Repair monitoring using Impulse - Response method

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- Mr. Claus Germann Petersen

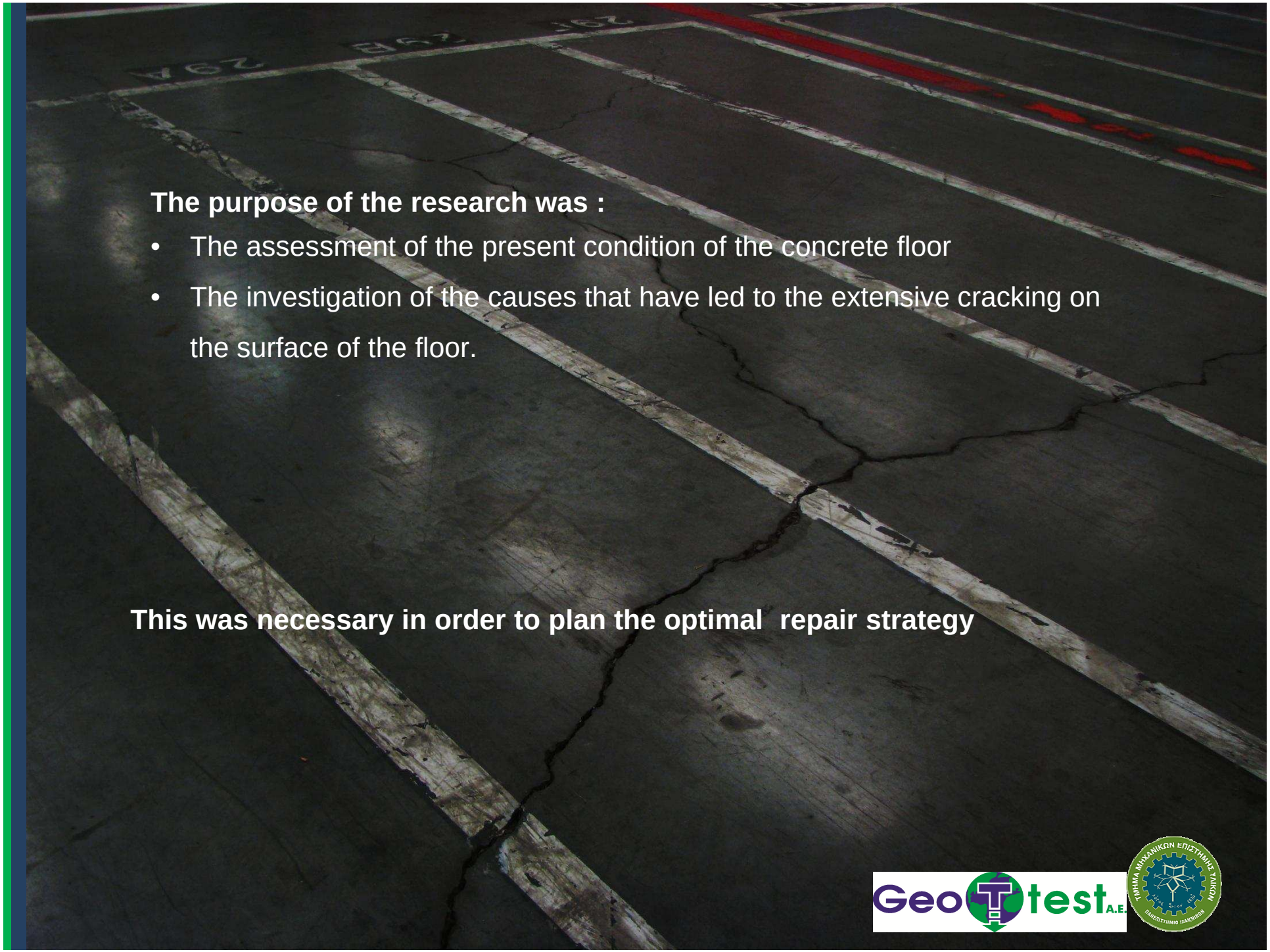
The tests were carried out by **GEOTEST SA** at a warehouse for foods and drinks. The warehouse covers an area of about 36.000m^2 and was build in 2005.

On the floor there are metal joints which divide the surface into independent sections about 1200m^2.

The warehouse's concrete floor suffers from extensive cracking on its surface.

The design thickness of floor is 18cm , C25/30 with metal fibres 40kg/m^3
Cracks deteriorate the ride quality of the vehicles that move in the warehouse.
(lift tracks, pallet carrying trucks and vehicles used for transporting, sorting and loading of products)


29A
29B
29F



The purpose of the research was :

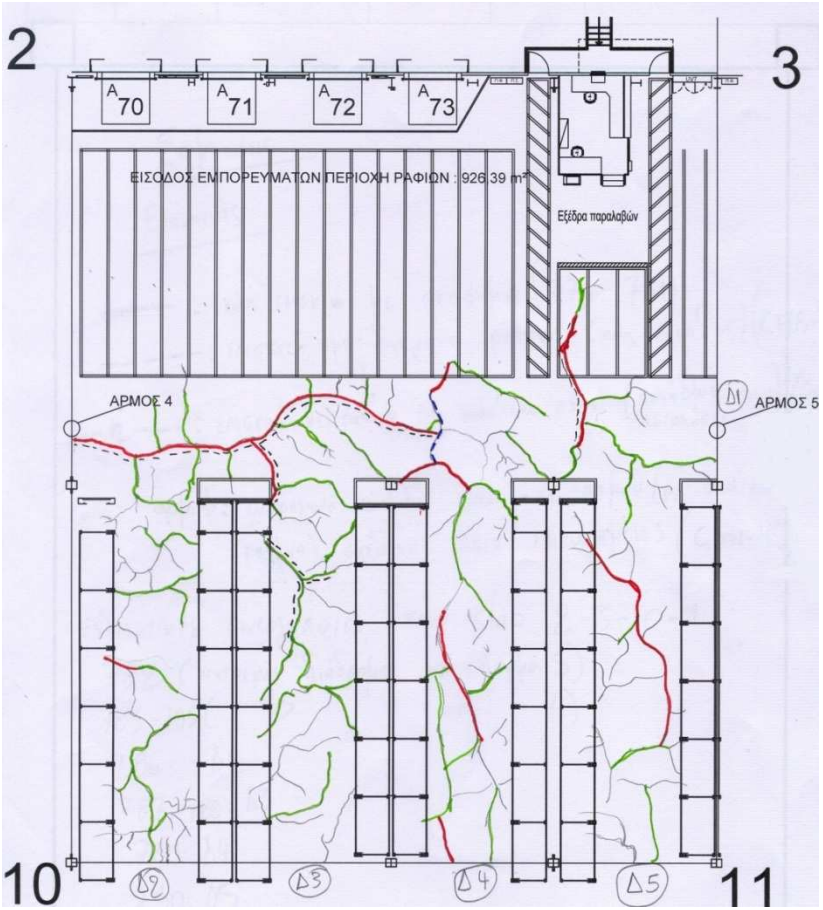
- The assessment of the present condition of the concrete floor
- The investigation of the causes that have led to the extensive cracking on the surface of the floor.

This was necessary in order to plan the optimal repair strategy

NDT methods that were used.

