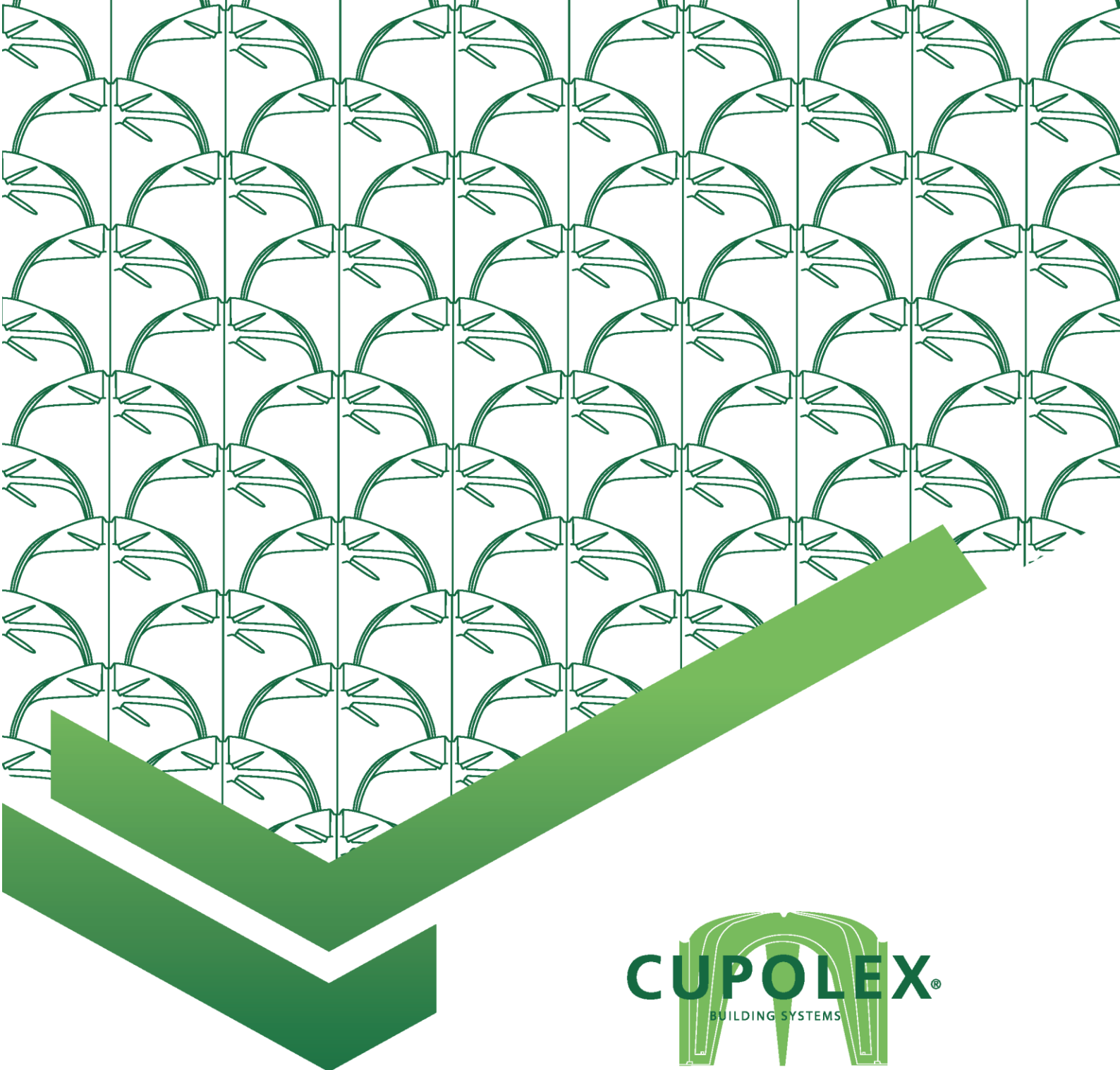


TECHNICAL MANUAL





Technical Manual – Cupolex System

TABLE OF CONTENTS

INTRODUCTION TO THE CUPOLEX SYSTEM	4
WHY USE THE CUPOLEX SYSTEM.....	5
<i>QUALITY.....</i>	<i>6</i>
<i>FLEXIBILITY</i>	<i>6</i>
<i>PERFORMANCE.....</i>	<i>6</i>
<i>SUSTAINABILITY</i>	<i>6</i>
CHARACTERISTICS OF THE CUPOLEX SYSTEM.....	7
SPECIFICATION OF A CUPOLEX FLOOR.....	9
DETAIL OF A CUPOLEX FLOOR	10
CONSTRUCTION OF A CUPOLEX FLOOR.....	14
<i>POLYPROPYLENE</i>	<i>15</i>
<i>ENVIRONMENTAL REQUIREMENTS.....</i>	<i>15</i>
<i>VAPOUR INTRUSION AND RADON GAS CONTROL</i>	<i>16</i>
<i>MORE EFFICIENT VENTILATION.....</i>	<i>16</i>
<i>PASSIVE VENTILATION POTENTIAL</i>	<i>16</i>
<i>SOLUTION FOR REDUCING MOISTURE AND MOULD AND IMPROVING INDOOR AIR QUALITY.....</i>	<i>17</i>
<i>VAPOUR PROTECTION SYSTEM.....</i>	<i>17</i>
<i>LOAD TEST DATA FROM STRUCTURES BUILT ON CUPOLEX.....</i>	<i>18</i>



INTRODUCTION TO THE CUPOLEX SYSTEM

The Cupolex system is based on principles of economic and environmental rationalisation that allow the construction of void fillings and ventilated ground-bearing slabs, with clear advantages in terms of functionality and comfort. By ensuring — through the ventilation of the voids created and the discontinuity of the surfaces — perfect insulation of the building's interior spaces from the external surroundings, Cupolex floors provide protection against moisture, thermal losses and vapours arising from contact with the soil, with positive effects on the healthiness of the habitable space.

Made from 100% recycled material, the Cupolex system also contributes to greater efficiency in the use of production factors, particularly in terms of materials — avoiding the use of natural resources and unnecessary quantities of concrete — and of human resources, owing to the simplicity of the system's application.

