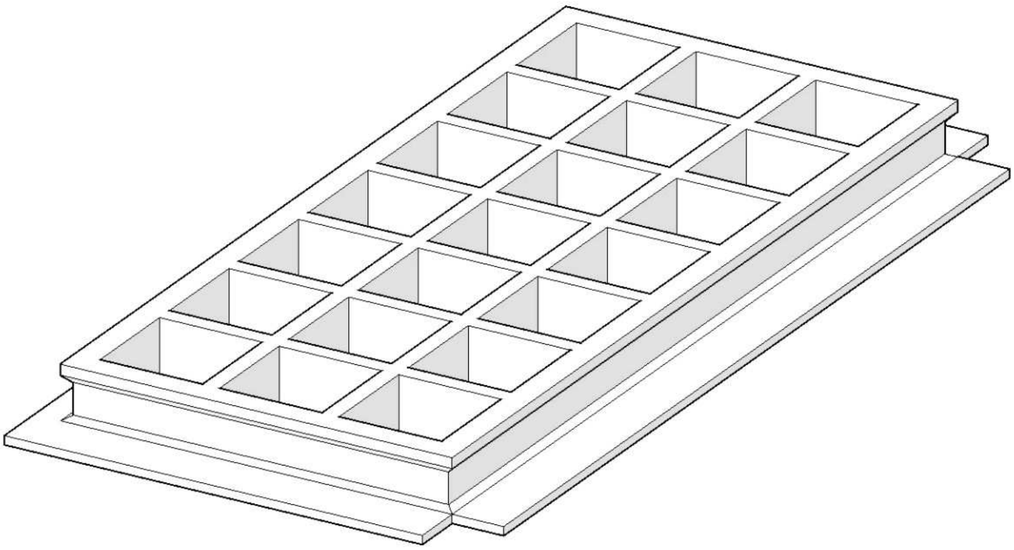
Option compression slad incorporated:



Option with filigree slabs:

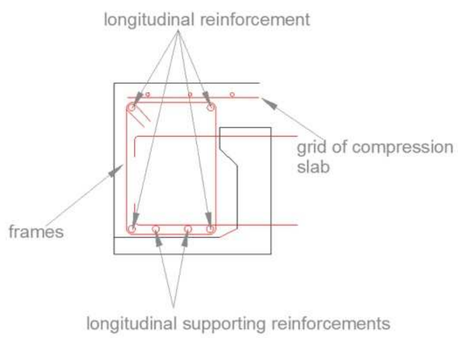


3D View

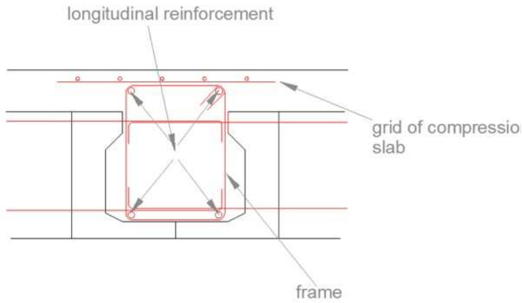


2.- BEAMS AND BANDS

REINFORCEMENT DETAIL PERIMETER BEAM



REINFORCEMENT DETAIL CENTRAL EDGE BEAM



3.- DOSAGE AND MATERIALS

The concrete to be applied will comply with the following dosage:

Aggregate	1700	Kg
Cement 42.5 R	400	Kg, (minimum content)
Plasticizer	2.4	l
Fiberglass 36 mm length	15	Kg
Fiberglass 12 mm length	4	Kg
Water	200	l, (according to cement content)

Aggregate:

Coarse fraction, 8/12 mm: 40%

Fine fraction, 0/5 mm: 60%.

The tests must guarantee a minimum characteristic resistance of 35 MPa and a flexotraction strength of 5.5 MPa.

Fibreglass will comply with the following prescriptions:

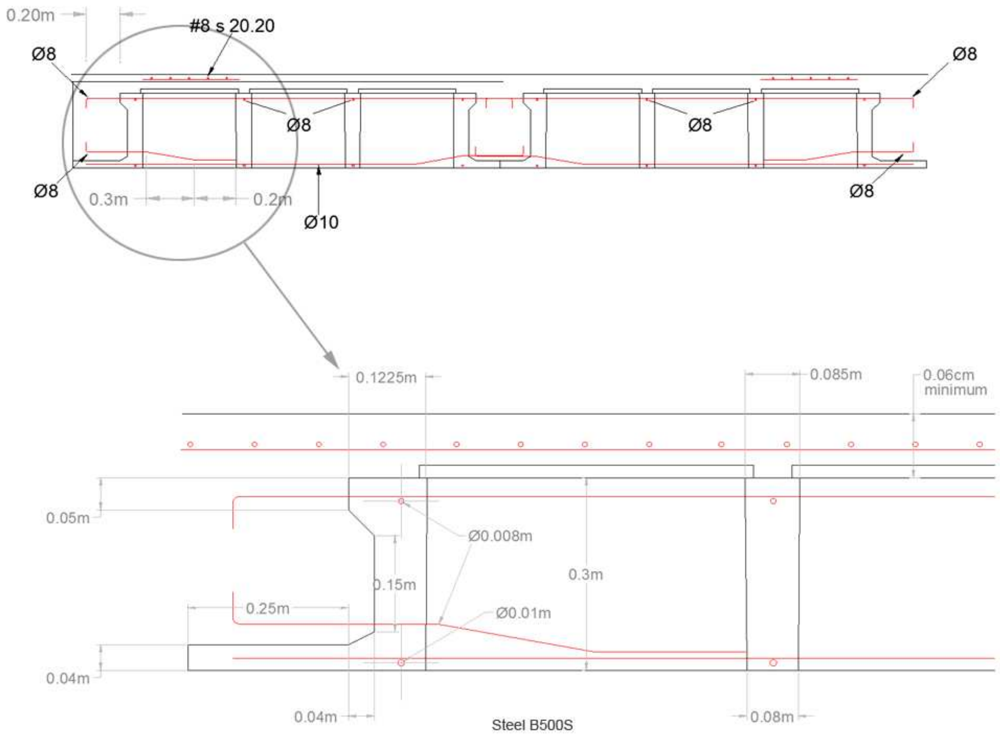
Fiberglass

- Minimum content in ZrO_2 >15%.
- Fibreglass length: 36 mm
- Loss on ignition = 2%.
- Filaments in roving form.
- Filament diameter = 14 µ
- Linear mass (g/km) = 2,450 Tex
- Density = 2.68 g/cm^3
- Elongation at break of the roving = 4.5%
- Young modulus (N/mm2) (MPa) = 72,000 Pa
- Traction resistance of the roving (Nw/mm2) (MPa) >1,700 MPa
- Traction resistance of the Virgin Filament = 3,500 MPa

Finally, steel will be certified of type B500S.

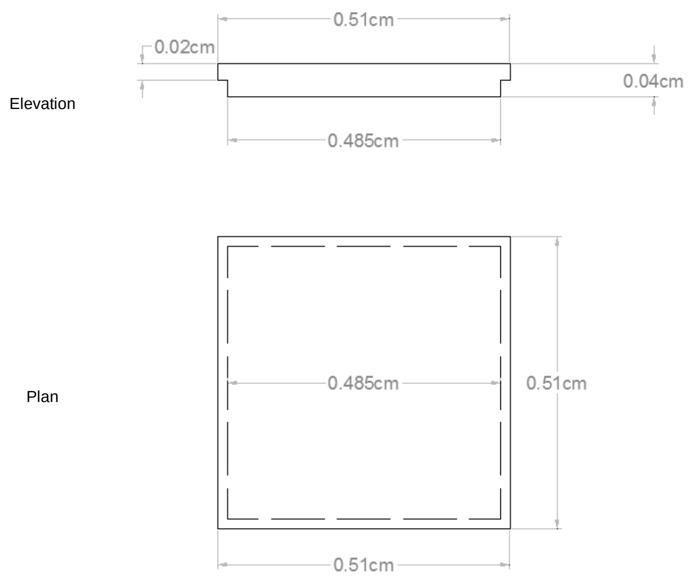
4.- REINFORCEMENTS, FASTENINGS AND COMPRESSION SLAB

Prefabricated slab reinforcement detail and compression slab



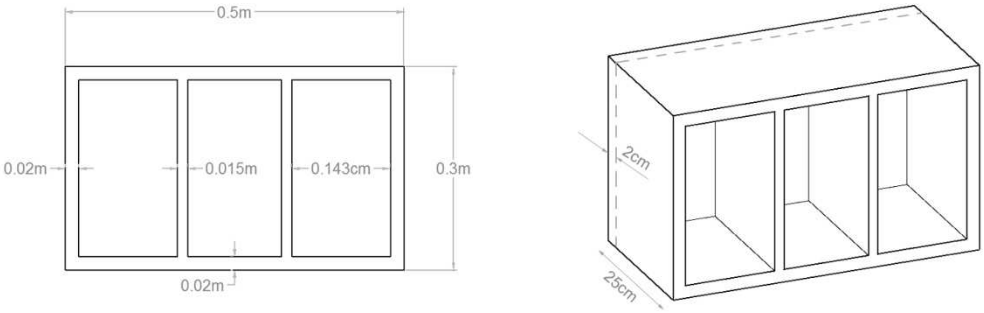
5.- FILIGREE SLAB OR WAFFLE BLOCK

Filigree slab



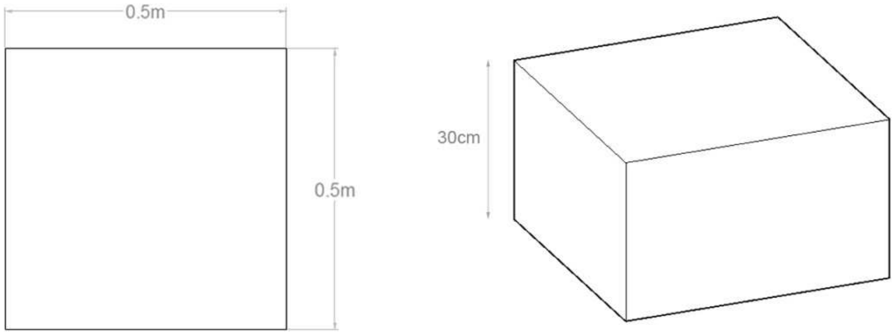
Block

(concrete)



Block

(EPS)



6.- WEIGHTS

Calculate according to geometric fitting (see attached software)

7.- MAXIMUM RESISTANCES FOR PREFABRICATED SLAB PER METER WIDTH

The engineer calculator will check the combination of efforts without increasing for the prefabricated slab to not overpass the following values of **solicitations**.

MAXIMUM SOLICITATION VALUES IN THE PERIMETER RIBS WHICH JOINT BEAMS AND BANDS

	Maximum positive moment, (m·kp/m)	Maximum negative moment, (m·kp/m)	Shearing, (kp/m)
FDSC-30-R	4,615.00	7,400.00	24480

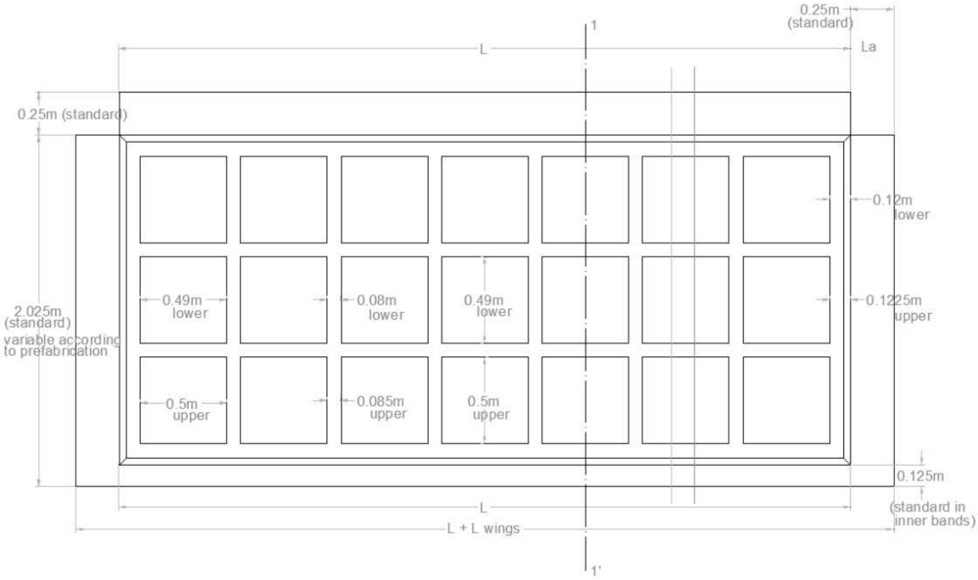
MAXIMUM SOLICITATION VALUES IN THE INNER RIBS

	Maximum positive moment, (m·kp/m)	Maximum negative moment, (m·kp/m)	Shearing, (kp/m)
FDSC-30-R	2,640.00	6,000.00	17820