- Visual Inspection
- Impulse – Response Method (Uniformity Test)
- Impact Echo Method
- Crack Depth Measurements
- Calibration by concrete cores
- Test of Sub-base Material (quality - compaction)

Visual Inspection

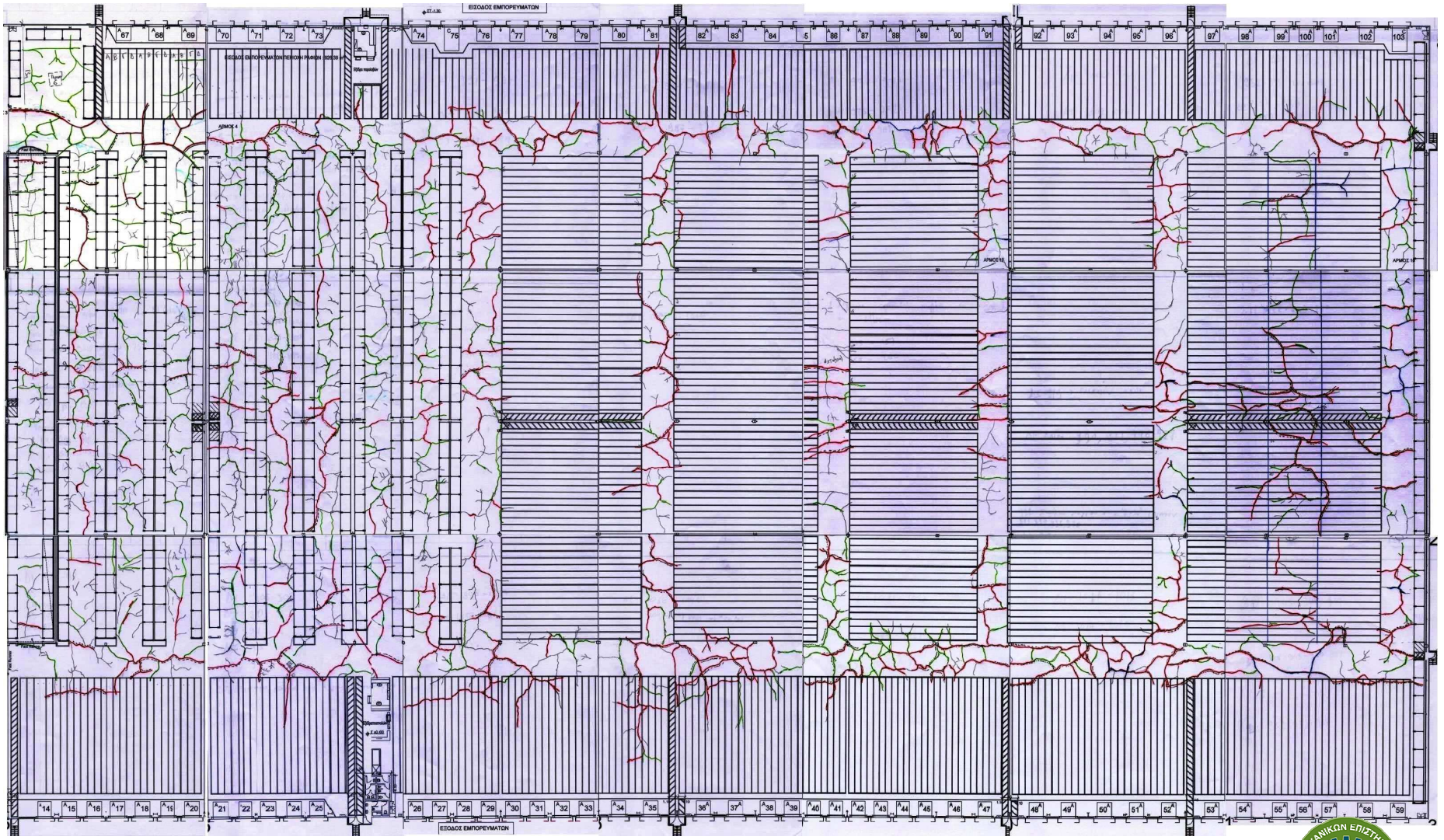


Visual Inspection was carried out to record the cracks that appear of the floor.

The cracks were divided in the following categories depending on their width.

Crack Width	Recorded as
0,2 to 1mm	
1mm to 6mm	
Bigger than 6mm	

Visual Inspection



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Uniformity test by Impulse – Response Method

ASTM C 1740: 1. Scope 1.1 This practice provides the procedure for using the impulse-response method to evaluate rapidly the condition of concrete slabs, pavements, bridge decks, walls, or other plate-like structures.

- The operating principle is based on a low strain impact produced by a hammer with a rubber tip . Stress waves sent through the tested elements
- The impact causes vibrations in the element and stimulates primarily flexural form.
- A velocity receiver set near to the point of impact, takes the response.
- The load cell and the velocity receiver are connected to a laptop computer analyze the results.

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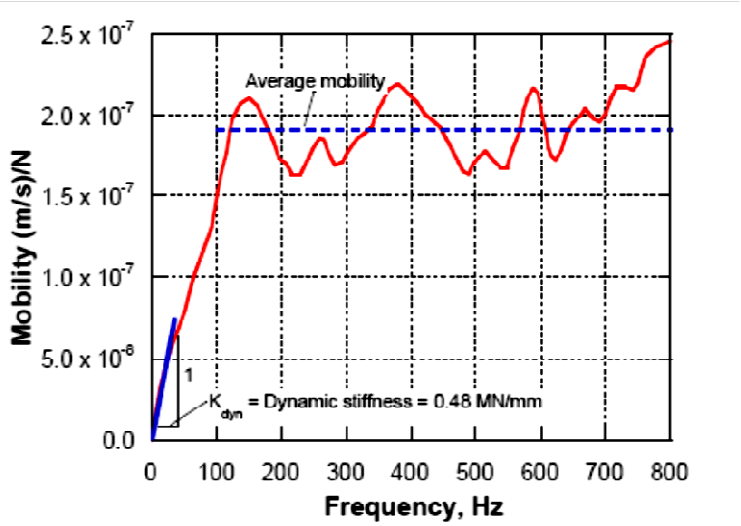
Impulse – Response Method

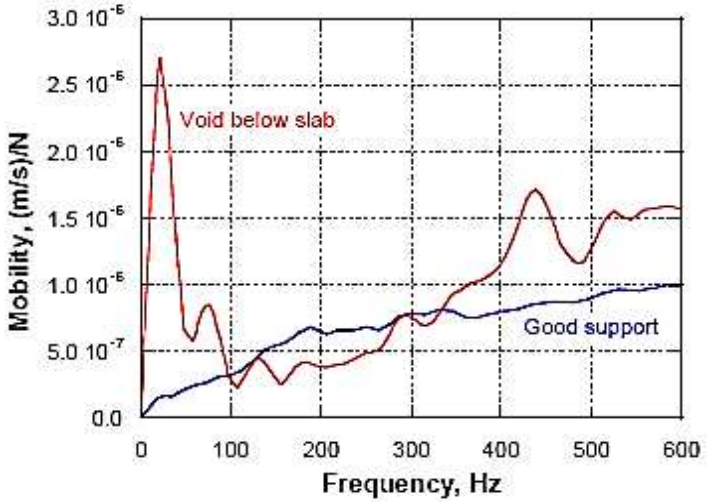
The function of the force in time, that is produced by the hammer and the measured velocity response is transformed in the frequency domain using the Fast Fourier Transformation (FFT).

The range of velocity response divided by the range of force and the "mobility" is shown as a function of frequency. The mobility is given in units of speed per power (m / s) / N.