Cupolex technology is of Italian origin and is already widely used in markets ranging from the USA to New Zealand. It is the result of a continuous research and development effort by Pontarolo Engineering, scrutinised through a programme of tests and trials carried out at leading Italian institutions.



WHY USE THE CUPOLEX SYSTEM

THE CUPOLEX CHALLENGE

The Cupolex system was created to enable engineers, designers and architects to specify a technically advanced, economically competitive and environmentally sustainable solution to the following challenges:

- Deformation and shrinkage of the slab;
- Eliminating rising moisture;
- Eliminating the effect of Radon gas and vapour intrusion;
- Improving the air quality and comfort of the habitable space;
- Reducing the environmental impact of the construction;
- Reducing construction time;
- Reducing the use of aggregates;
- Soil expansiveness.

CUPOLEX ADVANTAGES

The Cupolex system bases its advantages on three essential pillars — performance, economy and sustainability — which make it possible to respond to the challenges listed above.

Comportamento

- Adaptável a qualquer geometria
- Criação de caixa-de-ar ventilada
- Criação de barreira a humidades e vapours ascendentes
- Melhoria do comportamento térmico
- Possibilidade de instalações diversas na caixa-de-ar
- Resistente a loads até 18kN/m²
- Eliminação do gás cancerígeno, Radon

Economia

- Processo de installation célere e simples
- Redução do consumo de concrete e aço
- Redução de custos com mão-de-obra e equipamentos
- Redução de transportes, uma paleta de Cupolex equivale a três carros de brita
- Possibilidade de betonagem conjunta com outros elementos estruturais

Sustainability

- Redução de custos com climatização
- Redução da emissão de CO₂
- Utilização de material 100% recycled
- Maior eficiência na utilização de natural resources
- Redução dos transportes de materiais para a obra e correspondente emissão de CO₂



CUPOLEX - THE GUARANTEE OF A SOLUTION

QUALITY

The Cupolex system ensures healthier environments and offers advantages over conventional slabs, particularly in ease of construction and the reduction of costs and construction time. With more than 500 million square metres laid in residential, commercial and industrial floors, it is a widely tested solution. Cupolex products are manufactured in accordance with ISO 9001:2015 quality requirements, ensuring superior stability and strength characteristics in their structure.

FLEXIBILITY

Thanks to its modular form, supplemented by the Beton Stop units, any type of ground-bearing slab or geometry can easily be achieved through the layout of the Cupolex system. The system's full range covers standard heights from 9.5 to 70 cm, with the possibility of combining them at several levels, thereby allowing the desired floor / void-filling height to be obtained.

PERFORMANCE

The Cupolex system provides permanent formwork whose stability, once assembled, allows people and equipment to circulate during the construction process. The system has been dry-tested to ensure that, both on the domes and laterally, it can withstand a load of 150 kg, thereby ensuring the rapid progress of the works involved in its construction.

The final Cupolex solution likewise offers load capacities exceeding 1,800 kg/m², according to tests carried out as part of the system's certification, which guarantees the viability of this system for the most varied applications, from residential floors to industrial floors.

SUSTAINABILITY

In a world where the sustainability of natural resources is becoming increasingly important, the use of recycled materials to form the voids and the reduction of concrete requirements allow the Cupolex system, in itself, to promote a structure with a lower environmental impact and a significant reduction in the CO₂ emissions inherent to the construction process.

Made from 100% recycled raw material, Cupolex doubly promotes the environmental sustainability of the construction system, since it simultaneously contributes to the reuse of recycled goods and to the reduction of natural-resource consumption — one of the direct impacts being visible in the volume of transport to the site.

From an economic standpoint, the Cupolex solution reduces dependence on natural resources and the labour costs of the construction process, and significantly reduces operating costs over the structure's life cycle.





CHARACTERISTICS OF THE CUPOLEX SYSTEM

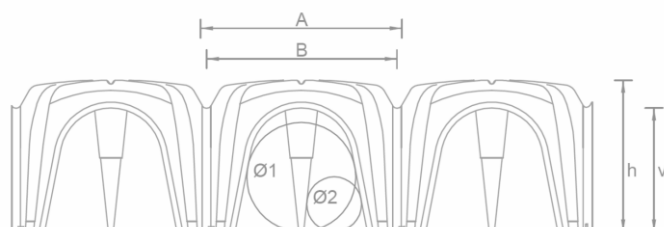
The Cupolex system consists of plastic components (recycled PP — polypropylene) which, when assembled together, form permanent formwork for the construction of ground-bearing slabs or void fillings. The system has no load-bearing function of its own; rather, its function is to give the poured concrete a self-supporting geometry thanks to the domes and the numerous supports thus created, while at the same time allowing free circulation during the assembly phase.

The system's full range includes a variety of dimensions between 9.5 cm and 70.0 cm, allowing a diverse set of solutions and configurations with permissible loads of up to 18 kN/m².

The Cupolex Windi models, with heights of 5 and 10 cm, were specifically designed for use on terraces and roofs, ensuring the discontinuity of the concrete to be placed relative to the supporting base and providing the insulation and ventilation of these surfaces. Owing to its dimensions, the Windi module is also suitable for refurbishment works, allowing the creation of a plenum to collect rising moisture and the corresponding insulation of the interior space.