Slab FDSC-35-R

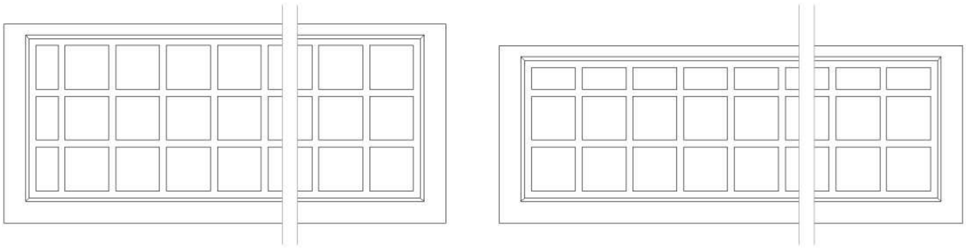
1.- GEOMETRY

Plan

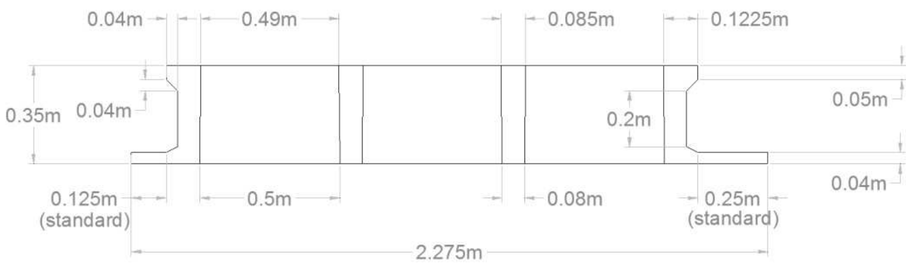


The wings size can be adjusted to the perimeter size required by the slab

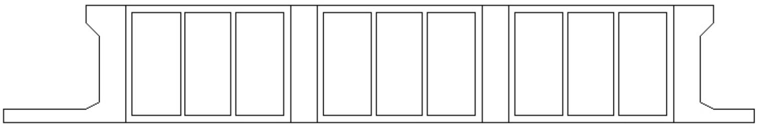
Solutions with mid-blocks



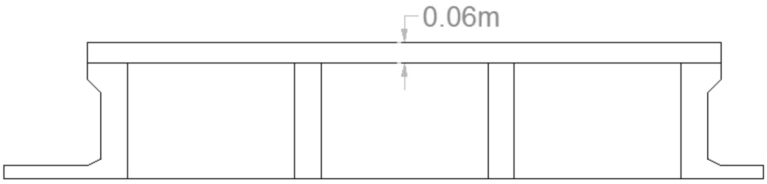
Section 1-1'



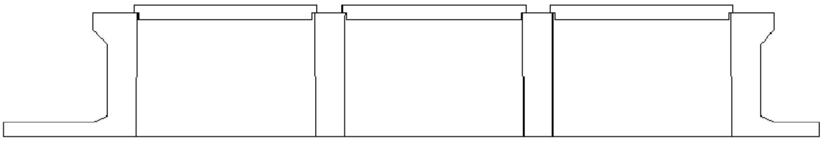
Option with waffle blocks incorporated during prefabrication:



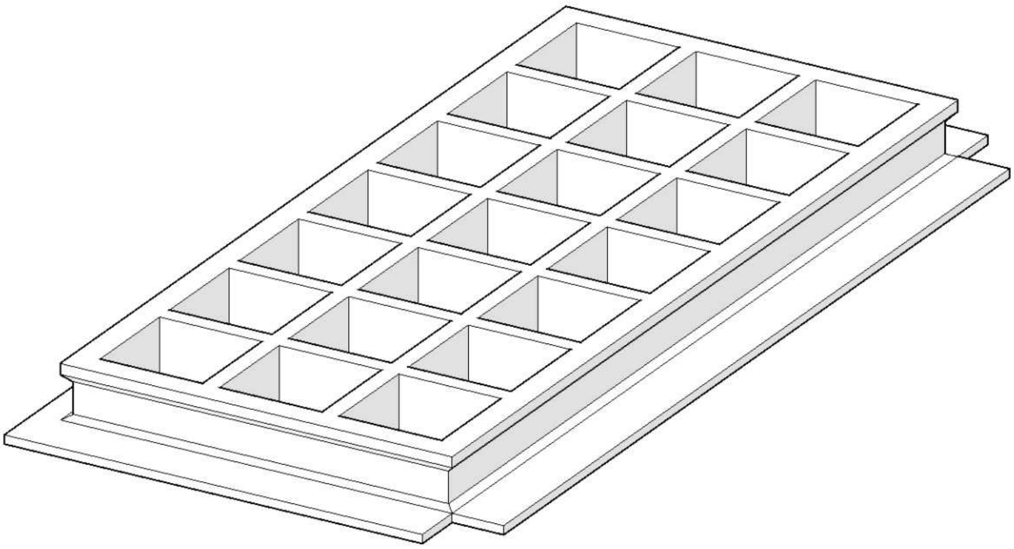
Option compression slab incorporate:



Option with filigree slabs:

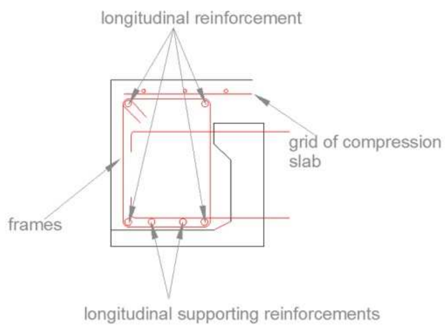


3D View

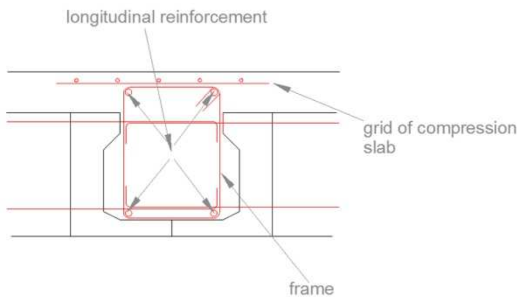


2.- BEAMS AND BANDS

REINFORCEMENT DETAIL PERIMETER BEAM



REINFORCEMENT DETAIL CENTRAL EDGE BEAM



3.- DOSAGE AND MATERIALS

The concrete to be applied will comply with the following dosage:

Aggregate	1700	Kg
Cement 42.5 R	400	Kg, (minimum content)
Plasticizer	2.4	l
Fiberglass 36 mm length	15	Kg
Fiberglass 12 mm length	4	Kg
Water	200	l, (according to cement content)

Aggregate:

Coarse fraction, 8/12 mm: 40%.

Fine fraction, 0/5 mm: 60%.

The tests must guarantee a minimum characteristic resistance of 35 MPa and a flexotraction strength of 5.5 MPa.

Fibreglass will comply with the following prescriptions:

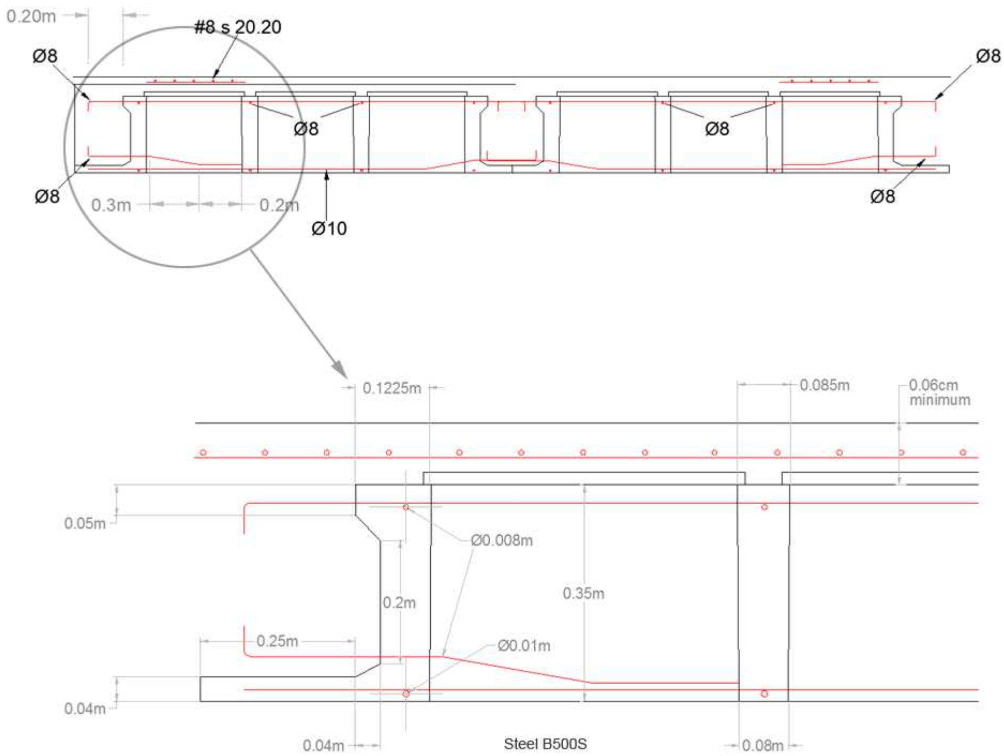
Fiberglass

- Minimum content in ZrO2 >15%.
- Fibreglass length: 36 mm
- Loss on ignition = 2%.
- Filaments in roving form.
- Filament diameter = 14 µ
- Linear mass (g/km) = 2,450 Tex
- Density = 2.68 g/cm^3
- Elongation at break of the roving = 4.5%
- Young modulus (N/mm2) (MPa) = 72,000 Pa
- Traction resistance of the roving (Nw/mm2) (MPa) >1,700 MPa
- Traction resistance of the Virgin Filament = 3,500 MPa

Finally, steel will be certified of type B500S.

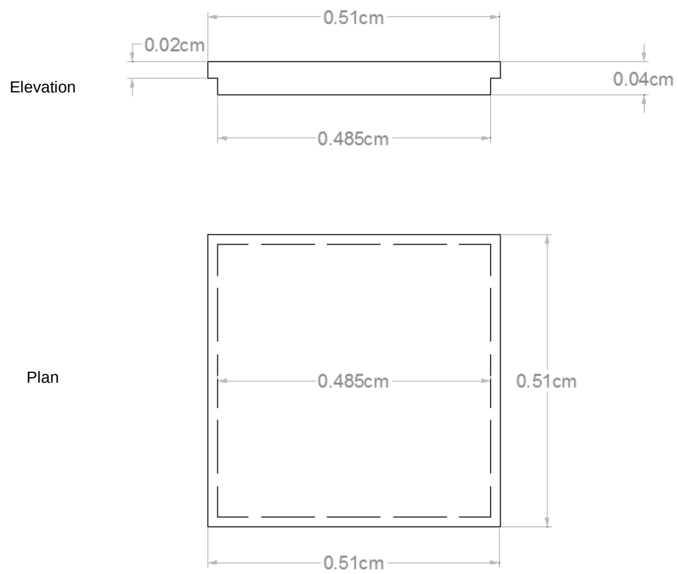
4.- REINFORCEMENTS, FASTENINGS AND COMPRESSION SLAB

Prefabricated slab reinforcement detail and compression slab



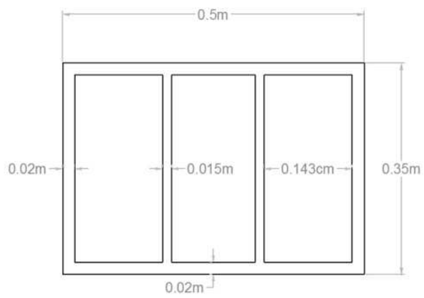
5.- FILIGREE SLABS OR WAFFLE BLOCKS

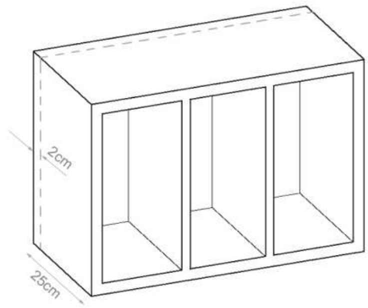
Prelosa



Casetón

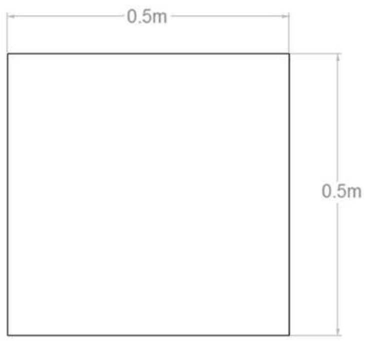
(hormigón)

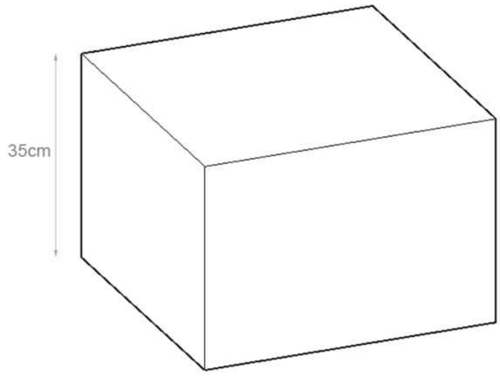




Casetón

(porexpan)





6.- WEIGHT

Calculate according to geometric adjust. (See attached software)

7.- ESFUERZOS MÁXIMOS PARA EL FORJADO PREFABRICADO POR METRO DE ANCHO

The engineer calculator will check the combination of efforts without increasing for the prefabricated slab to not overpass the following values of solicitations.

MAXIMUM SOLICITATION VALUES IN THE PERIMETER RIBS WHICH JOINT BEAMS AND BANDS

	Maximum positive moment, (m·kp/m)	Maximum negative moment, (m·kp/m)	Shearing, (kp/m)
FDSC-35-R	5,950.00	9,230.00	25980

MAXIMUM SOLICITATION VALUES IN THE INNER RIBS

	Maximum positive moment, (m·kp/m)	Maximum negative moment, (m·kp/m)	Shearing, (kp/m)
FDSC-35-R	3,525.00	7,675.00	20460

CAP 4. CAISSONS WALLS

CAP 4.

CAISSONS WALLS

PART 1. GENERAL OVERVIEW.

The caissons walls provide a very quick, rigid and stable solution for small and big heights of earth pressure.

The main advantages of this solution are:

- Quick construction.
- Optimization of materials when applying grounds for stabilizing the caissons.
- Great rigidity and, therefore, less wall deformation.
- Less space between the caisson and its backfill.