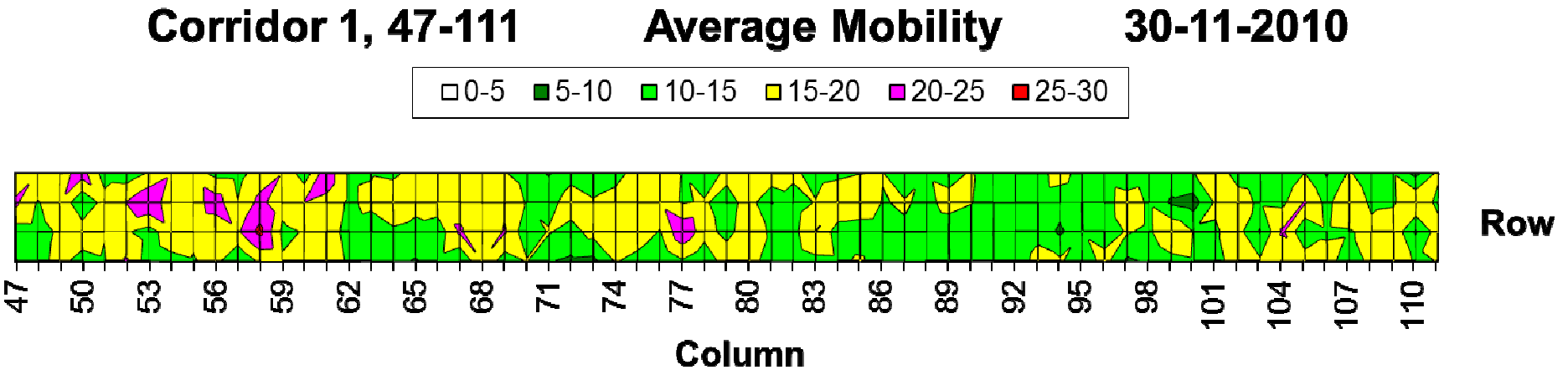
The parameters of the mobility diagram (Figure 1) used for assessing integrity are:

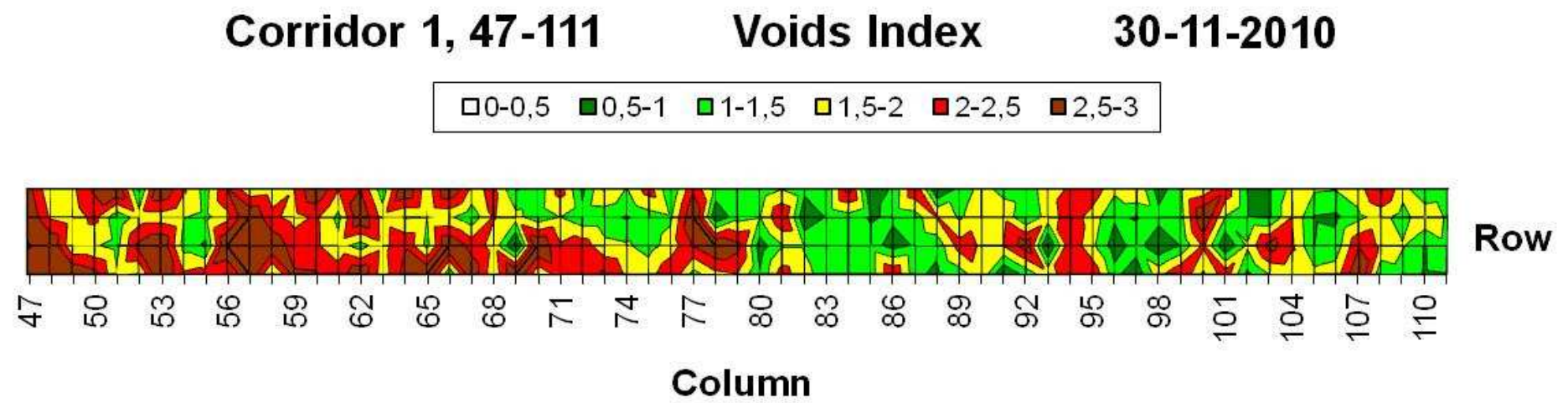
- The dynamic stiffness
- The average mobility (lined bar)
- The mobility slope between 100 and 800 Hz
- The voids index (the ratio between the width of the initial maximum mobility to the value of the average mobility)



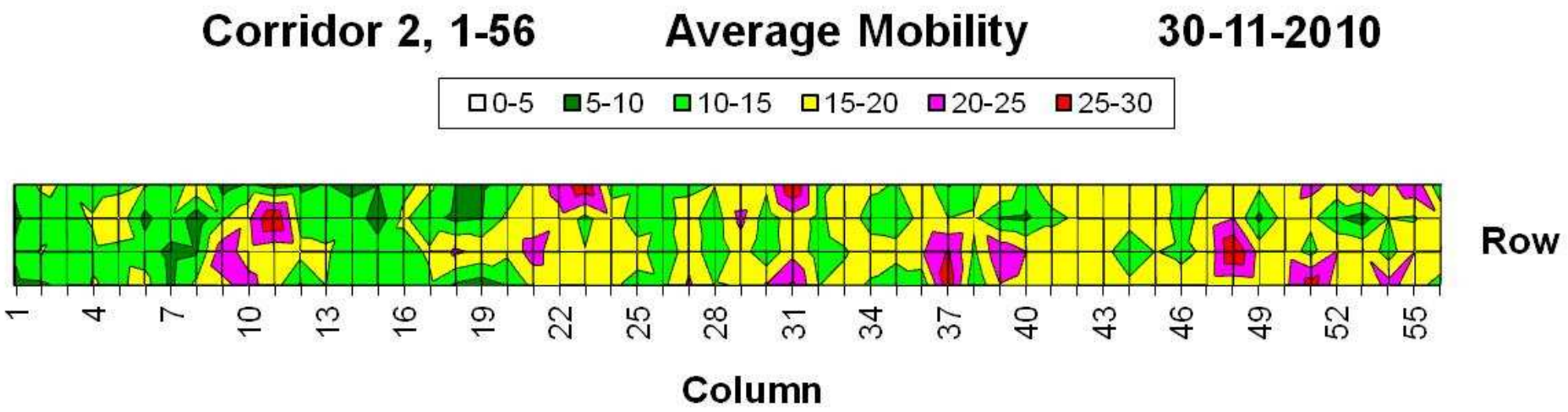


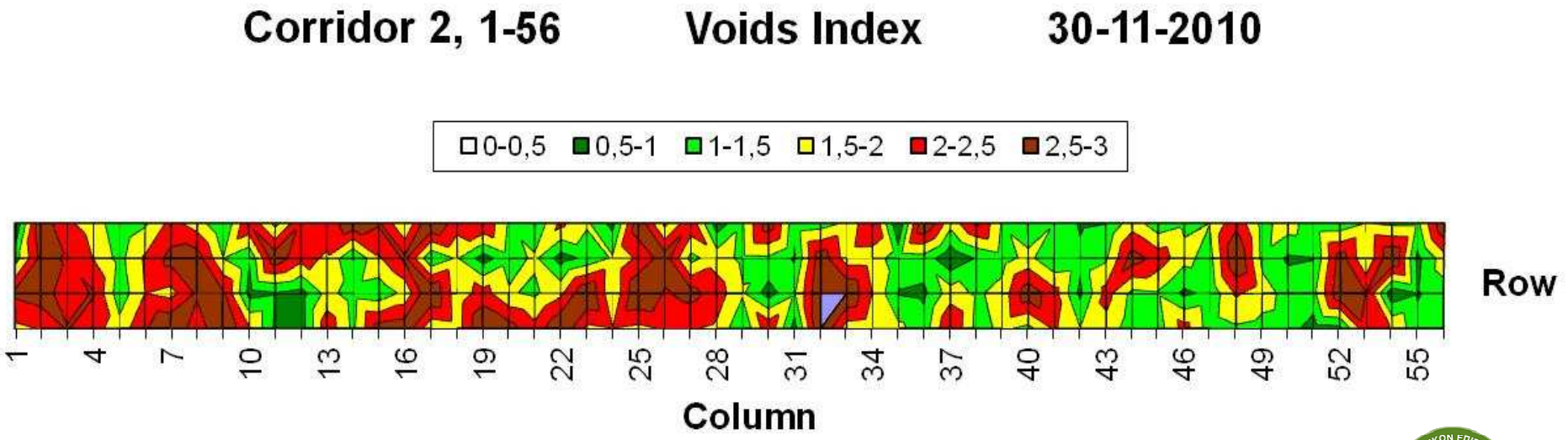
Impulse – Response Method





Impulse – Response Method





Impulse – Response Method - Cores

1st Finding:

Voids Below Slab

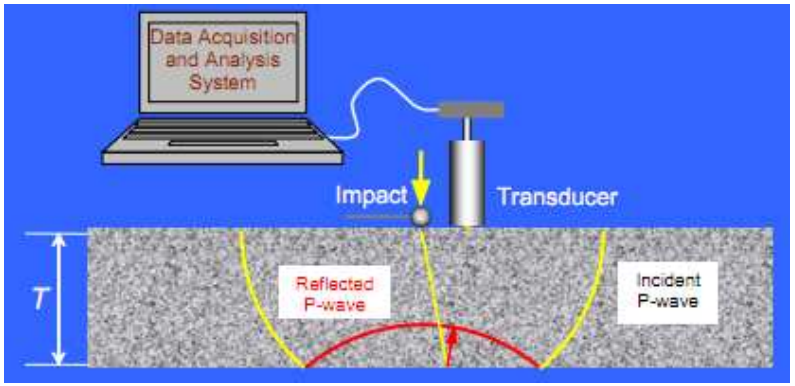
Impact - Echo Method (ASTM C1383)

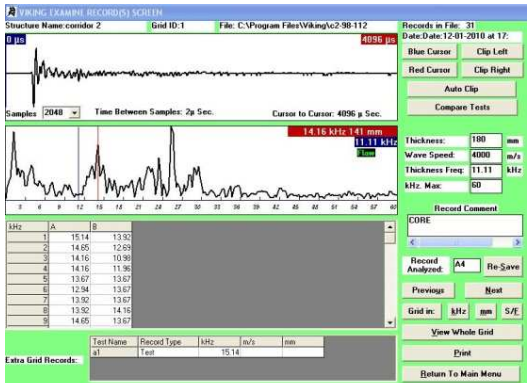
- The operating principle is based on a short-duration stress pulse by a mechanical impact and a transducer that receives the reflected signal.
- The impact generates three types of waves: Rayleigh, **P-waves**, S-waves.
- **P-waves** propagate through the slab and reach the opposite surface where are reflected back. These P-waves reflect for several times between the two surfaces.
- Transducer receives the waveform of surface movement which is related to the thickness of the slab and the wave velocity.
- Through Fourier Transformation of the wave is available to estimate the thickness of the slab by the following equation:

$$T = C_p/2f$$

where: C_p is the P-wave speed
(measured by calibration on drilled cores)
f is the frequency of the P-waves

- For the measurements was used DOCter system from Germann Instruments.





Impact - Echo Method

Corridor C1		Corridor C2		Corridor C5		Corridor C12		Corridor C16	
Axis	Thickness (cm)	Axis	Thickness (cm)	Axis	Thickness (cm)	Axis	Thickness (cm)	Axis	Thickness (cm)
1	17,8	44	17,8	1	15,8	1	17,8	1	17,1
10	16,4	54	17,1	5	15,8	7	17,8	5	15,2
20	16,4	59	15,8	10	15,2	14	16,4	10	15,8
30	16,4	68	17,1	15	16,4	21	17,1	15	15,2
40	17,8	75	15,2	20	17,1	28	16,4	20	15,8
50	17,8	80	16,4	25	16,4	35	16,4	25	17,8
60	17,1	85	15,8	30	15,8			30	16,4
70	17,8	89	14,1	35	16,4			35	16,4
80	17,8	98	13,2					39	16,4
90	17,8	105	14,4						
100	17,8	111	15,5						
110	17,8								
Ave.	**17,4**	**Ave.**	**15,6**	**Ave.**	**16,1**	**Ave.**	**16,9**	**Ave.**	**16,2**

Design thickness
18,0cm

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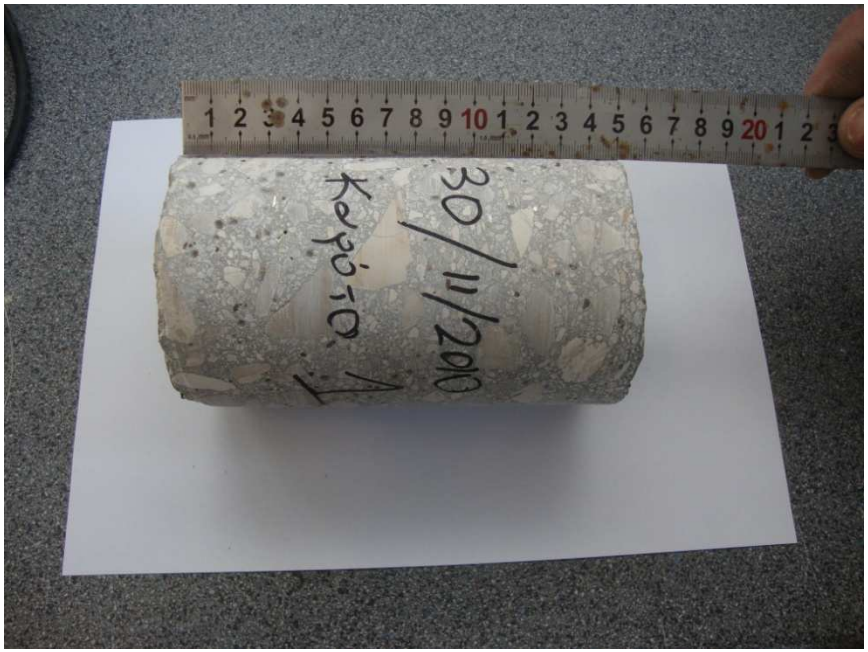
Impact - Echo Method and Cores



2nd Finding:

Low Thickness

Crack Depth Measurements

- The process of calculating the crack depth is the following:

    1. Measure the ultrasonic velocity at a healthy part of the concrete,
    2. Measure the ultrasonic velocity by placing the transmitter and the receiver on both sides of the crack,
    3. Calculation of the crack through the equation:

$$d = \frac{L}{2}\sqrt{\left(\frac{t_c}{t_p}\right)^2 - 1}$$

where d = crack depth, L = distance between transmitter and receiver, t_c = propagation time to healthy part of concrete, and t_p = propagation time across the crack.

- For the measurements was used PUNDIT ultrasonic equipment from PROSEQ company and portable Surfer's from ACS company.

Crack Depth Measurements using Ultrasonic

No	Surface crack width (mm)	Reading (mm)	Correction factor	Correct reading (mm)
1	0,1	10,0	0,833	8,0
2	0,2	35,0	0,833	29,0
3	0,3	71,0	0,833	59,0
4	0,5	135,0	0,833	112,0
5	0,8	186,0	0,833	155,0
6	1,0	166,0	0,833	138,0
7	2,0	188,0	0,833	157,0
8	5,0	205,0	0,833	171,0
9	10,0	212,0	0,833	177,0
10	>10,0	*	0,833	*

- From the instrument calibration was showed that the measurements taken from instrument was 20% higher than the real cracks depth .