MAIN PARAMETERS OF THE CUPOLEX SYSTEM

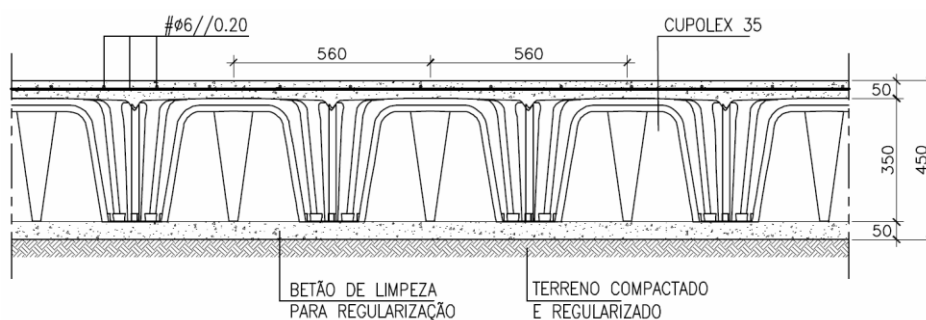
Cupolex Model		9.5	13.5	16	20	26	30	35	40	45	50	55	60	65	70	W5	W10
Concrete Consumption	[m ³ /m ²]	0.014	0.030	0.035	0.035	0.035	0.042	0.045	0.060	0.064	0.065	0.069	0.070	0.071	0.073	0.008	0.011
Total Height (h)	[cm]	9.5	13.5	16	20	26	30	35	40	45	50	55	60	65	70	5	10
Void Height (v)	[cm]	7	9	10.6	15	19	26	30	31	35	46	46	51	56	61	3	8
Total Width (A)	[cm]	57	58	58	58	58	57	58	58	58	57	74.5	74.5	74.5	74.5	-	-
Useful Width (B)	[cm]	56	56	56	56	56	56	56	56	56	56	71	71	71	71	56	56
Φ1	[mm]	-	90	90	125	180	250	300	250	300	300	450	460	470	480	-	75
Φ2	[mm]	70	80	80	100	145	145	150	140	150	150	-	-	-	-	30	50
No. of Units	[un/m ²]	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	1.98	1.98	1.98	1.98	3.19	3.19
Beton Stop	[-]	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●



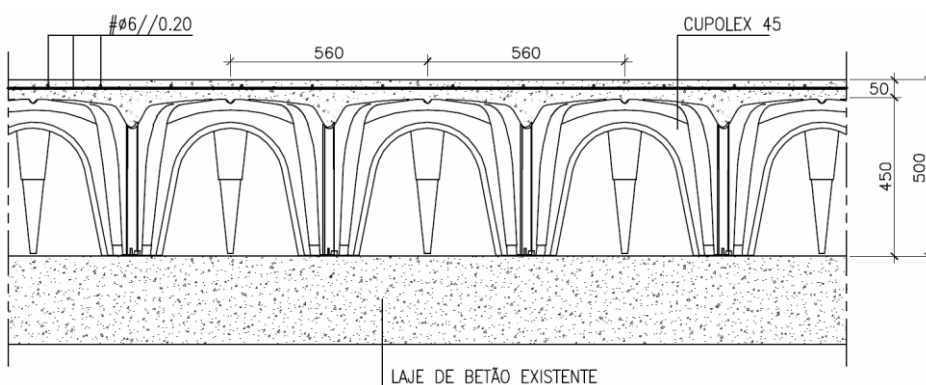


CONFIGURATION OF A CUPOLEX FLOOR

A Cupolex floor or void filling must, from the outset, take into account a solid base to support the system's modules. In the case of a ground-bearing slab, this base must be ensured by compacting the substrate soil and by applying a layer of blinding concrete. On this base, the Cupolex modules are placed from left to right and from top to bottom, in accordance with the arrows on the pieces themselves. The final floor height is given by the sum of the Cupolex height (indicated up to the dome) and the prescribed compression layer.



Typical section of a Cupolex ground-bearing slab



Typical section of a Cupolex void filling

When analysing the total concrete consumption, the sum of the consumption indicated in the previous table (up to the module dome) and the concrete provided for the compression layer must likewise be taken into account.

$$\text{Consumo total de concrete} = \text{Consumo do module Cupolex} + \text{Consumo da lâmina de concrete}$$



SPECIFICATION OF A CUPOLEX FLOOR

The Cupolex system is not a structural system.

The Cupolex system consists of permanent formwork that allows the construction of a volume of concrete with the configuration needed to ensure the previously identified advantages of the system. The resulting concrete section is itself self-supporting, benefiting from the shape of the vaults and the multiple supports the system provides.

The design of the concrete section — namely the compression layer and height — as well as the reinforcement requirements, results from the imposed loads and the deformability of the floor's supporting base, which is inherent to the intrinsic characteristics of the soil and to the floor geometry. For ordinary situations in which a base with a Winkler coefficient equal to 1 kg/cm³ is ensured through compaction or the construction of a blinding concrete, the following minimum compression layers and reinforcement bars are recommended for the following generic load cases.

Occupancy	Permanent Load (kg/m ²)	Imposed live load (kg/m ²)	Layer thickness (mm)	Minimum reinforcement in bars
Car park	100	300	40	#6//0.25
Housing	400	200	50	#6//0.20
Offices	200	300	50	#6//0.20
Industry	300	1200	60	#8//0.20

Ferca has technicians and dedicated software for the calculation of Cupolex floors, and is available to provide all the support needed for the specification, calculation, drawing and construction of a Cupolex floor or void filling. For more information on tests carried out on Cupolex floors and their respective load capacities,

Contact us.

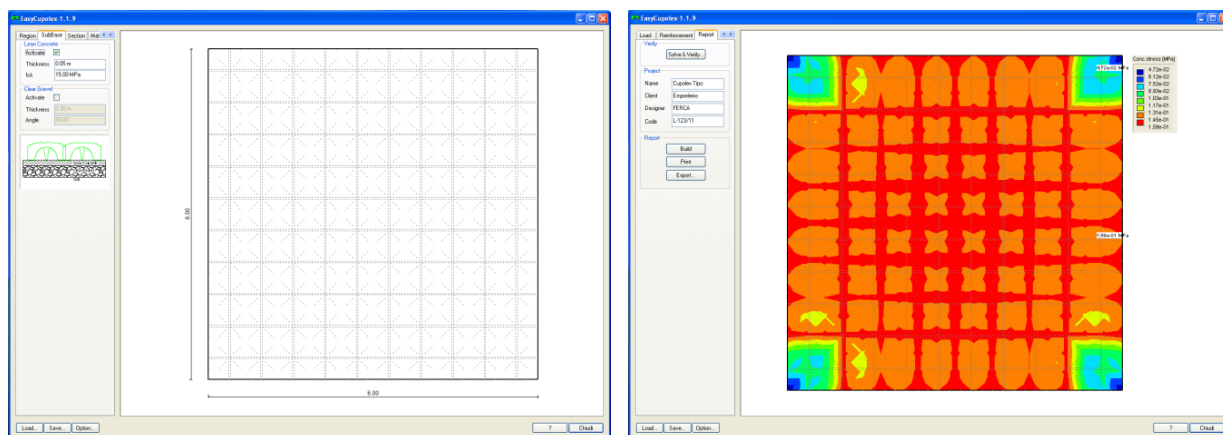


Figure 1 – Calculation example using EasyCupolex software.