The caissons walls allow considering new solutions on alternative structures to the traditional slopes, which will reduce drastically the expropriations.

Compared with the traditional prefabricated solutions, the caissons walls have the following advantages:

- It is achieved a quite higher rigidity compared with that of reinforced earth walls or keystones.
- It is not required a great wide space for backfilling and, therefore, the solution is valid for stabilizing cut section slopes in infrastructure banks.
- The concrete reinforced with fibreglass provides no cracking, so guaranteeing the durability of the solution.
- No connectors are needed.
- No strappings or grids are needed for the backfill.
- Stability is guaranteed, unit by unit and in the base, against overturning or landsliding.

These solutions give an idea about how competitive the costs can be compared with prefabricated or in situ walls and their main advantage is their quick assembling.

The transport of units is very easy too as they are adapted to the truck dimensions.

PART 2. GEOMETRIES AND FORMATS.

Only one format of caissons walls is considered:

- Caissons walls: CCW

The wall works due to the contact between units as described in the calculation process.

As for their geometry, 5 possible sizes are considered:

For each unit, the sizes are identified with letters from A to E as follows:

- Module CCW- A: 1.25 m depth. Product code: CCW- A
- Module CCW- B: 2 m depth. Product code: CCW- B
- Module CCW- C: 2.75 m depth. Product code: CCW- C
- Module CCW- D: 3.5 m depth. Product code: CCW- D
- Module CCW- E: 4.25 m depth. Product code: CCW- E


Image 55. Caissons walls.

The size of CCW units is 2x2 m for the front and backfill and the length and depth is the same as indicated for unit A-E. Every unit, except for A ones, are internally divided including one backside bucket of 65 cm depth. This wall and the bord walls are 12 cm thickness in the base and 8 cm thickness at the top. Every unit's base is closed by a slab of 10 cm. Flaps of 5 cm depth jut from that base and contact with the inferior unit.

CCW walls have been proved for 10 cm height of in earth pressures and they do not require jointing concrete between units. Therefore, their contact is enough.

As defined previously, the joint between caissons is made by contact. The contact is produced as follows:

- from the caissons' base to the adjoining walls' top and the backside bucket's inner wall of the lower caisson (vertical contact).

- from the flaps to the bucket's front wall and to the backside bucket's wall. In some cases, to the backfill (horizontal contact).

In order to receive the higher caisson and avoid hard contacts, a mortar layer of 1 cm will be applied on the top of the higher wall.

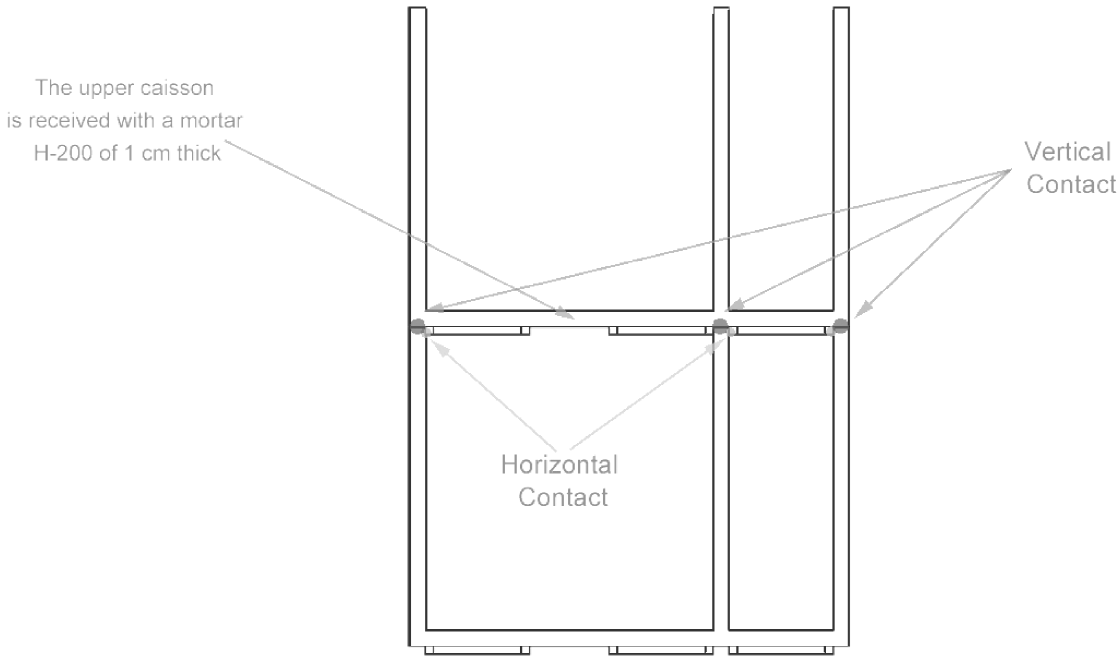


Image 56. Contact between caissons.

One of the main advantages of these caissons is that they can be arranged in a stepped way, improving the stabilizer moment.

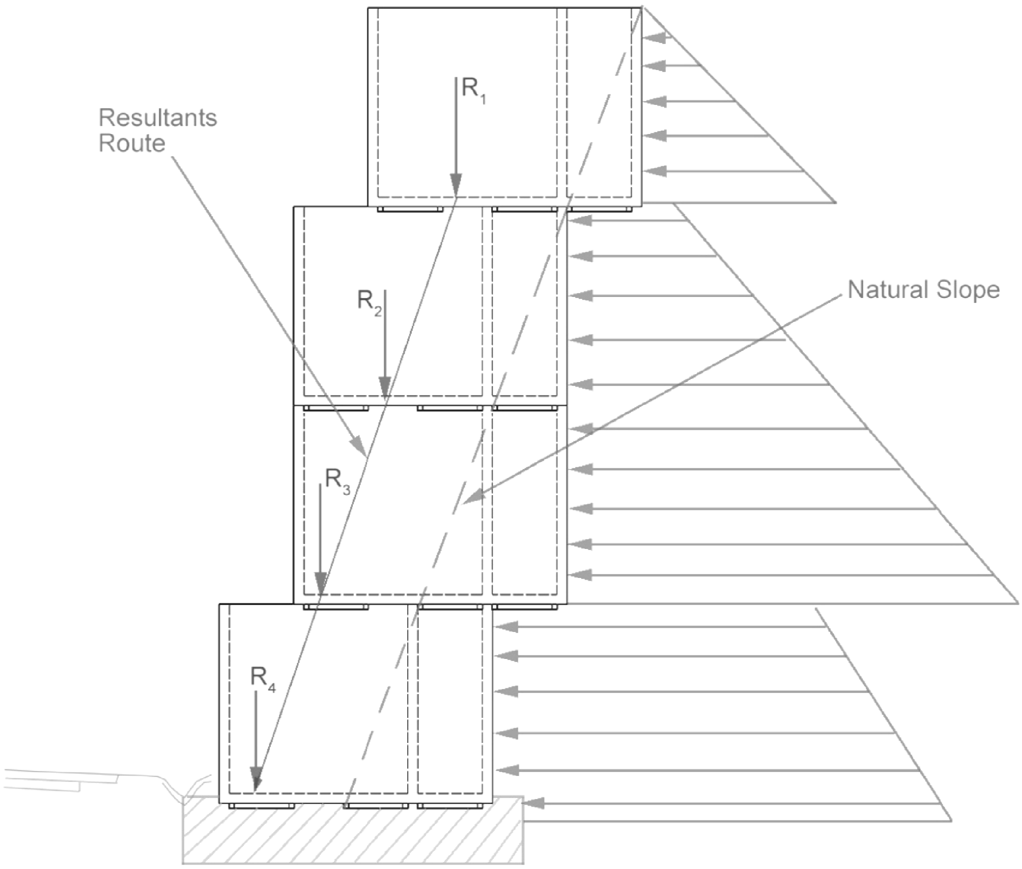


Image 57. Stability caisson by caisson, without intermediate or base overturning. Stepped modules.

The possible stepped arrangements are as follows:

Caissons Measures	L (m)	H(m)	D1(m)	D2(m)	D3(m)	D4(m)
CCW-A	1.25	1.05				
CCW-B	2.00	1.05	0.5			
CCW-C	2.75	1.80	0.1	0.5		
CCW-D	3.50	2.55	0.1	0.3	0.3	
CCW-E	4.25	3.30	0.1	0.23	0.24	0.23

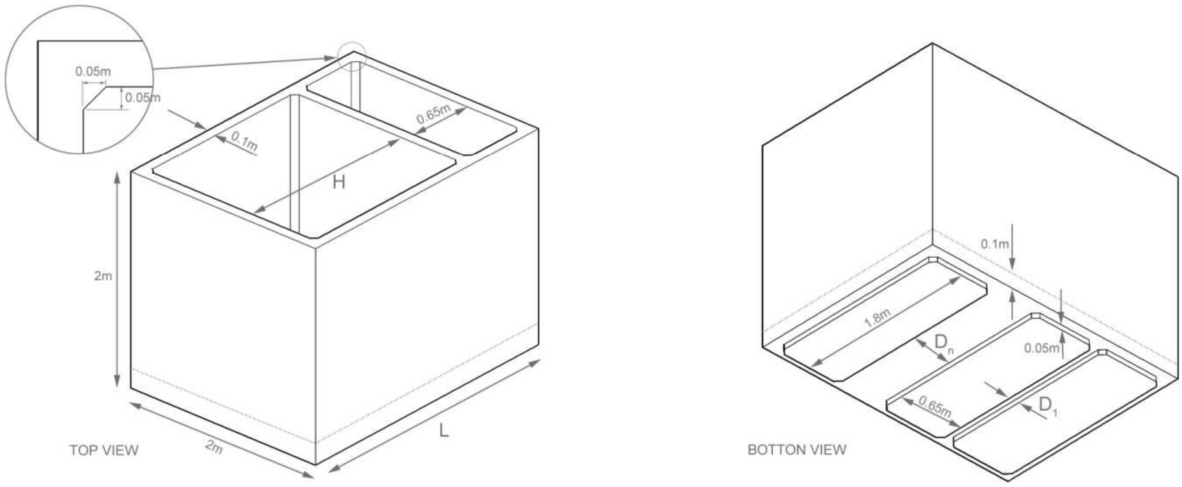


Image 58. Concrete caissons 2x2 m.

POSSIBLE STEPPED ARRANGEMENTS									
D-E	2.65	1.77	0.88		**E-D**	3.40	2.45	1.50	0.75
D-D	2.65	1.70	0.75		**D-D**	2.65	1.70	0.75	
C-D	1.90	0.95			**D-C**	2.65	1.50	0.75	
C-C	1.90	0.75			**C-C**	1.90	0.75		
B-C	1.15				**C-B**	1.90	0.75		
B-B	1.15				**B-B**	1.15			
A-B					**B-A**				
A-A					**A-A**				
* The left letter of each couple is the lower caisson									

Table 4-1. Stepped arrangements of the different caissons combinations.

Finally, the use of these caissons on embankments can be made with a wider-base and tighter-top module. In addition, when applying walls on both embankments sides, it is possible to tauten the walls from one bank with the walls from the opposite bank, allowing the use of wider-base modules and fixing the braces through filling buckets with concrete. This fastening is not needed to be located in every wall line nor in every module.

Likewise, concrete trays can be fixed to the backside buckets, improving stability.

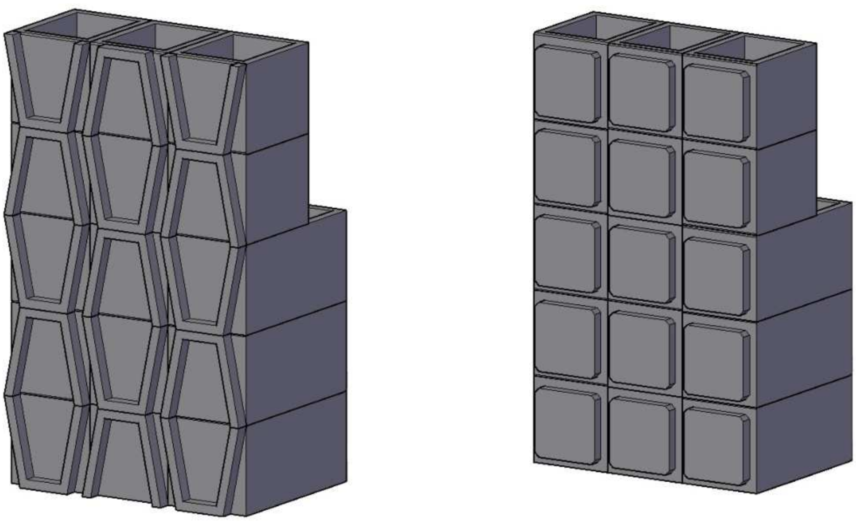


Image 59. Module overlap for making walls in filling areas or embankment.