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Crack Depth Measurements

3rd Finding:

Deep Cracks and deterioration area in both sides

Compaction control and sub-base quality

- After 50cm diameter core cutting, it has been executed compaction test with cone and sand method, to the sub-base layer underneath the slab
- The test was carried out at two (2) sites

No	Site	Compaction (%)
1	Site 1	103.1
2	Site 2	107.9

4th Finding:

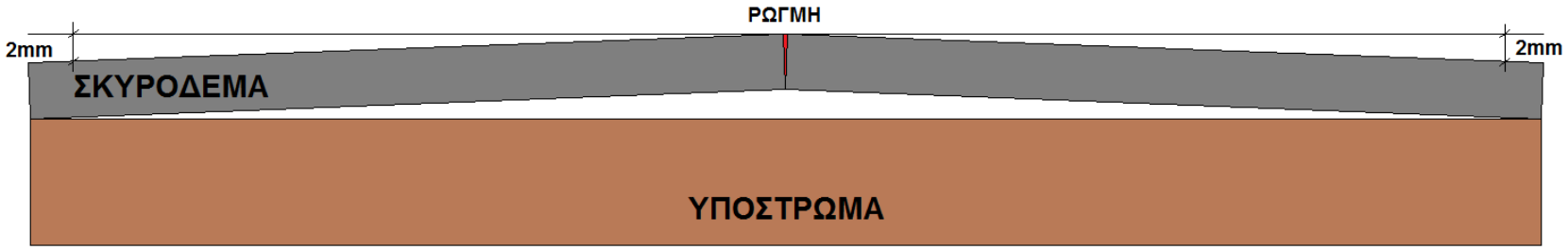
Low thickness extra sub-base layer (5cm)

Cannot have been compacted successfully during the construction and created local weak areas

Floor pathogenesis

After the research, the following appeared to be the basic causes of the problem :

- Initial cracks on the concrete floor appeared due to shrinkage.
- Bending cracks appeared due to the reduced thickness of the slab and the locally un-compacted base.
- Creation of gaps between the plate and sub-base due to the bending of the plate.
- Expansion of the phenomenon of cracks due to the bad support of the plate.



Conclusions

The use of NDT methods particularly helped to research and diagnose the causes of cracking.

Specifically:

- The use of the Impact- Echo method gave us a clear picture of the thickness of the plate by making a lot of measurements across the surface.

- The use of the Impulse –Response method identified gaps between the flooring and sub-base.

- Using the ultrasonic pulse velocity measurements, the depth of cracking was calculated.

All the results of the NDT testing methods were calibrated by cores.

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REPAIR

After the research and the according proposals, the owner of the warehouse chose a repair strategy aimed at limiting the evolution of the phenomenon.

The chosen strategy included the following:

- Filling of the the voids between the slab and the sub-base by grout injections, while strengthening the sub-base

- Sealing of the cracks.

  Some of the cracks will be sealed using epoxy products to offer structural support

  Some of the cracks will be sealed using elastic products, in order to continue to function as extra joints

Choosing this kind of repair strategy, that doesn't include increasing the thickness and/or reconstruction of the slab, the full restoration of the structural integrity of the floor is not possible

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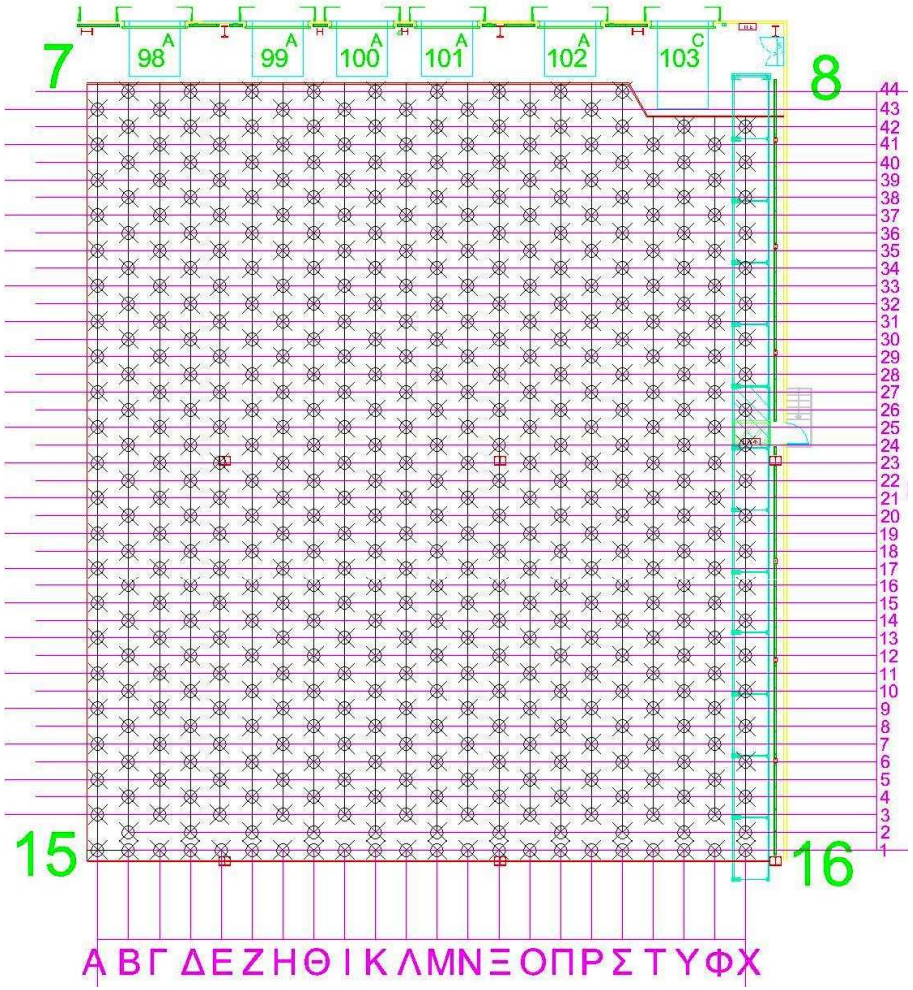
The grout injections at the first part of the floor were assigned to GEOTEST S.A.

The following methodology was chosen :

- A triangular grid was designed, with side dimension of 1,60m
- Holes of 26mm diameter were drilled up to a depth of around 20-22cm
- Grout with a W/C ratio of 0,7 to 0,9 (under pressure of 2bars at the maximum) was injected through the drilled holes using equipment specifically designed according to the needs of the project