DETAIL OF A CUPOLEX FLOOR

For correct assembly of the Cupolex floor, drawings of its geometry should be produced that include the layout, characterisation and quantification, as well as dimensions relative to the surroundings, in order to optimise its use and facilitate the assembly process. They should also state the choice and identification of cut pieces, or include the use of Beton Stop units.

The system's layout drawings must contain the following elements:

- Dimensions relative to the surroundings or to the limit of the layout;
- Characteristic section of the floor, identifying the Cupolex module and the thickness of the layer;
- Indication of the assembly starting point and identification of the pieces to be cut;
- General notes on the use, handling and assembly of a Cupolex floor.

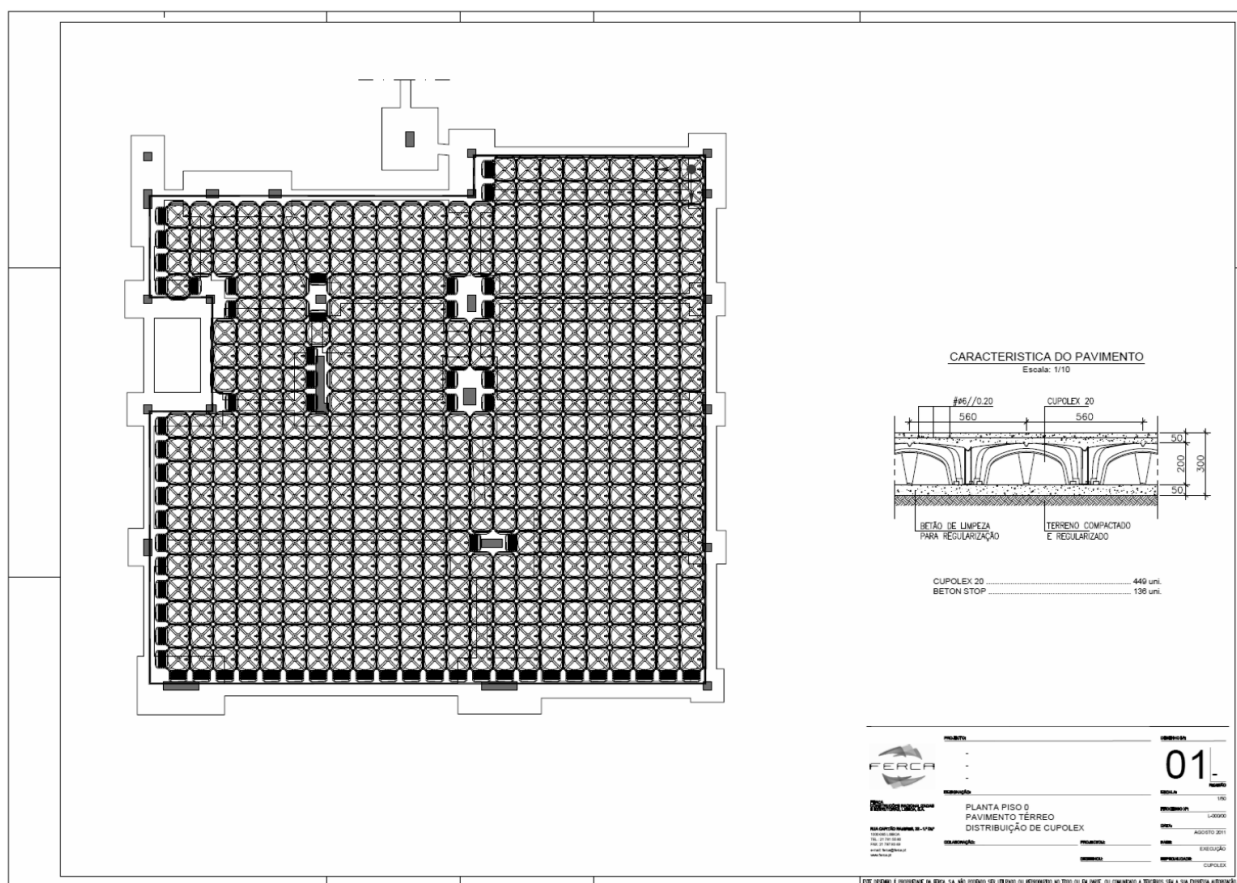


Figure 2 – Cupolex layout drawing.



Particularly relevant is the way in which the system's layout adapts to the geometry in question, the Cupolex modules always being capable of being cut. For this purpose, Pontarolo Engineering developed the Beton Stop, an element likewise produced from 100% recycled material and designed to close the arches left by the Cupolex around the perimeter of the surface to be filled, avoiding the cutting of modules and the wastage of material, and allowing a perfect fit to the geometry of the structure.

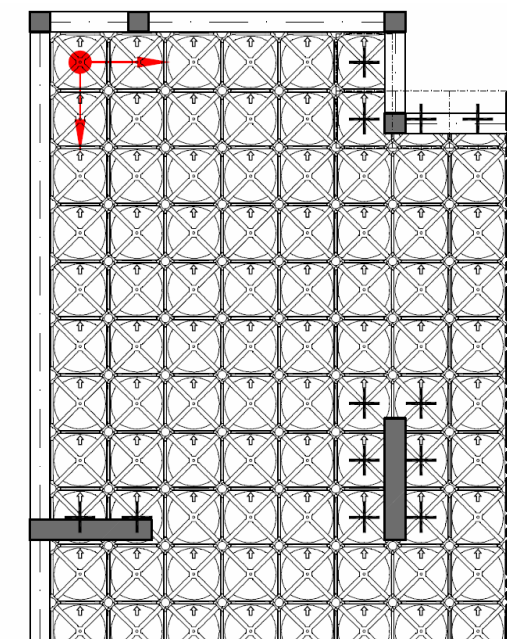


Figure 3 – Example of a Cupolex layout, identifying the pieces to be cut for adaptation to the geometry.