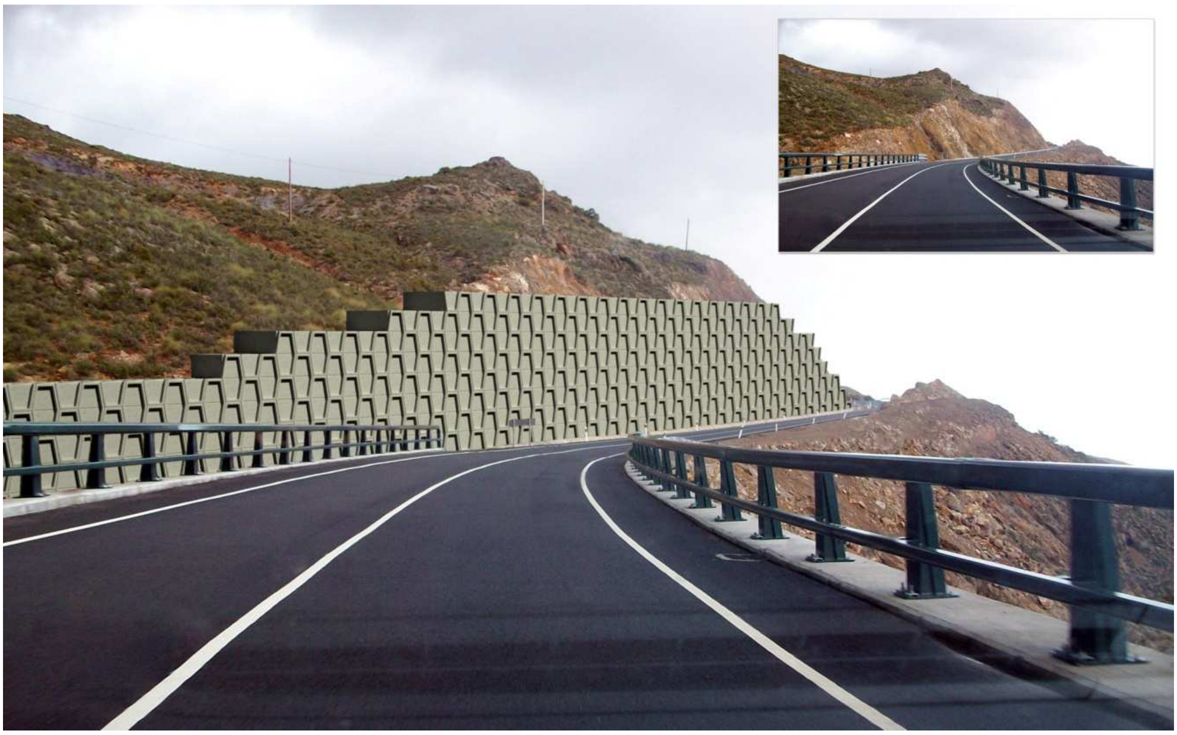


Image 60. Cut section slopes protection with caissons walls.

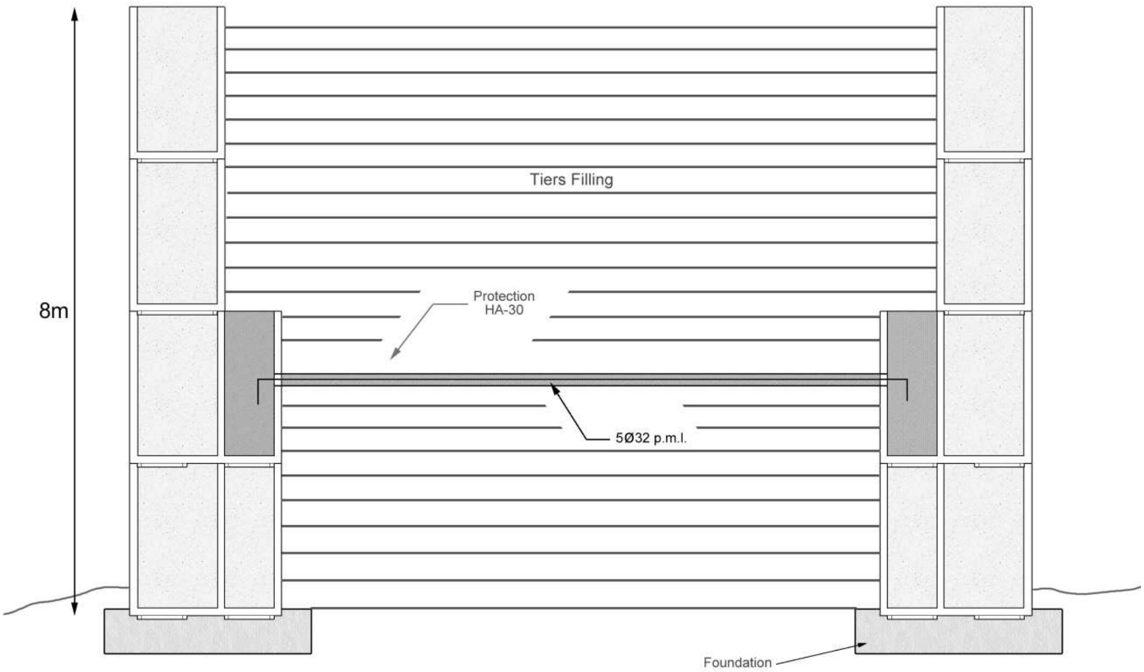


Image 61. Intermediate tautening for optimizing walls.

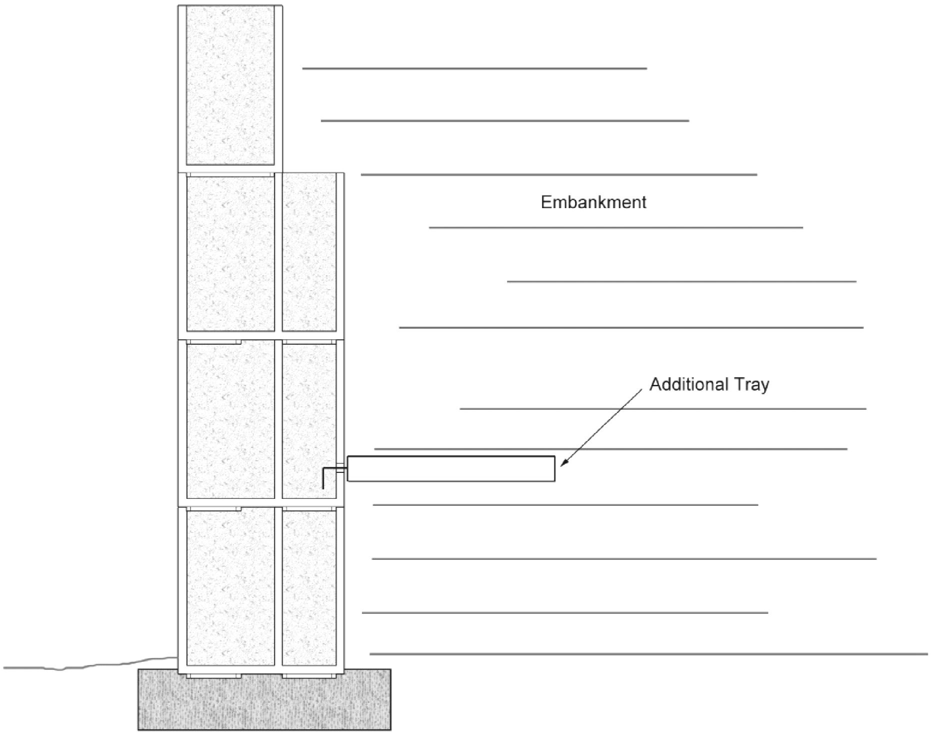


Image 62. Intermediate trays for improving stability.

PART 3. MATERIALS

The concrete to be applied will comply with the following dosage:

Aggregate	1760	Kg
Cement 42.5 R	360	Kg (minimum content)
Plasticizer	2	l
Fibreglass 36 mm length	18	Kg
Water	180	l (according to cement content)

Aggregate:

Coarse fraction, 8/12 mm: 40%

Fine fraction, 0/5 mm: 60%

The tests must guarantee a minimum characteristic resistance of 30 MPa and a flexotraction strength of 5.0 MPa Optionally, no fibres concrete can be used provided that the aforementioned resistance values are guaranteed. In this case, it will be used a minimum welded-wire mesh of ø 6 s15.15 cm.

Fibreglass

Fibreglass will comply with the following prescriptions:

- Minimum content in ZrO_2 >15%.
- Fibreglass length: 36 mm
- Loss on ignition = 2%.
- Filaments in roving form.
- Filament diameter = 14 µ
- Linear mass (g/km) = 2,450 Tex
- Density = 2.68 g/cm3
- Ultimate elongation of the roving = 4.5%
- Young modulus (N/mm2) (MPa) = 72,000 Pa
- Traction resistance of the roving (Nw/mm2) (MPa) >1,700 MPa
- Traction resistance of the Virgin Filament = 3,500 MPa

PART 4. QUALITY CONTROL.

The corresponding tests will be carried out at the manufacturing place for controlling concrete according to the national standards.

Each package will include the test verifying the characteristic resistance of concrete and the flexotraction strength as well as any other prescribed in the corresponding instructions.

The concrete packages will not overpass the following limits:

Built panel surface: 300 m^2.
Delivery of concrete time: 2 weeks.

Fibreglass will include the quality certification.

The manufacturer will deliver the control planning and the corresponding tests carried out for controlling the delivered walls.

__PART 5. CONSTRUCTIVE SOLUTIONS__

The planner will determine the best combination of modules for the earth pressures to support.

As for the wall finishing, the following solutions are considered:

- stalactites
- squares
- rhombus
- stratus
- stone masonry

Image 63. Constructive solutions for the finishings in the front part.

PART 6. CONSTRUCTIVE PROCESS.

For the solutions of caissons walls, the constructive process and the performance are justified as follows:

- the modules can be transported by an articulate heavy vehicle; the total amount of transportable modules may vary between 3 (for modules of 4.25 m depth) and 12 (for modules of 1.25 m).

- the module arrangement can be made by a high-tonnage truck crane or a crane (more recommendable for greater heights and heavier caissons).

- the module arrangement (unload from the transport vehicles), if locating them on the foundation layer or on an existing line of modules, must have a performance of 4 units per hour for A-modules and 8 units per hour for E-modules.

- the modules filling can be made with a performance of 12 units per hour (if compacting is not required) and 6 units per hour (if compacting is required, i.e. E-modules). For an A-module, performances are considered to be 24 units per hour without compacting and 12 units per hour with compacting.

- the mortar application process must have an average performance of 8 units per hour per workman for modules of 1.25 m and 4 units per hour per workman for modules of more than 4.25 m.

For repairing a cut section slope in a road bank where a landslide has happened, the application steps are described in the following images:

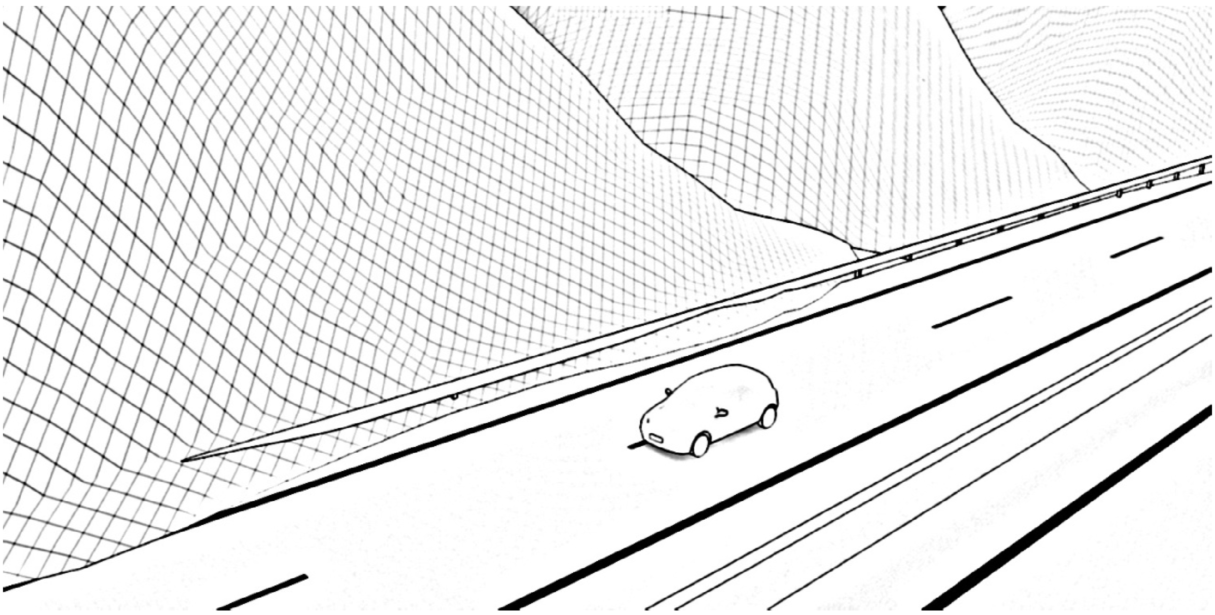


Image 64. Landsliding slope in the road bank.

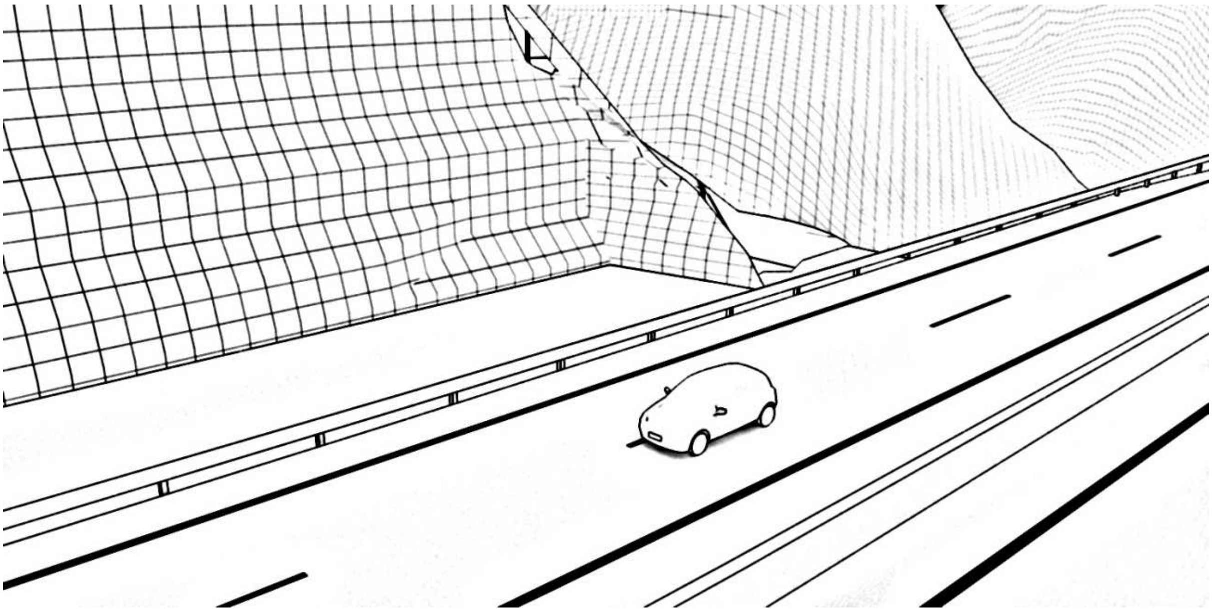


Image 65. The displaced material is removed and the wall base is filled with concrete. (It can be made also with foundation trenches when the stability is not guaranteed).