The project was monitored by extensive use of the Impulse – Response method

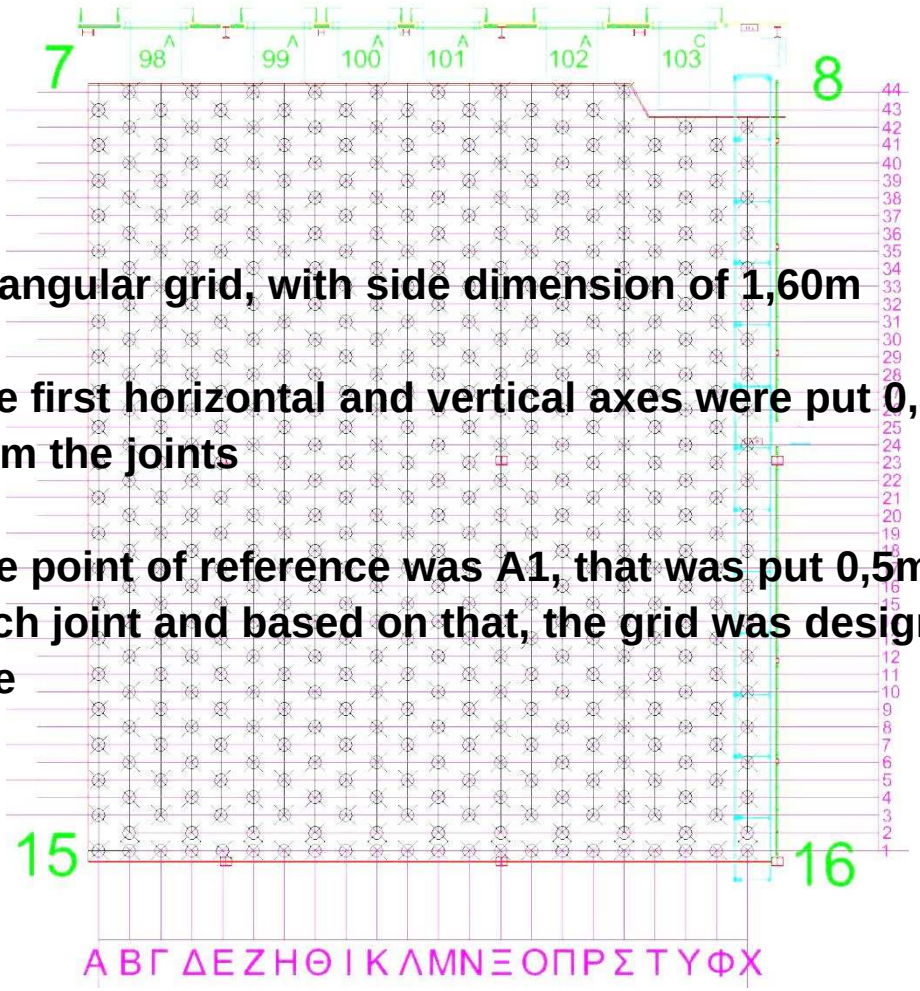
Grid Design



44 axes

22 axes

Grid Design



- **Triangular grid, with side dimension of 1,60m**
- **The first horizontal and vertical axes were put 0,5m from the joints**
- **The point of reference was A1, that was put 0,5m from each joint and based on that, the grid was designed on site**

Used Equipment

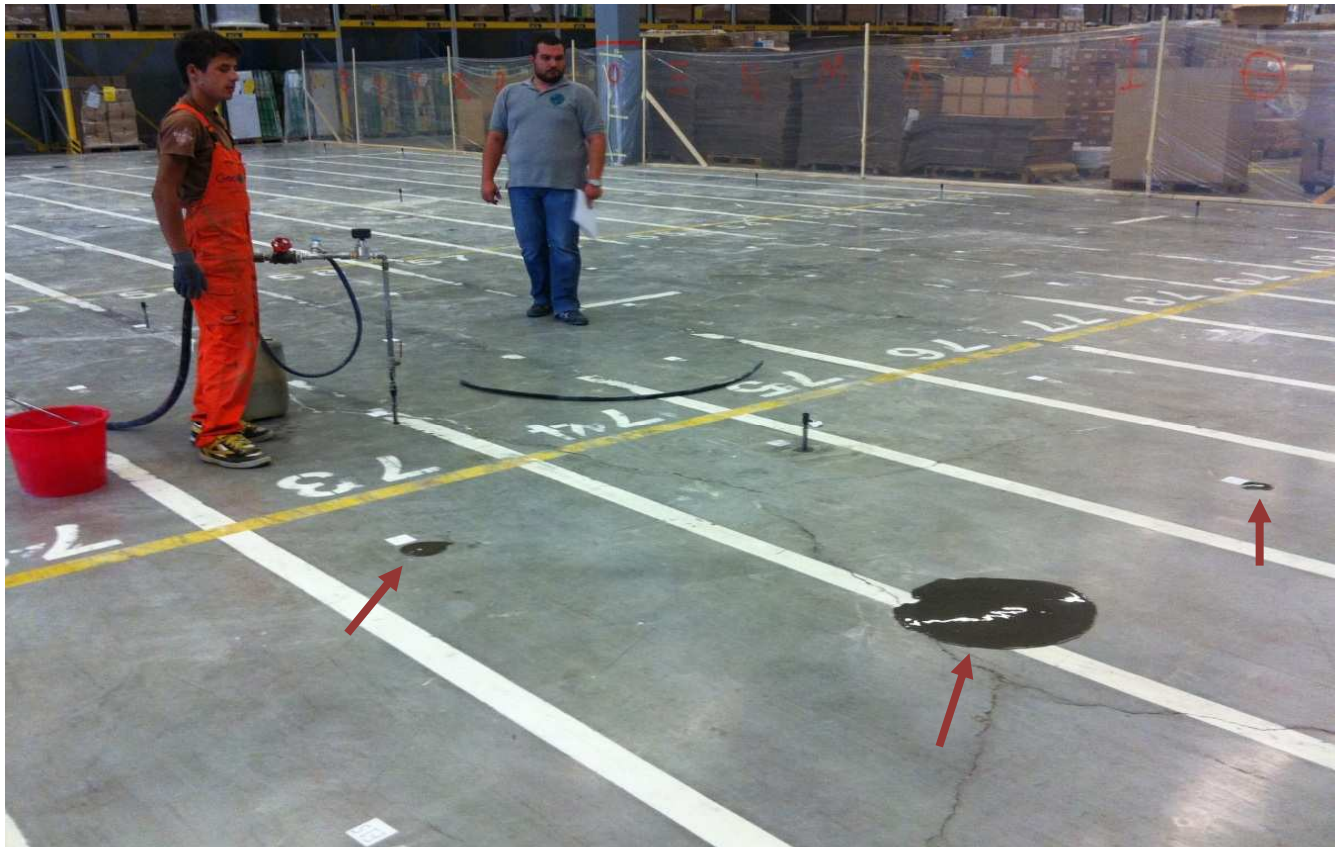
Photos from the procedure

Drilling

Photos from the procedure

Injection

Photos from the procedure



Grout pouring from adjacent holes

Photos from the procedure

Test using the Impulse – Response method

Impulse – Response Method

The slab was tested using the Impulse – Response method for voids below the slab, using a 22x44 grid:

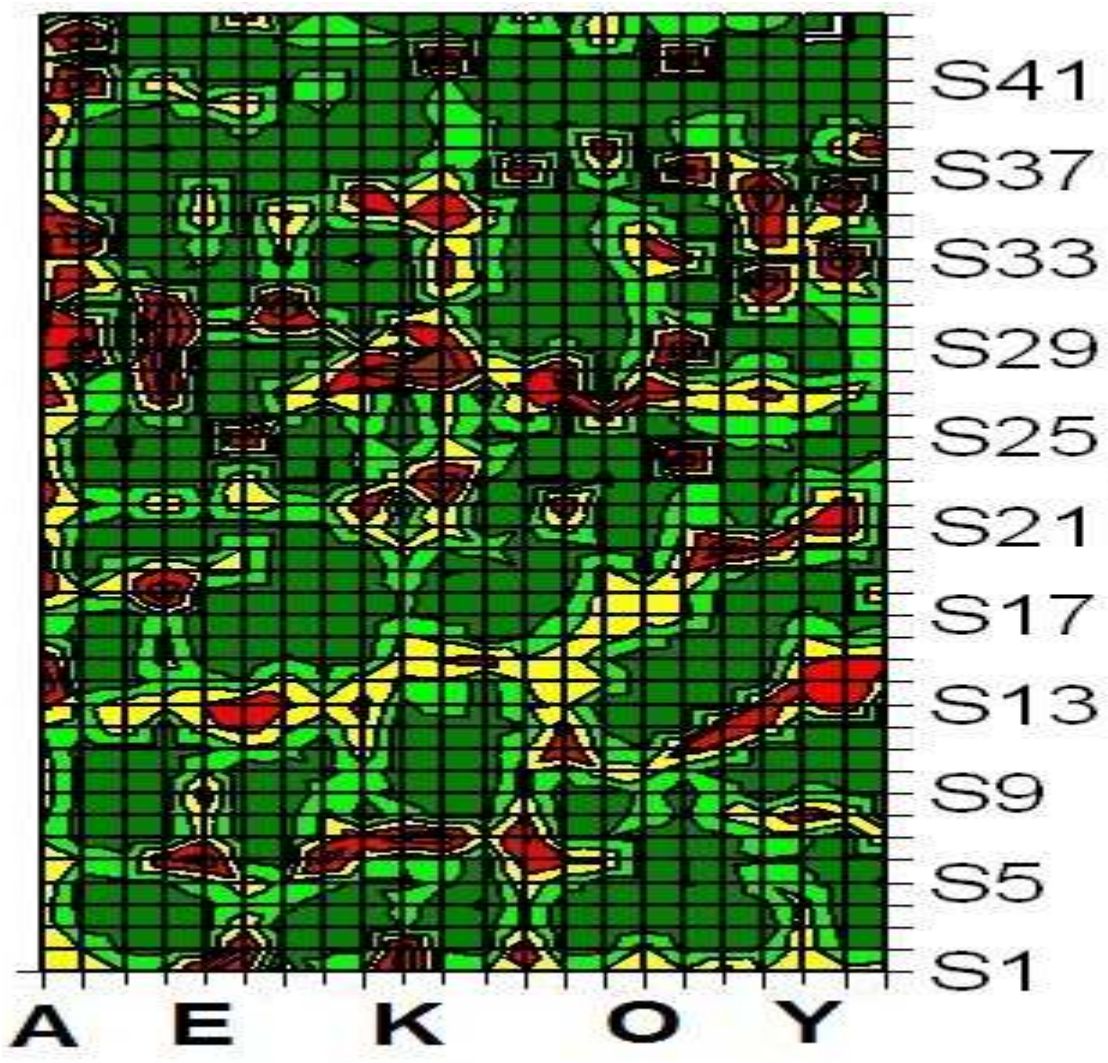
- **Before the beginning of the injections**
- **After the injection of grout in the primary grid**