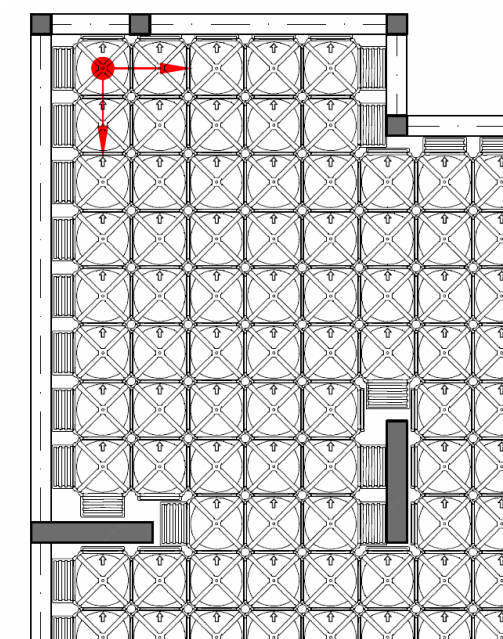


Figure 4 - Example of a Cupolex layout using Beton Stop units for adaptation to the geometry.

Ferca is available to carry out the system's layout and to provide all the technical support deemed necessary during the design or construction phase of the floor.

EXAMPLE 1 – GENERIC CUPOLEX FLOOR

The most conventional case of a Cupolex floor occurs in the pre-filling of the void in the space between existing lintels and foundation beams at, or at the boundary of, the level of the ground-bearing slab. In these cases, the height of the module to be used is defined so as to minimise the necessary excavation and to allow ventilation of the space beneath the final floor.

In these situations, the use of the Cupolex system allows the floor and lintels to be cast together, eliminating a set of operations that usually take place after casting the elements bounding the building's interior space.

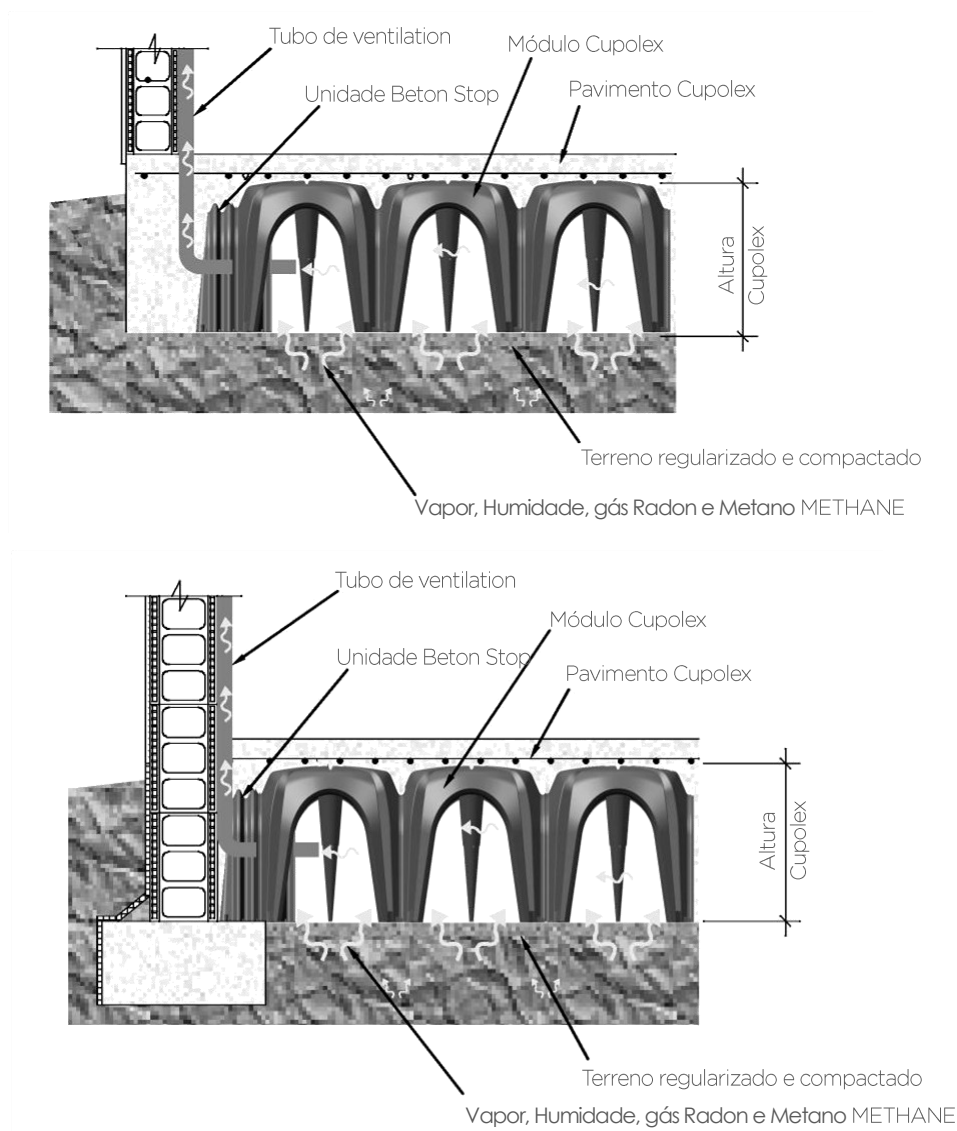


Figure 5 – Generic configurations of a Cupolex floor.

EXAMPLE 2 – INDUSTRIAL AND COMMERCIAL FLOOR

The Cupolex system can be specifically engineered for industrial applications, allowing imposed live loads of up to 1,800 kg/m². In these cases, a detailed study of the solution is required in order to define the supporting base, the compression layer and the reinforcement bars needed for the efficient distribution of forces at the system's supports, and in particular for the spreading of point loads.

Special — cold storage rooms

The Cupolex system is particularly suitable for cold storage room installations, since it ensures efficient insulation of the industrial space while at the same time preventing the freezing of the adjacent soils.