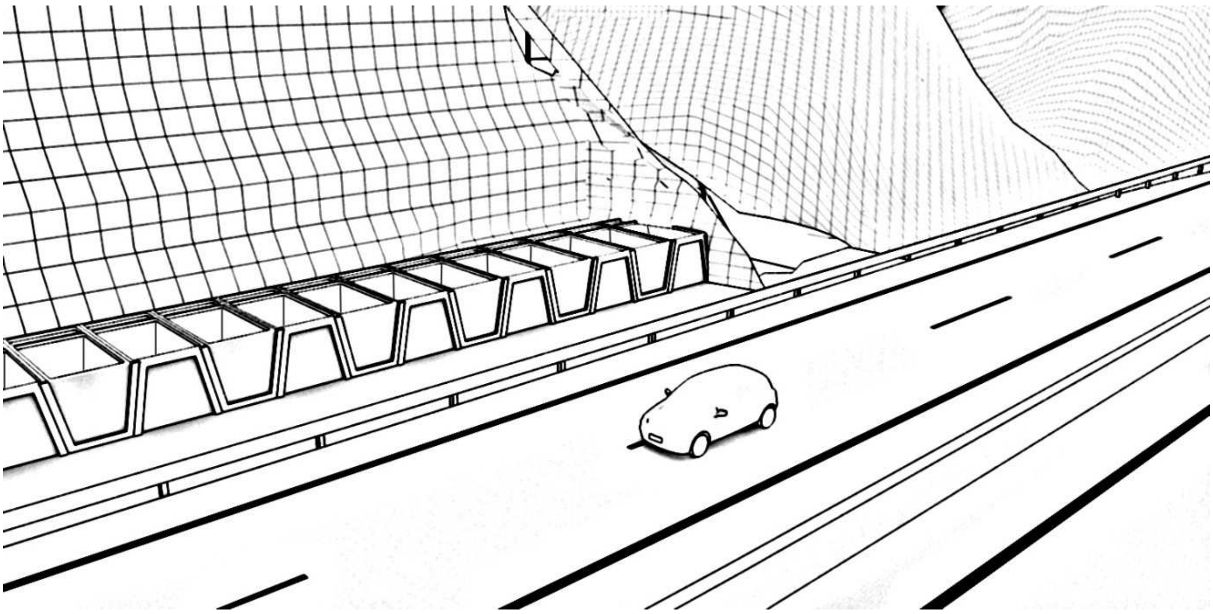


Image 66. Setting of the first line of caissons.

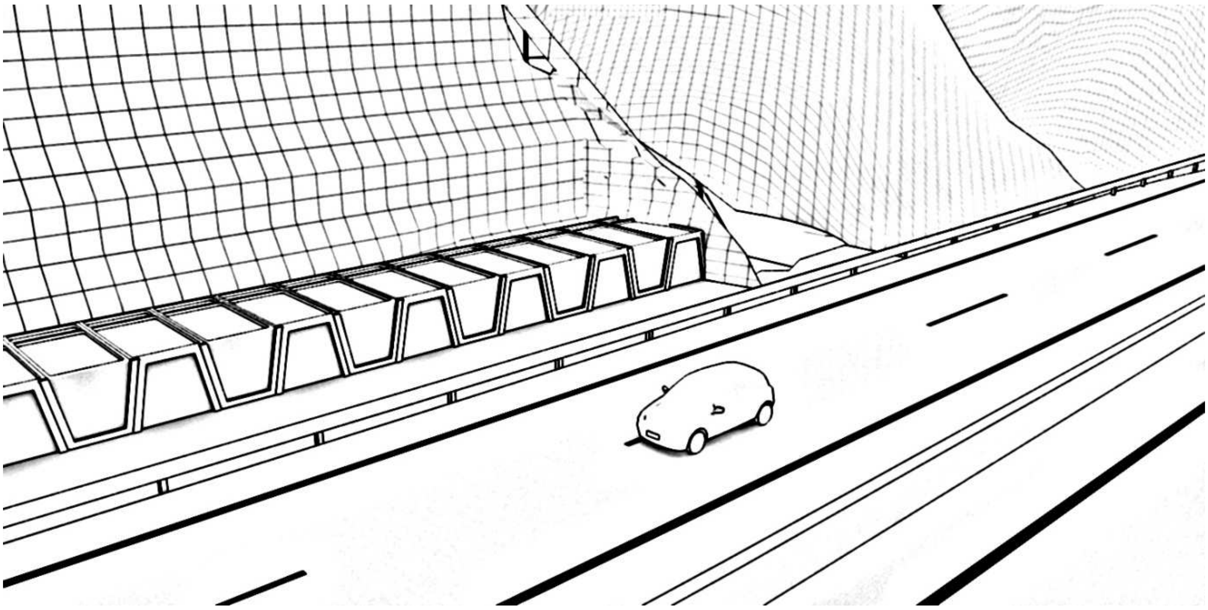


Image 67. Filling of the first line.

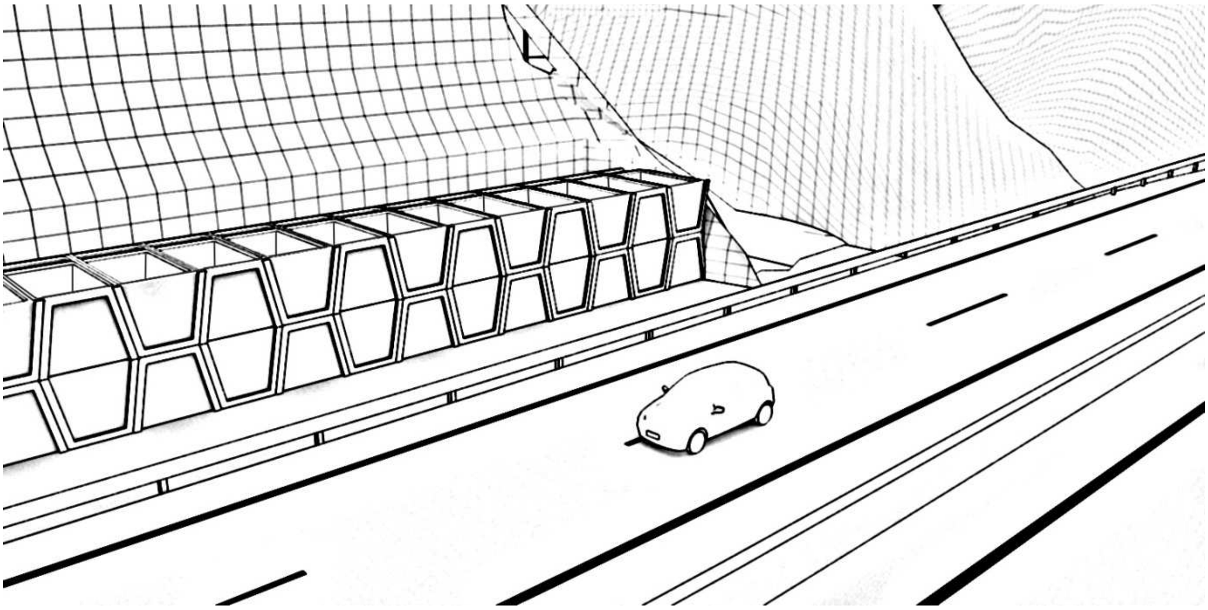


Image 68. Setting of the second line of caissons.

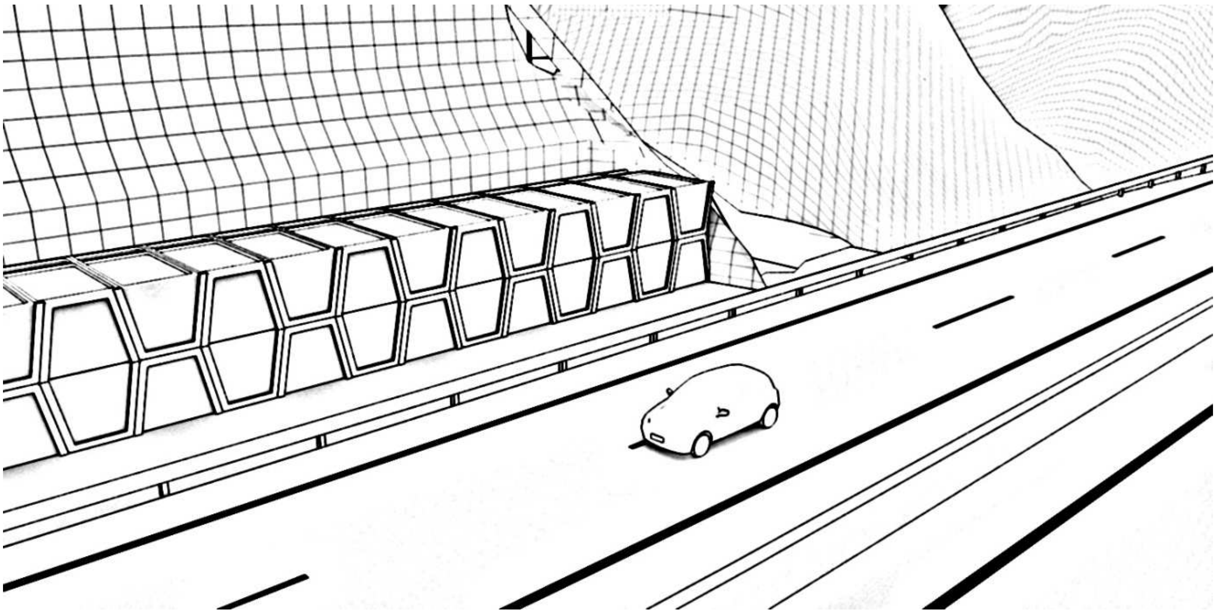


Image 69. Filling of the second line.

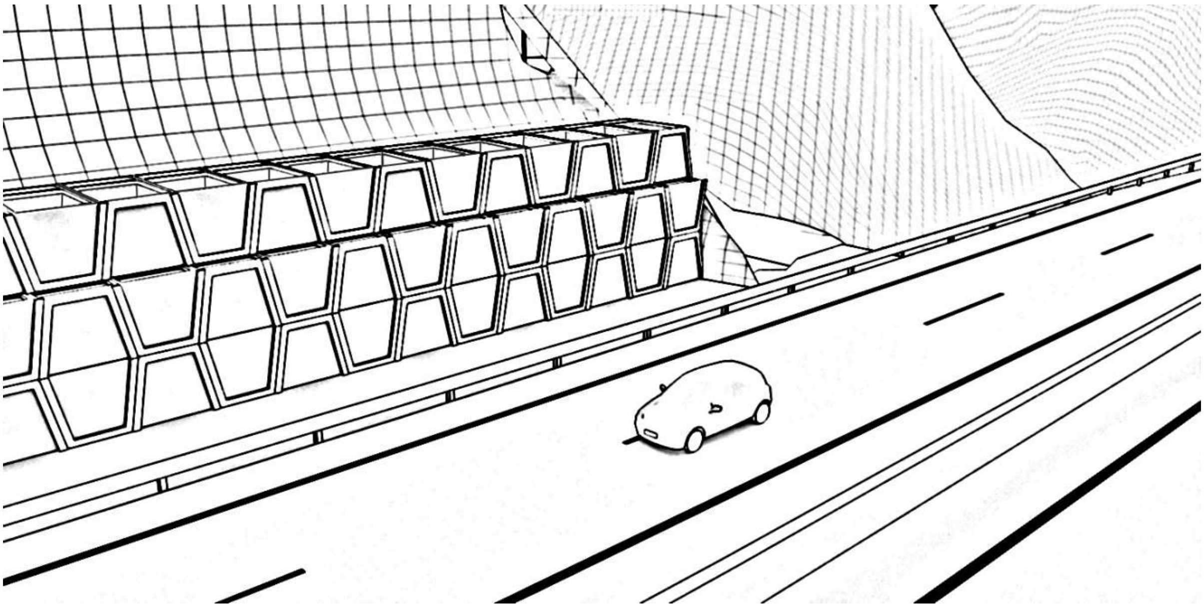


Image 70. Stepped setting of the third line of caissons.