  A secondary grid was designed on site taking into consideration the results of the method

- **After the injection of grout in the secondary grid**

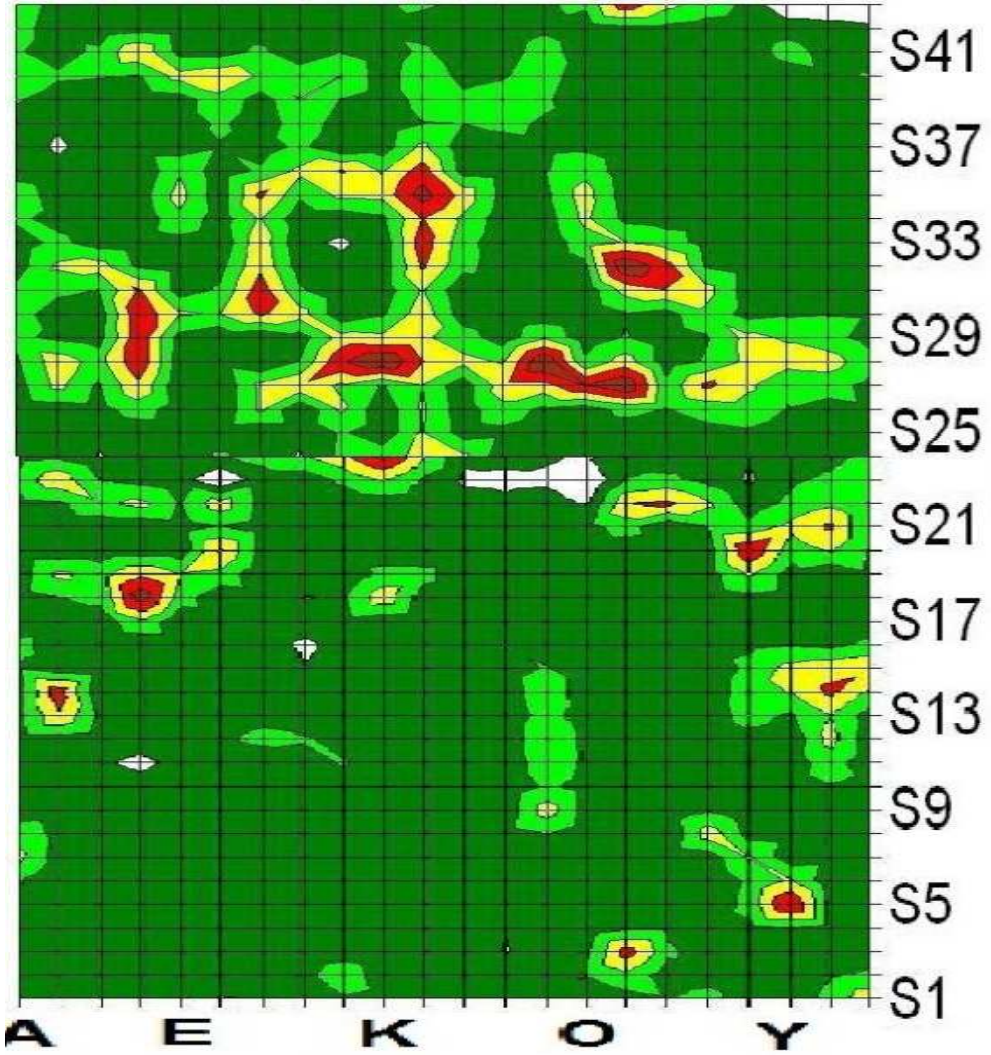
Impulse – Response Method Results

Before the Injections



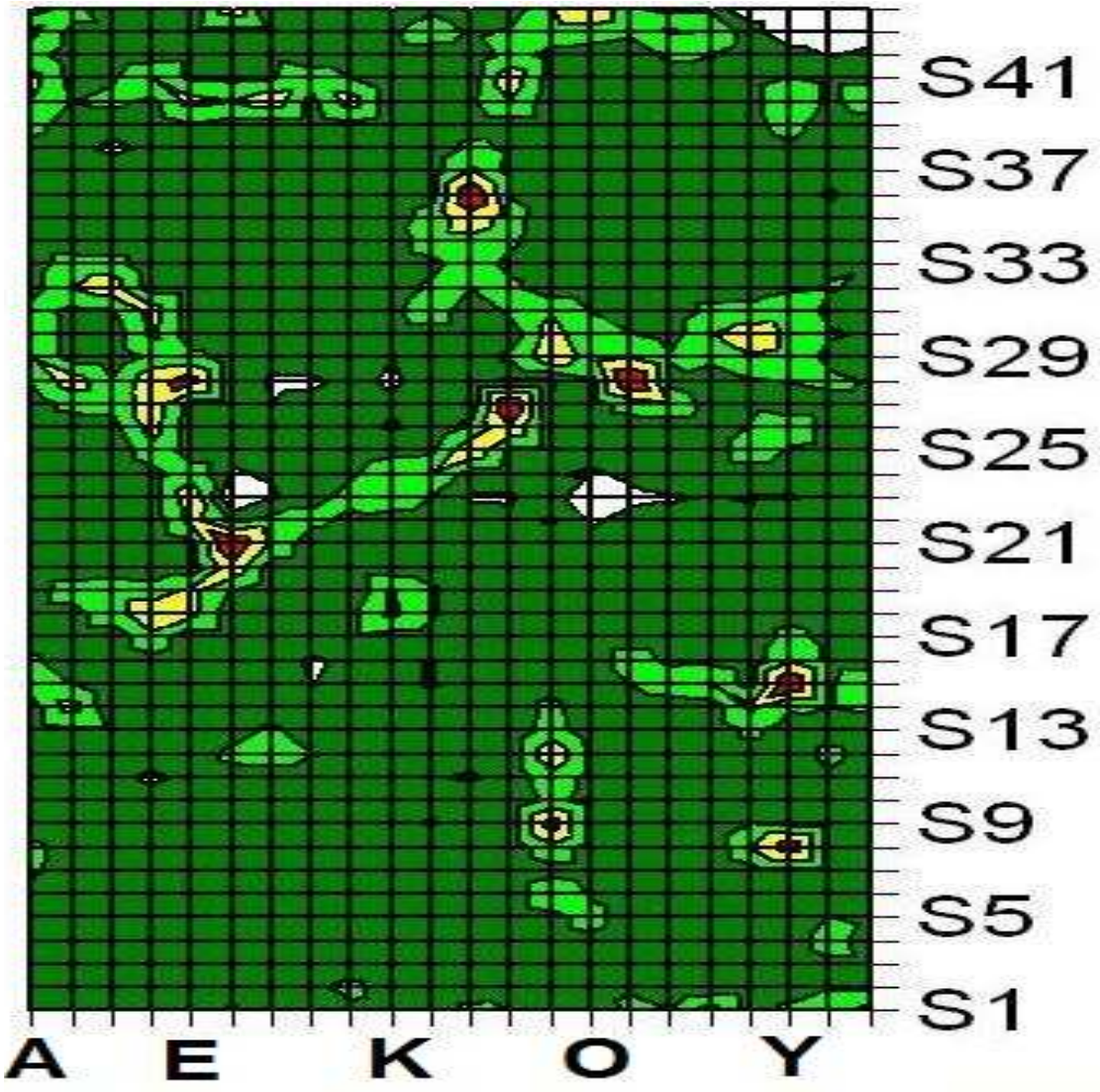
Impulse – Response Method Results

After Injecting the Primary Grid



Impulse – Response Method Results

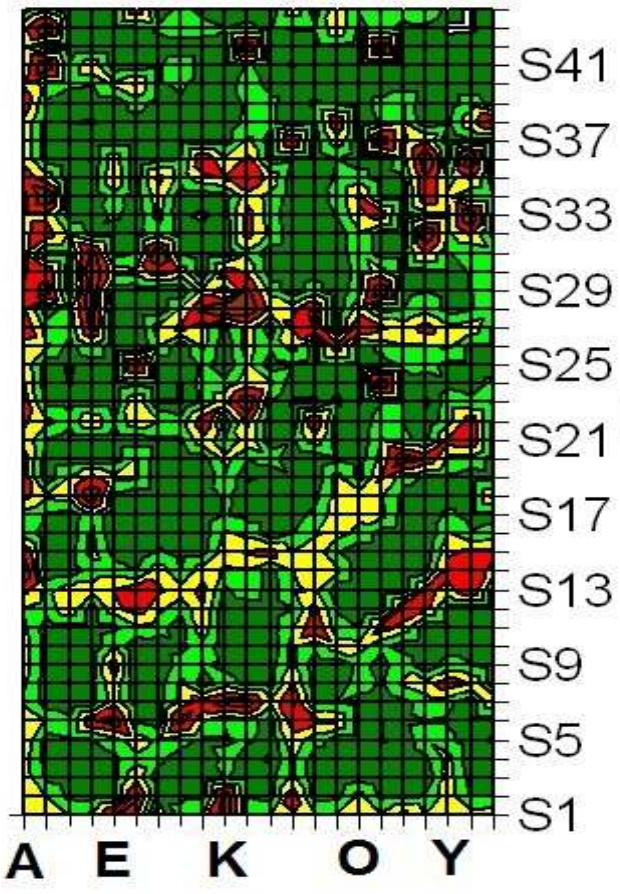
After Injecting the Primary Grid



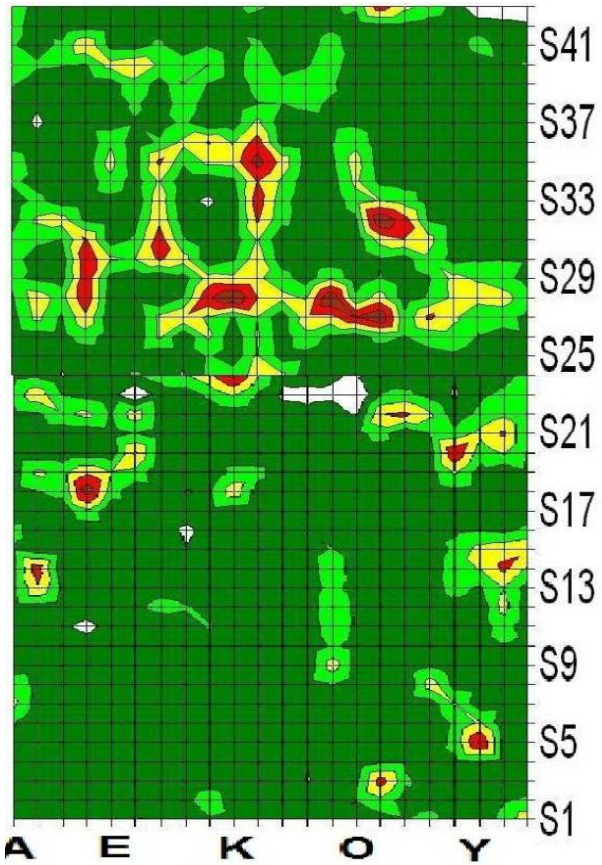
Impulse – Response Method Results

Comparative Examination

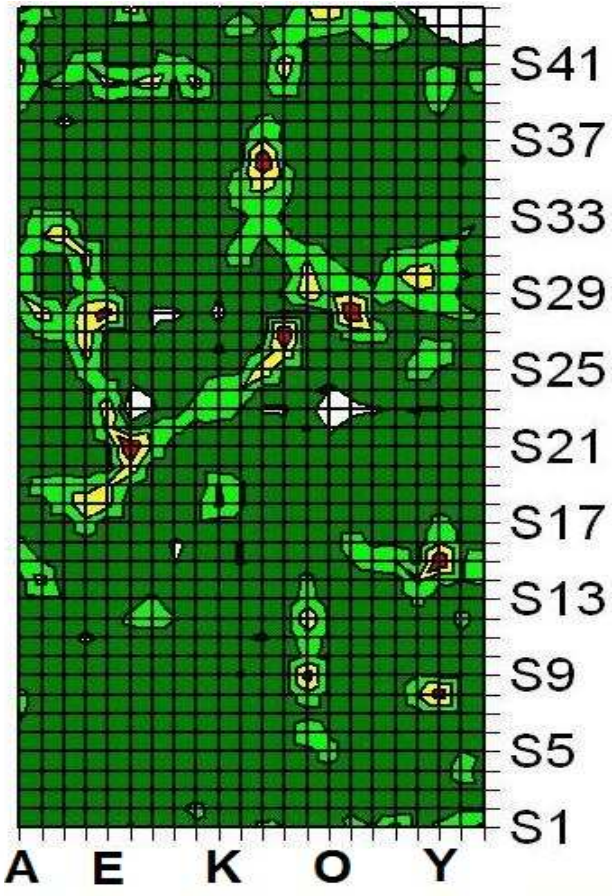
Before the Injections



After Injecting the Primary Grid



After Injecting the Secondary Grid



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Impulse – Response Method Results

	Before the Injections		After Injecting the Primary Grid		After Injecting the Secondary Grid	
Voids Index	***Number of points***	***Percentage (%)***	***Number of points***	***Percentage (%)***	***Number of points***	***Percentage (%)***
0 – 0,5	691	71,38	857	88,53	921	95,15
0,5 – 1						
1 – 1,5						
1,5 – 2	154	15,91	78	8,06	38	3,92
2 – 2,5	81	8,37	24	2,48	6	0,62
>2,5	42	4,34	9	0,93	3	0,31

The results of the Impulse – Response method were confirmed by concrete cores that were cut off


2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

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THANK YOU