Figure 6 - Examples of various Cupolex floor installations.



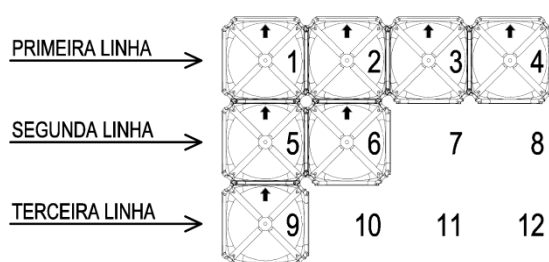
CONSTRUCTION OF A CUPOLEX FLOOR

The Cupolex system is characterised, in both its technical and product components, by a speed and ease of assembly which — when properly designed — give considerable speed to the construction process.

The system's layout drawing is therefore an important step in defining the solution and preparing the works. Depending on the designer's choice, the Cupolex may be laid between lintels, foundation beams, footings, pile caps, or between already-built masonry. To this end, the necessary height(s), the assembly starting points, and the layout that reduces or avoids the wastage of Cupolex modules must be defined beforehand.

Assembly process:

- The layout drawing must indicate the starting point;
- The Cupolex modules are marked with an arrow indicating the assembly position;
- The Cupolex modules are assembled from left to right and from top to bottom;
- The Beton Stop units must be placed (if specified in the design);
- The reinforcement bars are placed on spacers positioned on the dome of the Cupolex module;
- Casting is carried out conventionally, and mechanical finishes may be used.



Assembly sequence of the Cupolex modules



Figure 7 - Assembly stages of the Cupolex floor.



ANNEX A - COMPOSITION

Pontarolo Engineering produces the Cupolex system from recycled polypropylene — or, more precisely, from a thermoplastic material obtained through a process of grinding selected and controlled plastic objects (for example, chairs, bumpers, etc.). Generally, the main elements that make up recycled polypropylene are:

- Polypropylene (PP) and polyethylene (PE), of both low density (LD) and high density (HD), in a co-polymer;
- Calcium carbonate / talc, which forms the so-called matrix that gives the material high external rigidity;
- Fluidity, necessary for the moulding process.

POLYPROPYLENE

Polypropylene is a thermoplastic vinyl polymer made from ethylene and propylene, which are by-products obtained from refined benzene gas. These gases are polymerised into polypropylene and polyethylene at high temperature and pressure in gated systems in a closed process, where they are produced with no emissions to the atmosphere. The finished products are plastic granules of polypropylene and polyethylene composed of hydrogen and carbon molecules. When incinerated, the only substances released are carbon dioxide and water. As thermoplastics, they can be easily recycled, incinerated or sent to landfill. All consumption and production waste can be easily recycled. The final product is strong and durable, capable of withstanding extreme temperatures and ageing without breaking or tearing.

ENVIRONMENTAL REQUIREMENTS

The Cupolex system thus addresses four of the main parameters of environmental sustainability:

- Minimising the use of natural resources;
- Reducing the emission of polluting substances;
- Long product life cycles;
- Reuse and recycling of all its components.

ANNEX B – GAS INTRUSION

VAPOUR INTRUSION AND RADON GAS CONTROL

Years of research and application have shown that the intrusion of vapours, such as Radon gas, can be effectively controlled by using fans to draw air from the soil beneath the floor (see EPA 1994, ITRC 2007), a well-known technology often used in subsoil depressurisation.

MORE EFFICIENT VENTILATION

Traditionally, depressurisation requires drawing air from the subsoil of a building by means of localised ventilation beneath the slab. In the case of conventional floors, the fans must be powerful enough to depressurise the soil so as to extract air through the layers of sand or gravel placed there, requiring a large number of suction points to depressurise the entire floor of the building. Cupolex ventilated floors can simply replace the sand and gravel with a large plenum created by the system in the lower part of the floor, thus constituting a more efficient, effective and predictable means of air circulation.

PASSIVE VENTILATION POTENTIAL

While subsoil depressurisation is, in theory, the most effective way to control vapour intrusion, passive ventilation is, on the other hand, the simplest and most economical solution, both during the assembly phase and over the structure's life cycle. The ability of traditional systems to depressurise subsoils in order to ventilate floors is questionable, and it is often simply difficult to move air through the soil without the reliable energy of a fan (EPA, 1994).

The application of the Cupolex system therefore creates a new opportunity for passive ventilation, with a plenum that allows air to move very easily under natural thermal gradients or wind. Ove Arup (1997) shows that the amount of air moving through an open system such as the Cupolex void is about 10 times greater than the volume of air circulating through a layer of gravel, thereby increasing the viability and effectiveness of a passive system.

Detailed studies were carried out by Arup Environmental and Kingston University, comparing various vapour-intrusion mitigation alternatives.

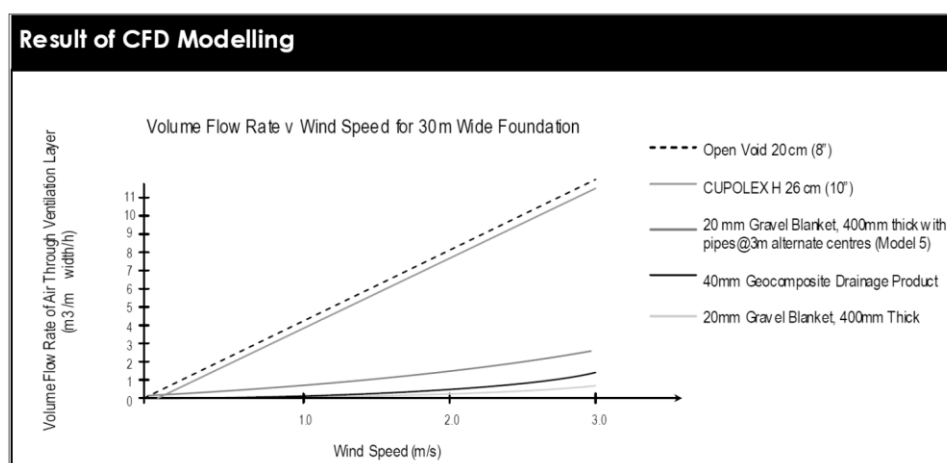


Figure 8 – Comparative chart of the performance of various floor solutions.