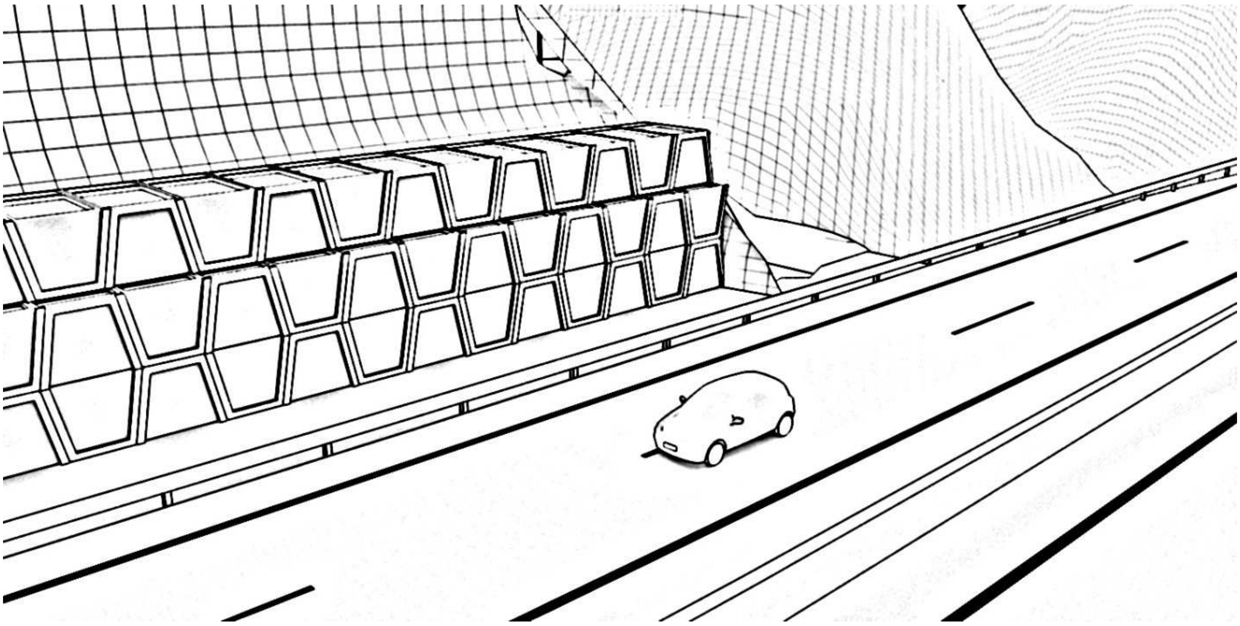


Image 71. Filling of the third line.

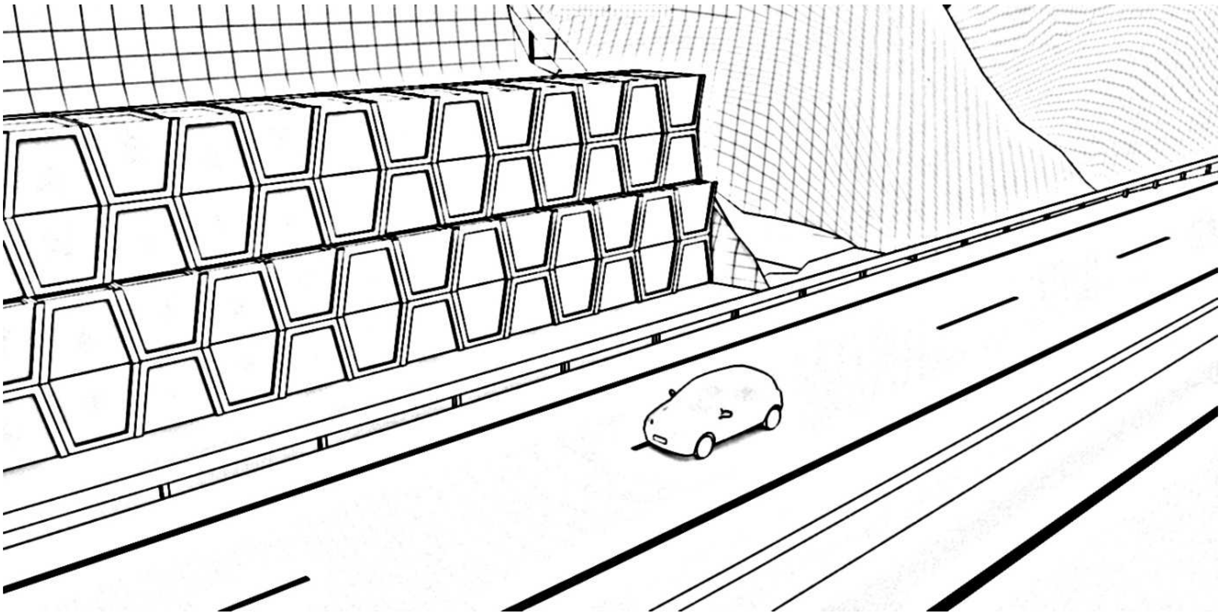


Image 72. Setting of the fourth line of caissons.

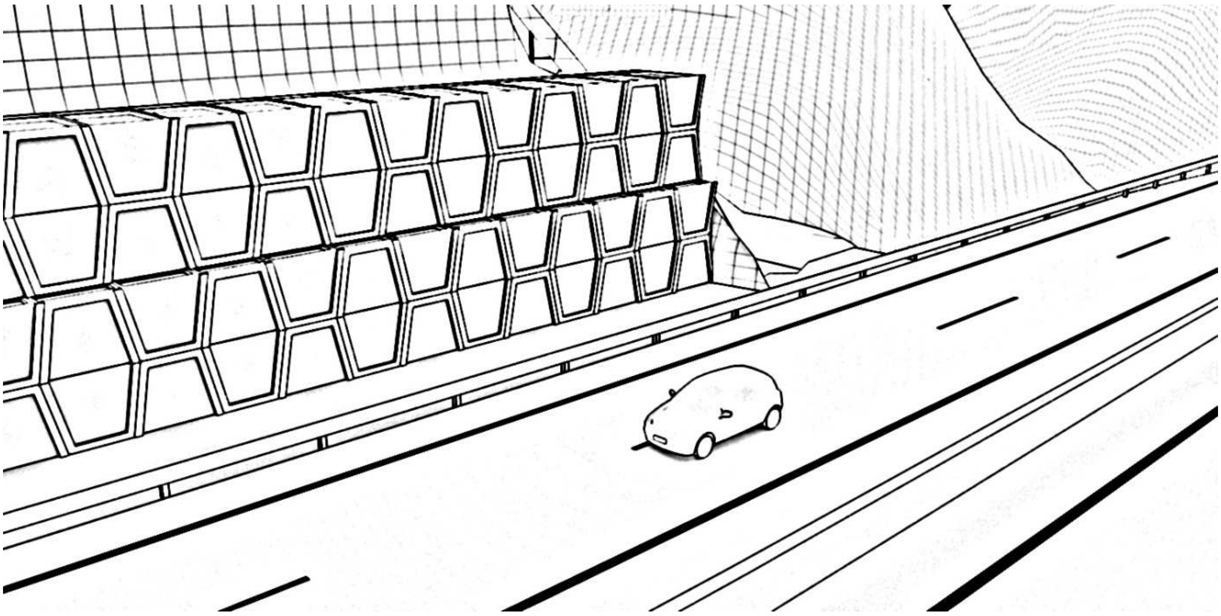


Image 73. Filling of the fourth line.

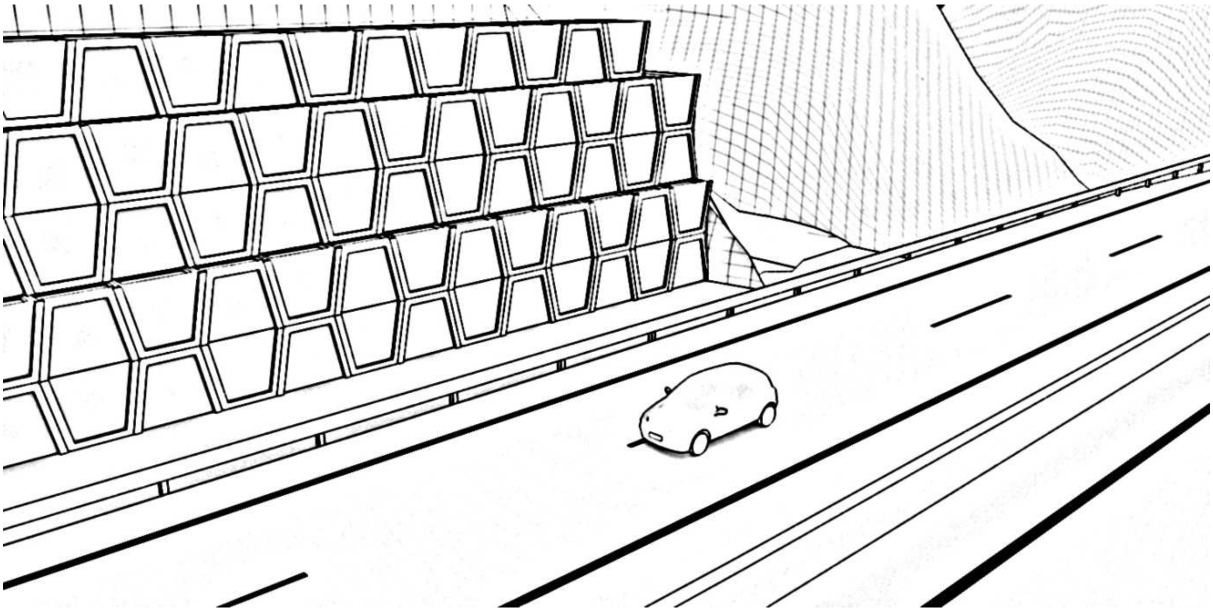
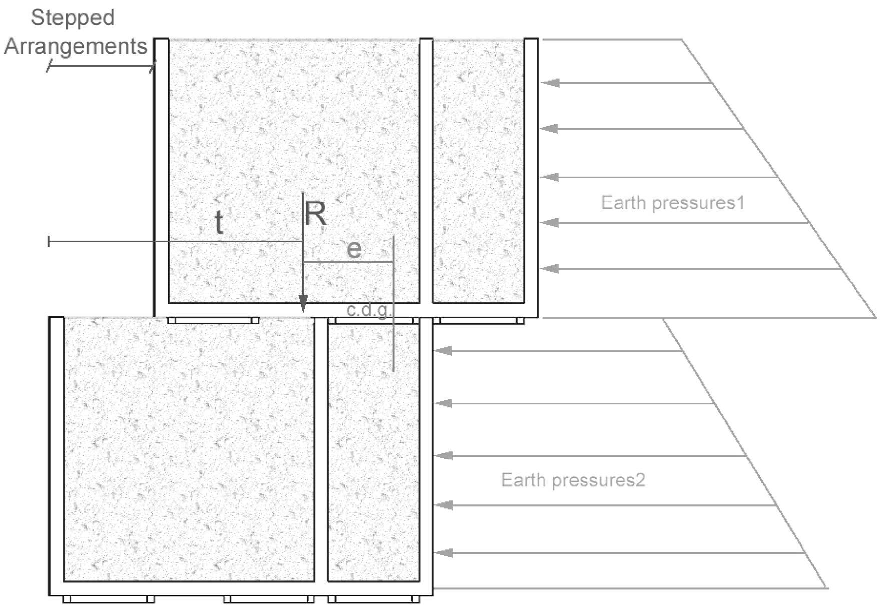


Image 74. Setting and filling the last stepped line (total height: 10 m).

<u>*PART 7. STRUCTURAL CALCULATION.*</u>

The model of structural calculation is based on the fact that walls transfer their vertical reaction into the lower wall's base. The non-centred higher vertical force is justified by the earth pressures generating the mechanical arm of the bending moment as regards the centre of gravity.

The stepped arrangement allows increasing artificially the mechanical arm of the higher module as regards the lower, so improving the stabilizer moment.



t = mechanical arm caused by stepped arrangements.

e = mechanical arm by destabilizing moment caused by earth pressure .

R = vertical reaction over the lower module

Image 75. The stepped arrangement facilitates the vertical force to centre over the lower caisson.

When a caisson is supported on another, for avoiding any lack of vertical contact, every point must be compressed. When this does not happen, there will be a lack of contact between modules, which will only contact in the front side.

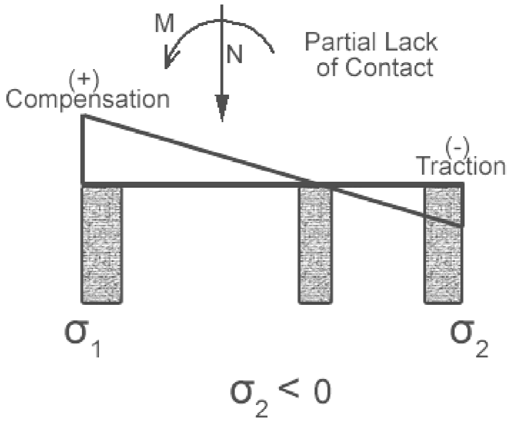


Image 76. Lack of contact between modules in the backfill.

When there is lack of contact, for non-stepped walls, the contact will be as the following graphic shows:

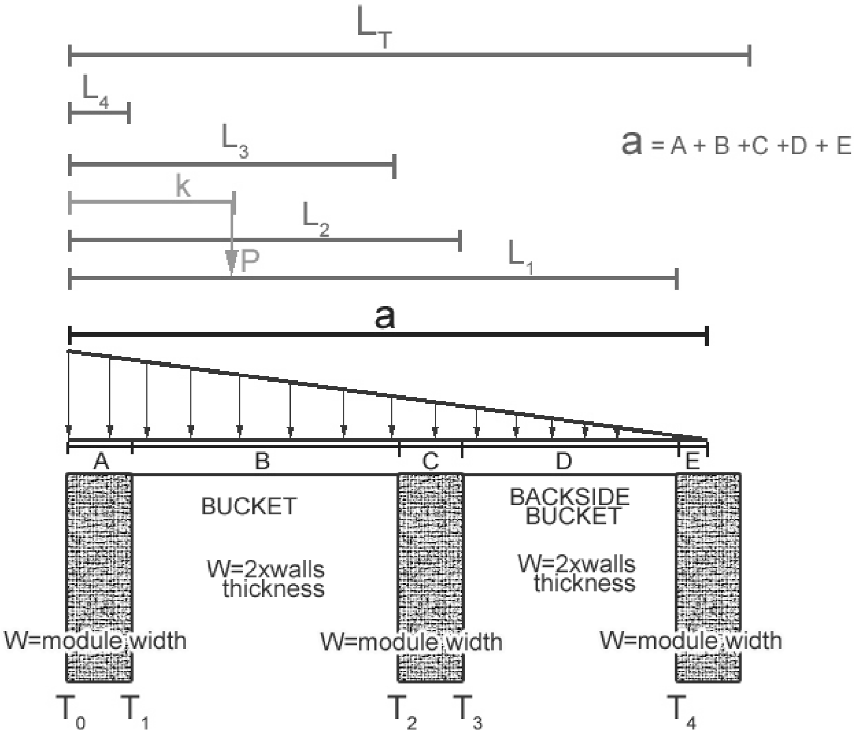


Image 77. Contact mechanism of caissons 2x2 when there is lack of contact.

