Quality Control of Sidewalk Pavements Based on Total Station Surveys

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Key words: quality control, pavements, total station

SUMMARY

The 3-D geometrical characteristics of sidewalk pavements covered by concrete plates were defined using a total station and a comparison between two representative road sidewalks of high and poor quality of material and craftsmanship, respectively. Instrument and a small reflector was placed at the four corners of sampled rectangular sidewalk plates, in order to define standard for their geometric quality control.

Collected data, representing coordinates of the four corners of all concrete plates, 0.5m times 0.5m wide, were measured with a small plastic reflector and were processed to estimate (1) dimensions of plates; (2) rotation of plates relative to sidewalk axis; (3) titling of plates relative to the longitudinal and transverse axes of sidewalks; (5) horizontal and vertical offsets between plates.

The average values and standard errors of all these variables estimated for the selected high quality sidewalk defined by visual inspection were used to define high quality standards, and the deviations from these standard values for the low quality sidewalk were computed and plotted in graphs permitting an easy identification and presentation of even small (for instance 0.5-1^{o}) deviations from the defined standard values.

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1. INTRODUCTION

In modern cities and villages sidewalks and pedestrian routes are usually covered by pavements, the aim of which is to offer easy, comfortable and secure circulation to pedestrians but also offer protection to underground utility networks, etc.
Although construction of pavements requires simple techniques, problems are not missing, both after a long period of use of the pavements, or just after their construction: For instance, hollows which are transformed to small pools, dangerous for dirtying cloths but also delaying the circulation of pedestrians, or even transformed to slippery traps in case of freezing temperatures, pavements with wrong inclination not permitting the flow of rainwater, slippery pavements and paving plates with vertical offsets along adjacent plates, and even unevenly spaced plates which may cause accidents, are not unusual cases in most countries and areas.

On the other hand, construction and restoration of defective pavements is an expensive project producing much nuisance to the public (traffic problems, noise, economic cost etc.). For these reasons the quality control of pavements, aiming at their functionality, durability and aesthetics is necessary.

In this article we explain how a simple analytical study of recordings of modern total stations instruments can permit an assessment of the quality of pavements made of plates at least a few tens of cm wide, as far as their geometric characteristics are concerned, and how it can be used to define specification for their construction.

Our work was based on a pilot field survey and study of two different pavements, one apparently of high, and another of low quality. An analysis of the data collected led us to understand from a quantitative point of view, which are the specifications that may permit to distinguish between a good and a low quality construction.

2. SAMPLED PAVEMENTS

Two samples of pavements, representative of low and high quality geometry structures were selected and studied. Both pavements were of reinforced concrete with sheathing of quadrangular plates.

The “low quality” pavement is located in the area of St. Dionysios in the city of Patras. It is 12.5m long and 1.5m wide approximately, covered by quadrangular plates (3 plates vertical to the sidewalks axis and 25 plates along the sidewalks axis) as shown in Fig. 1. The presence of wrong inclinations of some plates could be easily noticed. These inclinations were getting worse because of the presence of two trees, the roots of which have contributed in the uplift of the surrounding plates. This pavement is representative of the conditions of most pavements in the city of Patras.

Fig. 1: The Low Quality Pavement that was chosen for the Analysis. Tilting of the Plates, Occasionally Caused by Roots of Trees are Evident.

Fig. 2: Photo of the High Quality Pavement. There is no Evidence Significant Tilting or Rotation of the Plates.

The selected "high quality" pavement is located in the area of Patras University Campus, and it was recently constructed. The dimensions of the "high quality" pavement were 7.5m long and 4.5m wide (Fig. 2).

3. FIELD MEASUREMENTS

The coordinates x_i, y_i, z_i of each one of the corners i of the plates on the “low” and “high quality” pavement were measured (Fig. 3) using a total station (NIKON DTM 310) and a small reflector relative to a coordinate system the x-axis of which was the long axis of the study pavement and z-axis the vertical.
The coordinates of 69 plates corresponding to 276 points (69×4) were measured for the “low quality” pavement and of 45 plates corresponding to 180 points (45×4) for the “high quality” pavement.