ANNEX C – MOISTURE AND AIR QUALITY

While membranes are normally required in insulation systems to act as barriers (essentially stagnating the flow of vapours), mitigation systems such as the CUPOLEX® floor system, which rely on ventilation or gas depressurisation (diverting and diluting the vapours), do not require membranes. In fact, depressurisation systems were developed for installation in existing buildings, where membranes could not be placed; moreover, mitigation systems that result in the dilution of vapours beneath the floor — and whose performance can be monitored and controlled (for example, through the operation of fans and pressure measurements) — have the advantage of not allowing vapours to concentrate.

SOLUTION FOR REDUCING MOISTURE AND MOULD AND IMPROVING INDOOR AIR QUALITY

The concrete slabs of conventional ground-bearing slabs are in contact with the soil; as a result, the moisture conducted through the concrete contributes to the appearance of mildew and mould on the finished floors, causing costly architectural damage. By keeping both the upper and lower faces of the floor's concrete slab dry, the problems of excessive moisture — which has been associated with adverse health effects, especially asthma and respiratory diseases — are reduced.

The Cupolex system provides a void beneath the floor, resulting in the absence of contact between the concrete and the soil, which constitutes its main advantage over any other ground-bearing slab system. Firstly, because the void formed is waterproof, since all the system's components are made of polypropylene, thereby providing an excellent barrier to moisture. Secondly, it prevents the leaching of water through contact with the concrete, thus avoiding its deterioration and the onset of an accelerated corrosion process that would affect the durability of the structural elements. Finally, the ventilation of the floors' air gap can effectively help to control and reduce air pollutants, moisture levels and temperature levels — factors that have been associated with human health, comfort and productivity.

VAPOUR PROTECTION SYSTEM

With the Cupolex system, designers, builders and other construction professionals can offer cost-effective preventive control and mitigation solutions in new buildings, reducing concrete consumption and the construction cycle.

Even when the soil types and water-table levels ensure the absence of water, vapours from volatile chemicals can migrate along underground pathways and infiltrate neighbouring buildings at levels that may compromise the indoor air quality. A long period of exposure to chemicals can have harmful effects on human health. When there is a high concentration of contaminants in the indoor air, it can be detected by smell, allowing it to be recognised so that the necessary corrections can be made quickly; however, in cases where the concentrations are low and not easily detectable, the need for action can be harder to perceive, giving rise to long periods of exposure to these agents.



ANNEX D – LOAD TESTS

LOAD TEST DATA FROM STRUCTURES BUILT ON CUPOLEX

The engineering company Pontarolo Engineering S.r.l. (San Vito al Tagliamento – Italy) carried out a series of load tests on various concrete structures built with Cupolex elements.

The test consists of loading the structure with a hydraulic piston to cause failure. The load is applied at the centre of the floor over an area of $0.56 \times 0.56 \text{ m}^2$. Between the piston and the concrete there is a rigid plate which, thanks to a rubber layer, ensures a uniform distribution of pressure over the loaded area. The piston is supported by an overhead travelling crane anchored to a reinforced-concrete pit 1.5 m deep, prepared to contain the soil.

The thickness of the ground and the size of the pit (in comparison with the model) ensure that, during the failure test, the behaviour of the soil is independent of the connections with the retaining walls and the bottom concrete slab. This statement has been verified with a finite-element model in which the field is represented as a homogeneous medium with linear elastic behaviour.

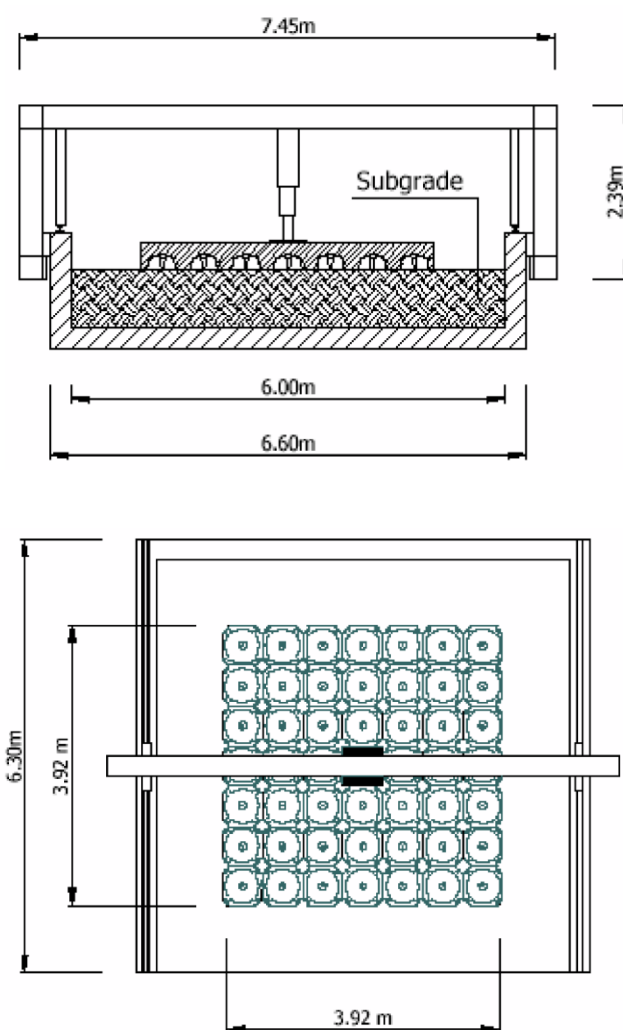


Figure 9 – Cross-section and plan of the test installation.