In the previous graphic, the caissons contact each other in a length a lower than the module L_T total length.

The lengths in the graphic correspond to:
L_1 = caisson's total length minus the backfill wall's thickness.
L_2= caisson's total length minus the wall's thickness and minus the backside bucket's length.
L_3= is L_2 minus the thickness of the backside bucket's inner wall.
L_4= is the thickness of the front side.
T_0, T_1, T_2, T_3, T_4, are the tensions in the edges of the module's walls.
e, is the walls' thickness.

Depending on the a value, the following situations can be considered:

Situation 1.

$a > L_1$,

Tensions: (T_0, T_1, T_2, T_3, T_4)

A=e

B=L_2-e

C=e

D=L_1-L_2

E=e-L_t+a

$T_1 = -T_0 L_4 (a)^{-1} + T_0$

$T_3 = -T_0 L_2 (a)^{-1} + T_0$

$T_2 = -T_0 L_3 (a)^{-1} + T_0$

$T_4 = -T_0 L_1 (a)^{-1} + T_0$

Situation 2.

$L_1 > a > L_2$,

Tensions: (T_0, T_1, T_2, T_3, T_4=0)

A=e

B=L_2-e

C=e

D=a-L_3

E=0

$T_1 = -T_0\, e\, (a)^{-1} + T_0$

$T_3 = -T_0 L_2 (a)^{-1} + T_0$

$T_2 = -T_0 L_3 (a)^{-1} + T_0$

$T_4 = 0$

Situation 3.

$L_2 > a > L_3$

Tensions: (T_0, T_1, T_2, T_3=0, T_4=0)

A=e

B=L_2-e

C=a- L_2

D=0

E=0

$T_1 = -T_0\, e\, (a)^{-1} + T_0$

$T_3 = -T_0 L_2 (a)^{-1} + T_0$

$T_2 = 0$

$T_4 = 0$

Situation 4.

$L_3 > a > L_4$

Tensions: (T_0, T_1, T_2=0, T_3=0, T_4=0)

A=e

B=a-e

C=0

D=0

$E=0$

$T_1= -T_0\ e\ (a)^{-1} + T_0$

$T_2= 0$

$T_3= 0$

$T_4= 0$

Situation 5.

$a<L_4$

Tensions: $(T_0, T_1=0, T_2=0, T_3=0, T_4=0)$

$A=a$

$B=0$

$C=0$

$D=0$

$E=0$

$T_1= 0$

$T_2= 0$

$T_3= 0$

$T_4= 0$

In any possible situation, the momentum balance must be fulfilled:

$$W \cdot T_1 \cdot A \cdot A \cdot 1/2 + (T_0-T_1)\cdot 0,5\cdot A\cdot A\cdot W\cdot 1/3 + T_2\cdot 2e\cdot B\cdot(B/2+e)) + (T_1-T_2)\cdot 0,5\cdot(B/3+e)\cdot \cdot 2e\cdot B+T_3\cdot C\cdot W\cdot(L_3+C/2)+(T_2-T_3)\cdot 0,5\cdot C\cdot W\cdot(C/3+L_3)+T_4\cdot D\cdot 2e\cdot(L_2+D/2)+(T_3-T_4)\cdot 0,5\cdot D\cdot 2e\cdot(D/3+L_2)+T_4/2\cdot E\cdot W\cdot(E/3+L_1)=M=P\cdot K$$

Likewise, in any possible situation, the force balance must be fulfilled:

$$(T_1+ T_2)/2 \cdot A\cdot W + (T_1+ T_2)/2 \cdot B\cdot 2\cdot e + (T_2+ T_3)/2 \cdot e\cdot W + (T_3+ T_4)/2 \cdot D\cdot 2e + (T_4)/2\cdot E\cdot W = P$$

Through successive iterations, the value a and, consequently, the tensions between modules will be obtained.

The previously defined contact will happen when the upper caisson has the same or more dimension than the lower caisson and there is not stepped arrangement. Hence, the overlapping between both caissons will be equal to the lower caisson's top. We will name this situation: situation 1.

SITUATION 1 CONTACTS

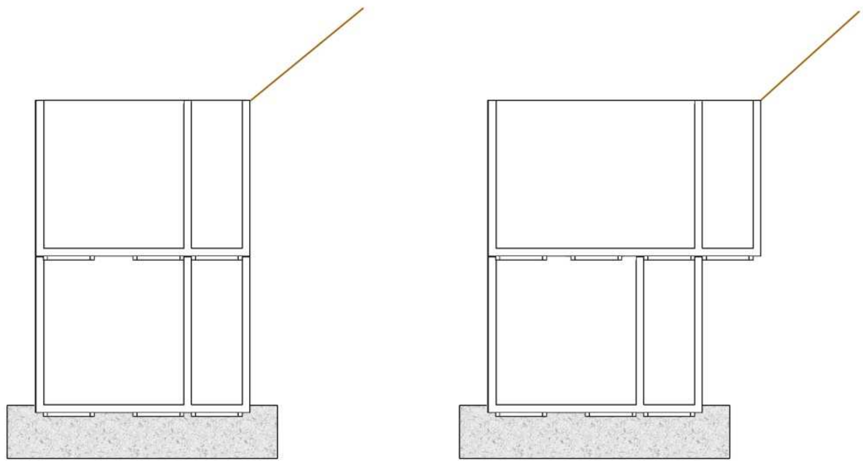


Image 78. Situation 1. Contacts.

When the lower waffle block is bigger than the upper one and there is no stepped arrangement, then the aforementioned formulation and the status will be simplified as T_3 y T_4 are 0.

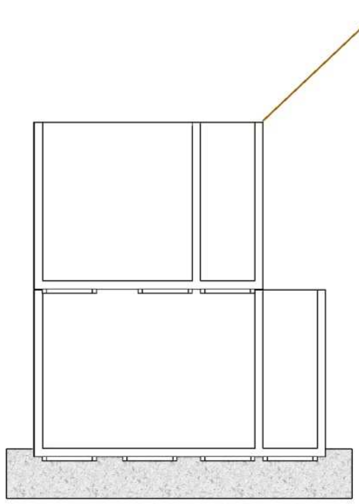


Image 79. Situation 2. Contacts.

The third contact situation is that where there is no stepped arrangement between blocks, (situation 3)

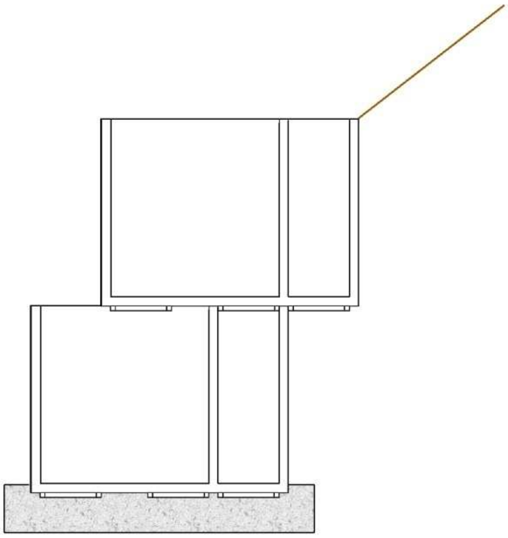


Image 80. Situation 3. Contacts.

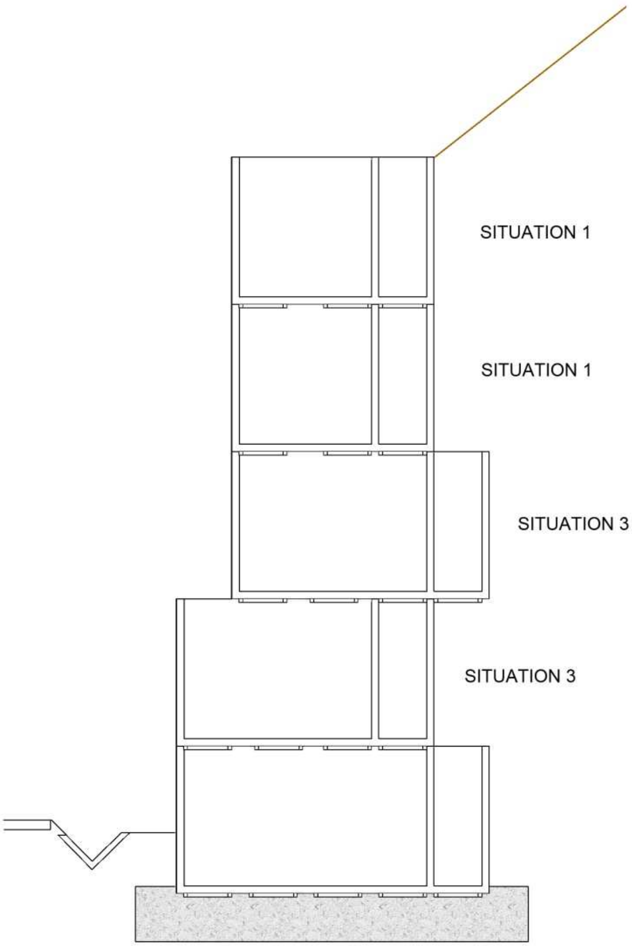


Image 81. Different contact situations in the same wall.

If there is stepped arrangement between caissons, two situations will be considered:

- 1. <u>Lack of contact in the lower caisson's backfill like in the previous case.</u> In this case, the diagram on contact tensions is as follows:

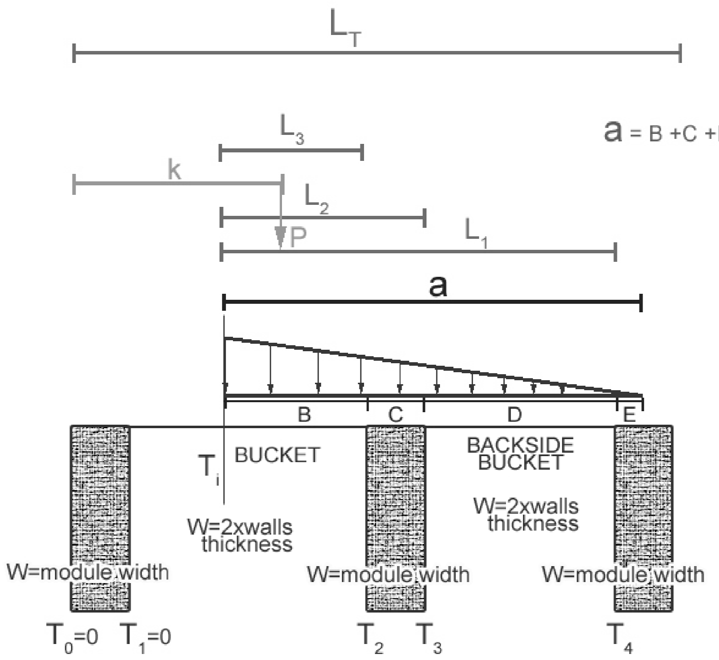


Image 82. Contact mechanism of caissons 2x2 when there is lack of contact and stepped arrangement.

The possible situations, if T_0 and T_1 are equal to 0 and if the tension under the higher caisson wall's edge is higher than Ti, are the following:

<u>Situation 1.</u>

$a>L_1$,

Tensions: (T_i, T_3, T_2, T_4)

$B=L_2-e$

$C=e$

$D=L_1-L_2$

$E=e-L_t+a$

$T_3= -T_i\, L_2\, (a)^{-1} + T_i$

$T_2= -T_i\, L_3\, (a)^{-1} + T_i$

$T_4= -T_i\, L_1\, (a)^{-1} + T_i$

<u>Situation 2.</u>

$L_1>a>L_2$,

Tensions: $(T_i, T_3, T_2, T_4=0)$

$B=L_2-e$

$C=e$

$D=a-L_3$

$E=0$

$T_2= -T_i\, L_2\, (a)^{-1} + T_i$

$T_3= -T_i\, L_3\, (a)^{-1} + T_i$

$T_4= 0$

Situation 3.

$L_2>a>L_3$

Tensions: $(T_{i,}\ T_2,\ T_3=0,\ T_4=0)$

$B=L_2-e$

$C=a-L_2$

$D=0$

$E=0$

$T_2=-T_i\ L_2\ (a)^{-1}+T_i$

$T_3=0$

$T_4=0$

Situation 4.

$L_3>a>L_4$

Tensions: $(T_2=0,\ T_3=0,\ T_4=0)$

$B=a$

$C=0$

$D=0$

$E=0$

$T_2=0$

$T_3=0$

$T_4=0$

In any possible situation, the momentum balance must be fulfilled:

$$T_2\cdot 2e\cdot B\cdot(B/2)+(T_i-T_2)\cdot 0,5\cdot(B/3)\cdot 2e\cdot B+T_3\cdot C\cdot W\cdot(L_3+C/2)+(T_2-T_3)\cdot 0,5\cdot C\cdot W\cdot(C/3+L_3)+T_4\cdot D\cdot 2e\cdot(L_2+D/2)+(T_3-T_4)\cdot 0,5\cdot D\cdot 2e\cdot(D/3+L_2)+T_4/2\cdot E\cdot W\cdot(E/3+L_1)=M=P\cdot K$$

Likewise, in any possible situation, the force balance must be fulfilled:

$$(T_i+T_2)/2\cdot 2e\cdot B+(T_2+T_3)/2\cdot C\cdot W+(T_3+T_4)/2\cdot D\cdot 2e+(T_4)/2\cdot E\cdot W=P$$

As in the previous case, through successive iterations, the value a and, consequently, the tensions between the modules will be obtained.