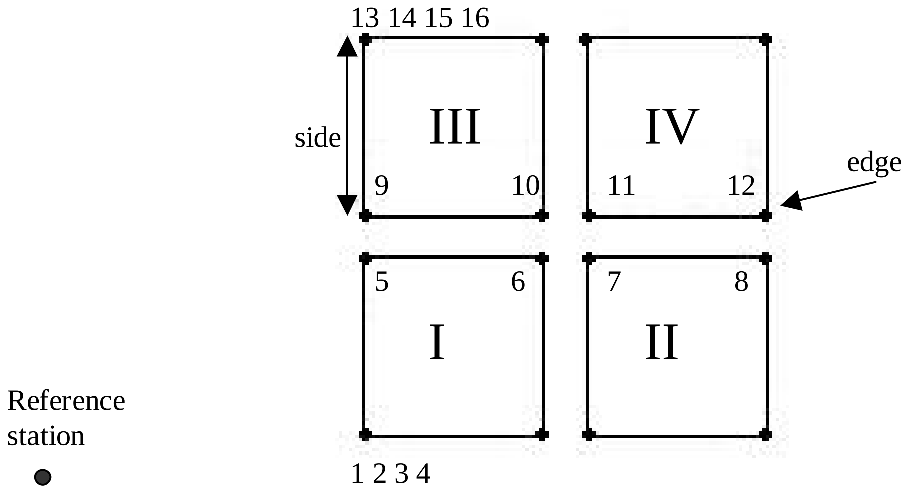

Fig. 3: Principle of measurement of the coordinates of each corner of the plate. Using a total station placed on an arbitrary reference station (solid dot) and pointing to the corner i of the plate, where a reflector was placed, the coordinates x_i, y_i, z_i of the corner i were recorded.

4. METHODOLOGY FOR DATA ANALYSIS

At a first step planes were analytically fitted to the two sidewalks, and the measured coordinates were transformed to the new system using conventional techniques (Bonford, 1971). Obviously, horizontal coordinates remained practically the same, while the initial vertical coordinates were equal to the residuals of the plane fitting. Collected data were subsequently processed to obtain average direction and inclination of sidewalks, and the following variables, determining the geometrical quality of the projects were computed: (1) horizontal and vertical offsets between plates; (2) dimensions of plates; (3) width of joints (4) rotation of plates relative to sidewalk axis; (5) inclination of plates relative to the longitudinal and transverse axes of sidewalks.

4.1 Plane Fitting

The surface of every pavement was approximated by a plane using the least-squares method. The equation that represents a plane is $z = Ax + By + C$ where x, y, z are the coordinates of the edges of the plates (see fig. 3) and A, B, C are coefficients of each of the two study pavements.

4.2 Cleaning Data for Outliers

In order to check the possibility of the presence of outliers, the residuals $z_r = z_{calculated} - z_{measured}$ were examined. Particularly it was checked wether the values of the residuals were or not between the boundaries $\bar{z}_r \pm 3\sigma$ (Bonford, 1971) where $\bar{z}_r$ is mean value and σ is the standard deviation of the residuals.

4.3 Dimensions of the Plates

The dimensions of every side of the plates of the two pavements that were analyzed, were calculated using the formula (Bonford, 1971)

$$L_{i\to i+1} = \sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2 + (z_i - z_{i+1})^2} \qquad \text{(eq.1)}$$

where

$L_{i\to i+1}$ dimension of the side of the plate between adjacent edges (see fig. 3)

x_i, y_i, z_i the coordinates of the edge i

The calculated dimensions of the sides of the plates were then classified in four classes (0.48m; 0.49m; 0.50m; 0.51m). The percentage of the sides of the plate in each class was then calculated and plotted in a histogram.

4.4 Width of the Joints

In good quality pavements, the width of the joints between two adjacent plates (e.g. I and II in Fig. 3) is nearly constant, and this yields the relationship

$$w_h = \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2} = \sqrt{(x_6 - x_7)^2 + (y_6 - y_7)^2} \qquad \text{(eq.2)}$$

In "low quality" pavements, on the contrary, because of the rotation of the plates along the vertical axis, the width of the joints is variable along two adjacent edges. For this reason a mean value of the width of the joints between adjacent plates was computed:

$$w_l = \frac{\sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2} + \sqrt{(x_6 - x_7)^2 + (y_6 - y_7)^2}}{2} \qquad \text{(eq.3)}$$

4.5 Rotations

The rotation of the plates of the "low" and "high quality" pavement was computed around the three axes X, Y, Z.