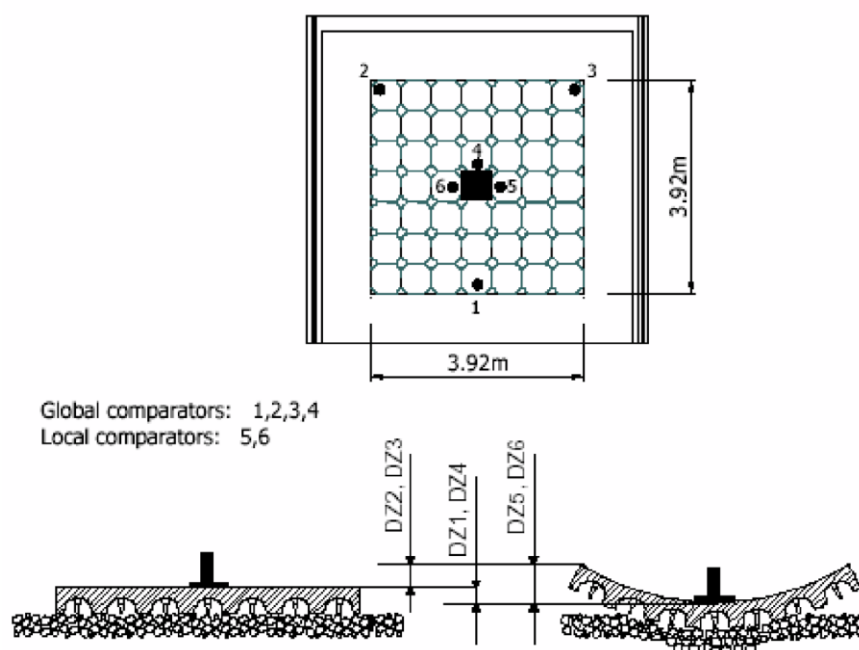


Figure 10 – Layout of the displacement gauges.

The sample consists of a set of 7×7 Cupolex modules placed side by side, as shown in the previous figure. In some tests the size was reduced to sets of 5×5 modules to assess the influence of the sample dimensions on the same type of ground, concluding that the difference in size is not relevant, given that the perimeter modules — for small compression-layer thicknesses (50 mm) and for loads concentrated in the central area — lift away from the soil during the test.

For the load conditions and the grounds considered, it can be stated that the supports at the perimeter of the sample have no influence on the assessment of the load-bearing capacity. Therefore, the 5×5 samples can be considered equivalent to the 7×7 ones.

The data is read using 6 centesimal displacement gauges arranged as indicated in the previous figure. Points 1, 2, 3 and 4 are connected to the concrete pit and measure the absolute vertical displacement. Points 5 and 6, by contrast, measure the relative displacement (designated DZ5 and DZ6 respectively), calculated as the difference between the displacement below the central point, located immediately next to the loaded area, and the outer side of the sample.

Contact between the sample and the ground is made through supports that form between the modular elements. Their dimensions in plan are approximately 12 × 12 cm² in the central areas. This area is reduced to ½ and ¼ at the perimeter and at the corners, respectively.

The applied load can be considered of short duration.

Through experimental tests, the typical flexural-shear failure mechanism is reproduced. In real cases, the load distributions of greatest interest are those that maximise the bending moments (positive and negative) which produce failures by exceeding the flexural resistance of the compression layer.

The ultimate load varies as a function of the slab geometry, the amount of concrete, the type of ground and the amount of reinforcement present in the compression layer.



The most common cases in traditional applications of the Cupolex system are represented by curves A, B and C and are generally composed of:

- Compacted ground
- 5 cm of blinding concrete
- Cupolex H26
- Compression layer of 5 cm (sample A), 8 cm (sample B) and 12 cm (sample C)
- Square mesh $\Phi 6/0.20$ in A500 in the layer

The loads that produced failure by the flexural-punching mechanism of the structure were:

- 300 kN for sample A
- 370 kN for sample B
- 560 kN for sample C

In all cases the forces were applied over a 56×56 cm metal base.

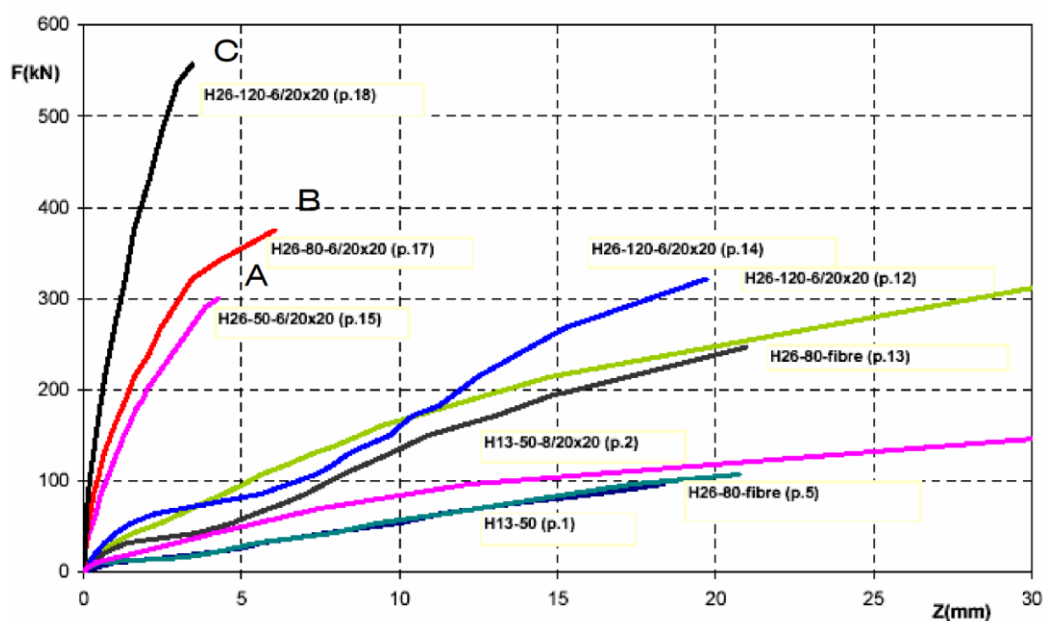


Figure 11 – Record of the load tests.

It is important to note that all these tests were carried out on weak concrete and ground — that is, on a flexible base — and it is estimated that, when applied over a rigid base (for example a concrete slab), the load capacities would be higher.

Note: This annex summarises the results of the tests carried out for Pontarolo Engineering, owner of the system's patent; authorship of the study is the responsibility of Prof. Stefano Secchi, a researcher at the University of Padua in Italy.