- 2. Contact in the edge of the front side. In this case, the diagram on contact tensions varies depending if there is a compression value in T_t, the backfill's edge. The tension and distance values are as follows:

Tensions: $(T_i,\ ,\ T_2,\ T_3,\ T_{4,}\ T_t)$

$B=L_2-e$

$C=e$

$D=L_1-L_2$

$E=e-L_t+a$

$T_2=(T_t-T_i)\ L_3\ (a)^{-1}+T_i$

$T_3=(T_t-T_i)\ L_2\ (a)^{-1}+T_i$

$T_4=(T_t-T_i)\ L_1\ (a)^{-1}+T_i$

In this situation, in general, the land may react in the backfill. However, the important difference between rigidities (1/100) allows us to disregard it, taking into account the limit established in the stepped arrangements.

In this model of calculation, it is obtained the pressure on the modules in static as well as dynamic situations. The Coulomb formula, modified by Mononobe-Okabe, is used for obtaining the results.

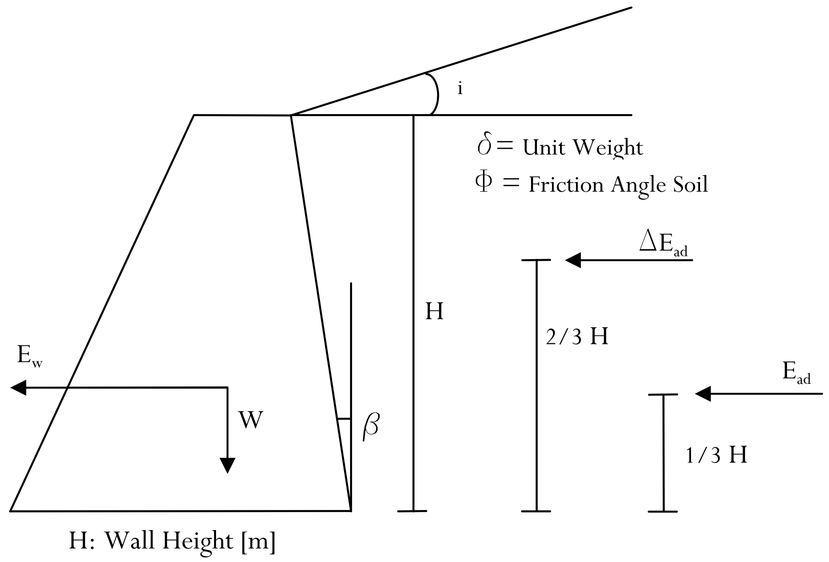


Image 83. Pressure mechanism in dynamic situations.

$$K_{ad} = \frac{cos^2\,(\emptyset - \theta - \beta)}{\cos\theta \cdot cos^2\beta \cdot \cos(\delta + \beta + \theta) \cdot \left[1 + \sqrt{\frac{sen(\emptyset + \delta) \cdot sen\,(\emptyset - \theta - i)}{\cos(\delta + \beta + \theta) \cdot \cos(i - \beta)}}\right]^2}$$

Where Φ is the friction angle, β is the back face, δ is the friction soil-wall, i is the slope angle and Θ is given by the following dynamic relation:

Θ = actg [k_h / (1-K_v)]

The proposed procedure is the following:

1. The active earth pressure for static conditions are determined.

   E_a= 1/2 g H^2 K_a

2. The active earth pressure is calculated

   E_{ad}= 1/2 g H^2 (1-K_v) K_{ad}

3. The dynamic increase of pressure ΔE_{ad} is obtained

   ΔE_{ad} =E_{ad} - E_a

E_a acts as one-third of H from the basement base

ΔE_{ad} acts as 0,6 H from the basement

<u>CALCULATION MODEL</u>

This Guide includes a software that enables to obtain the stability of modules one by one for any configuration following the previous formula. Likewise, it provides laws on the contact between modules.

For obtaining each module's tensions, the engineer calculator will be able to use a software of finite elements and to make the calculation module by module or jointly taking into account the contact between modules. For jointly calculations, the engineer calculator must use a software to treat contact between solids. For module by module calculations, the engineer calculator must consider the loads pressing over each module:

- The horizontal loads supporting the modules above the point it is calculated.
- The earth pressures against the module.
- The vertical load transferred by the higher module in the specific location for the stability calculation of modules.
- The module's weight with earth and fills to be used.
- The lower horizontal reaction.
- The vertical reaction properly located according to the stability analysis.

The previous values can be obtained from the stability calculation for overturning and landsliding and from the contact efforts between modules.

Once the aforementioned values had been obtained, the inner tensions can be calculated module by module.

Anyway, the services of ACTISA S.L., which come together with the order of CCW, will be available for the user. These services include the production of the whole project (with all the lists of efforts, tensions and stabilities).

The calculation may be for embankments and for cut section slopes.

For possible pressures, the following heights are considered:

- Up to 10m in some cases up to 12m
- The caissons can be manufactured with heights multiple of 0.5m (0.5, 1.0, 1.5m…)

MAXIMUM FLEXOTRACTION STRENGTH

The use of CCW walls allows guaranteeing tensions almost permanently below the limit of 50 kg/cm^2. Main tensions are located in the lower modules. When low tensions cannot be guaranteed, complete delivery of concrete will be made for the bucket and the backside bucket.

Therefore, no foreseeable failure due to cracks will affect the CCW caissons in Glassfibre Reinforced Concrete (GRC).

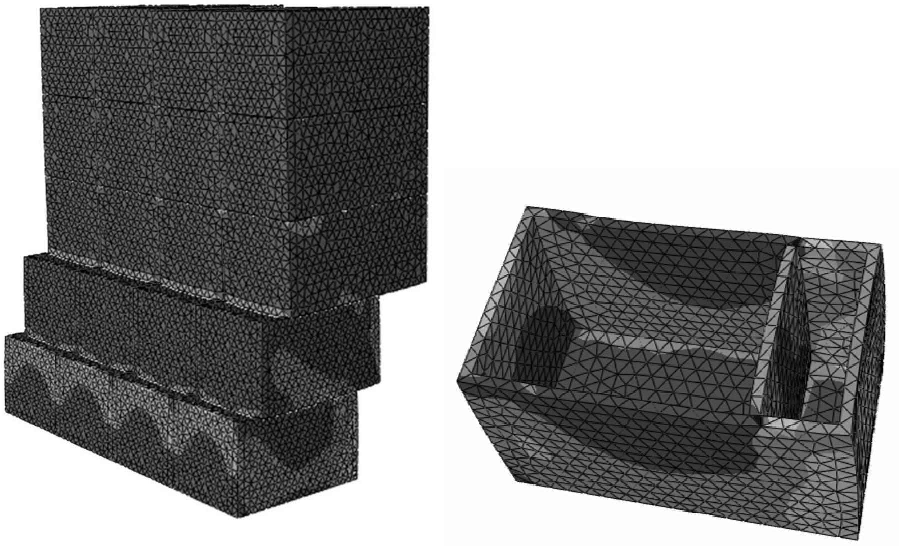


Image 84. Main maximum tensions for 10 cm height of cut section and seismic situation.

MAXIMUM TANGENTIAL TENSION

Tensions lower than 30 kg/cm^2 will be guaranteed and, consequently, the shearing safety coefficients will overpass 1.25.

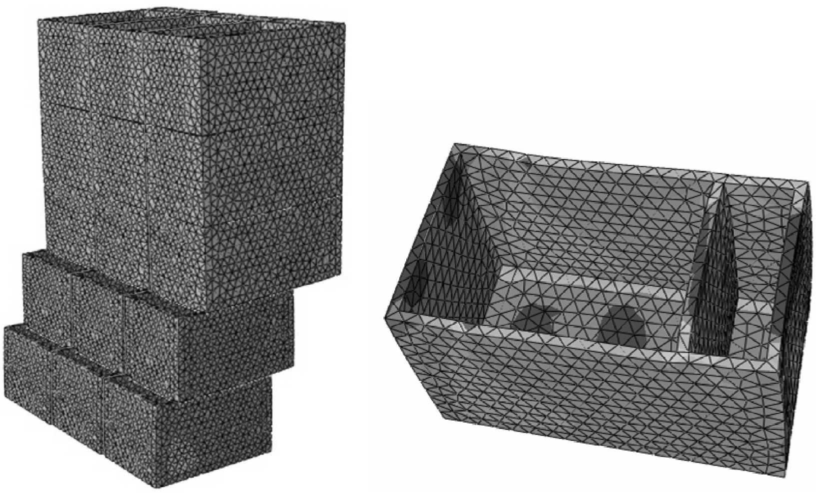


Image 85. Maximum shearing for 10 m height and seismic situation.

FAILURE DUE TO CRACKS

For the greatest height (10 m), the deformation at the top is usually lower than 5 mm, hence the height relation is 5/10,000 (a very high ratio compared with a conventional L-shaped retaining wall).

DEFORMATION AND LANDSLIDES

As stated before, the stability module by module can be calculated with the aforementioned formula or with the attached software. This software allows calculating the stability of each module and the contact tensions between modules, following the indicated methodology.

STABILITY OF EACH MODULE

As stated before, the stability module by module can be calculated with the aforementioned formula or with the attached software. This software allows calculating the stability of each module and the contact tensions between modules, following the indicated methodology.

GENERAL STABILITY

The general stability must be checked specifically for each project depending on the following variables:

- height of poor concrete layer in the basement.
- characteristics of natural soil under the concrete layer.
- need for drainage.

In general, once the stability to overturn has been achieved in the first module, the stability to overturn is guaranteed as a whole, foundation included. However, the stability to landslide will have an important influence on the foundation height and the passive pressure. Therefore, it is advisable that the first module is placed at least 25 cm below ground level.

The stability to landslide of the whole system will require a particular analysis of the wall to be planned. Likewise, the stability below the foundation must be checked globally for the treated slope.

REACTION AGAINST LAND

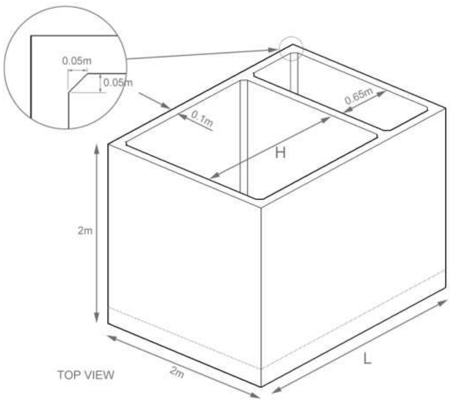
As in the previous case, the reactions against land must be determined specifically for each wall depending on the foundation function and the land characteristics.

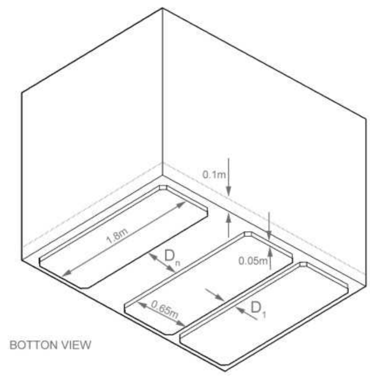
CAISSONS WALLS

1.- GEOMETRY

Caissons Measures	L (m)	H(m)	D1(m)	D2(m)	D3(m)	D4(m)
CCW-A	1.25	1.05				
CCW-B	2.00	1.05	0.5			
CCW-C	2.75	1.80	0.1	0.5		
CCW-D	3.50	2.55	0.1	0.3	0.3	
CCW-E	4.25	3.30	0.1	0.23	0.24	0.23

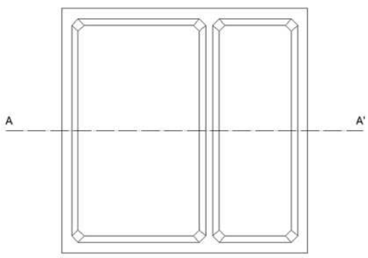
3D View

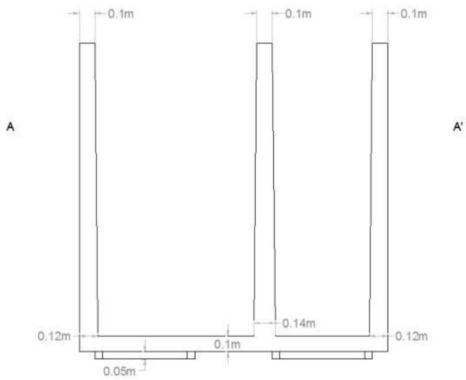




Section

SECTION A - A'





2.- DOSAGE AND MATERIALS

The concrete to be applied will comply with the following dosage:

Aggregate	1760	Kg
Cement 42.5 R	360	Kg, (minimum content)
Plasticizer	2	l
Fiberglass 36 mm length	18	Kg
Water	180	l, (according to cement content)

Aggregate:

Coarse fraction, 8/12 mm: 40%.

Fine fraction, 0/5 mm: 60%.

The tests must guarantee a minimum characteristic resistance of 30 MPa and a flexotraction strength of 5.0 MPa.

3.- ADMISSIBLE MAXIMAL TENSIONS

A) Maximal tension 50 Kg/cm^2
B) Maximal tangencial tension 30 Kg/cm^2