4.5.1 Rotation of the Plates Along a Vertical Axis

The rotation of the plates along a vertical axis was computed using the notation of fig. 3 and the formula

$$\tan \omega_X = \frac{y_1 - y_2}{x_1 - x_2} \quad \text{(eq.4)}$$

4.5.2 Tilting

The tilting of the plates is referred to the plane best fitting to the data to the data (see above, paragraph 4.1). The angle φ between the mean plane and the plate is given by

$$\tan \varphi = \frac{a_2 - a_1}{1 + a_2 \times a_1}$$

where

a_1 inclination A of the mean plane along the transverse axis of sidewalks (X axis)

a_2 inclination of the plate along the transverse axis of sidewalks (X axis) given by the formula (referring to the plate I in fig. 3)

$$a_2 = \frac{(z_1 - z_2) + (z_5 - z_6)}{(x_1 - x_2) + (x_5 - x_6)}$$

and

a_1 inclination B of the mean plane along the longitudinal axis of sidewalks (Y axis)

a_2 inclination of the plate along the longitudinal axis of sidewalks (Y axis) given by the formula (for the plate I in fig. 3)

$$a_2 = \frac{(z_1 - z_2) + (z_5 - z_6)}{(y_1 - y_2) + (y_5 - y_6)}$$

In the calculation of the parameter a_2 mean differences are used for the z as well as for the x and y coordinates in order to reduce possible errors during the measuring process.

5. RESULTS

5.1 Plane Fitting

The coefficients A, B and C of the equation z = Ax + By + C were calculated using the least-squares method. In Table 1 are presented the values of A, B, C and the correlation coefficients R for the “low” and the “high quality” pavements.

Table 1: Equations of the Fitted Plane to the Pavements Examined and Correlation Coefficients

Type of pavement	Equation of the fitted plane	Correlation coefficient R
Low quality pavement	z' = 0.0171x – 0.03401y + 1016.981	0.990
High quality pavement	z' = -0.016x – 0.021987y + 1038.2327	0.994

The fit is excellent due to the high redundancy of the system and the small deviations from the plane.

5.2 Cleaning Data for Outliers

The outlier analysis was applied to the values of the residuals of the measured coordinate z of the plates minus the corresponding calculated coordinate z' of section 4.1 for both the "high" and the "low quality" pavement.

Fig. 4 shows the plot of the residuals $z_{calculated} - z_{measured}$ for the "low quality" pavement. All values were between the boundaries $\bar{z}_r \pm 3\sigma$ where $\bar{z}_r$ = -6.485×10^{-4} and σ = 0.01344. This results that there were no outliers in the data of the "low quality" pavement and that all the available data could be used in the analysis.
Fig. 5 refers to the residuals $z_{calculated} - z_{measured}$ of the "high quality" pavement. In this case the values of $\bar{z}_r$ and σ were equal to 4.44×10^{-5} and 4.937×10^{-4} respectively. Only one point was outside the boundaries $\bar{z}_r \pm 3\sigma$ and it was excluded from the data referring to the "high quality" pavement in the further analysis.

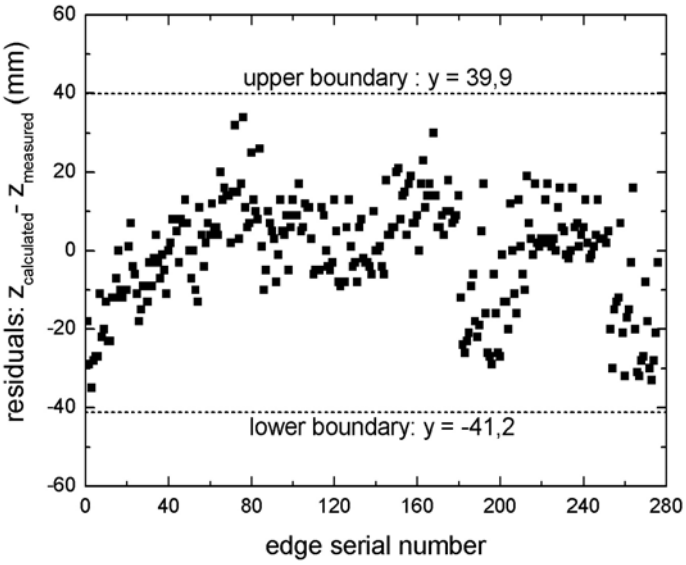

Fig. 4: Low quality pavement: scatter plot of the residuals $z_{calculated}$ - $z_{measured}$. The boundaries defined by the formula $\bar{z}_r \pm 3\sigma$ enclose the values of the residuals indicating that there are no outliers in our data.

5.3 Dimensions of the Plates

The dimensions of the sides of the plates for both pavements were calculated using the formula of (eq. 1). The results are plotted in the histogram of Fig. 6 showing the percentage of deviations of the plates from their ideal dimensions (0.50X0.50m). As expected, the deviation is much higher in the low-quality pavement.

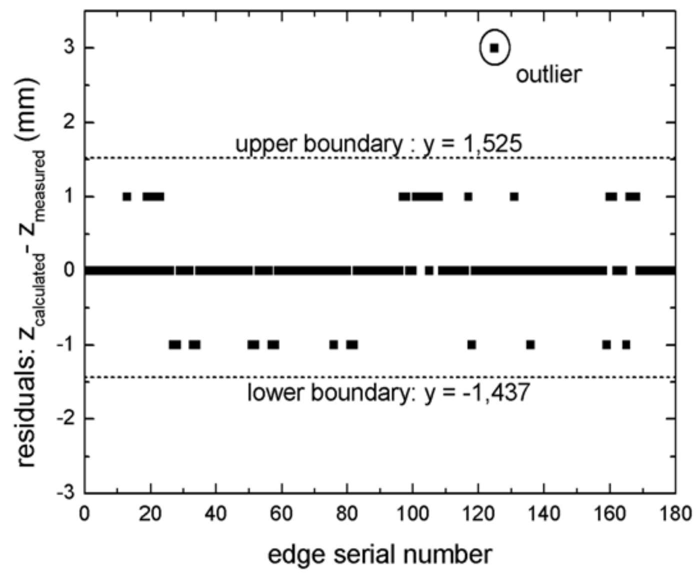

Fig. 5: High quality pavement: scatter plot of the residuals $z_{calculated}$ - $z_{measured}$. The boundaries defined by the formula $\bar{z}_r \pm 3\sigma$ enclose the values of the residuals except one. This value was not included in the further analysis.

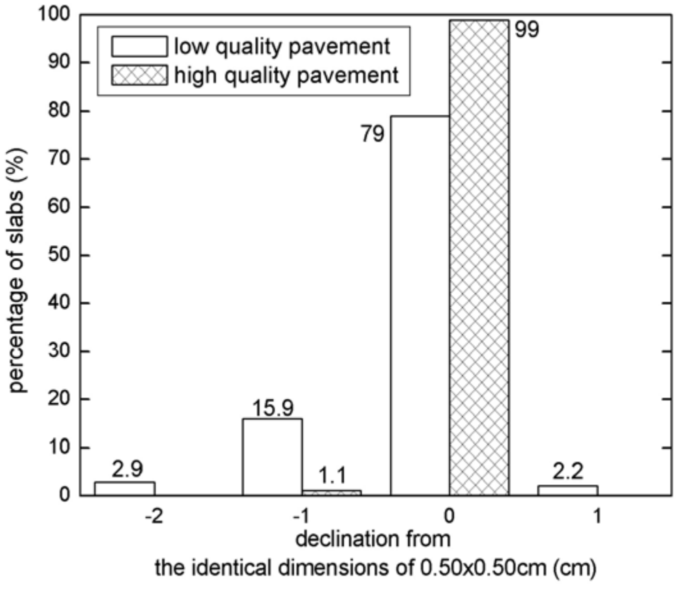

Fig. 6: Percentage of plates with side dimensions 0.48cm, 0.49cm, 0.50cm and 0.51cm. Only the 79% of the plates of the low quality pavement have the ideal dimensions of 0.50cm and the rest 21% differs by 1 or 2 cm, while in the high quality pavement 99% of the plates are equal to their ideal value.

5.4 Width of the Joints

The distribution of the width of the joints for the "low quality" pavement is shown in fig. 7. Because of the rotations of the plates the width of the joints was very variable, in contrast to the nearly constant width of the "high quality" pavement (fig. 8).

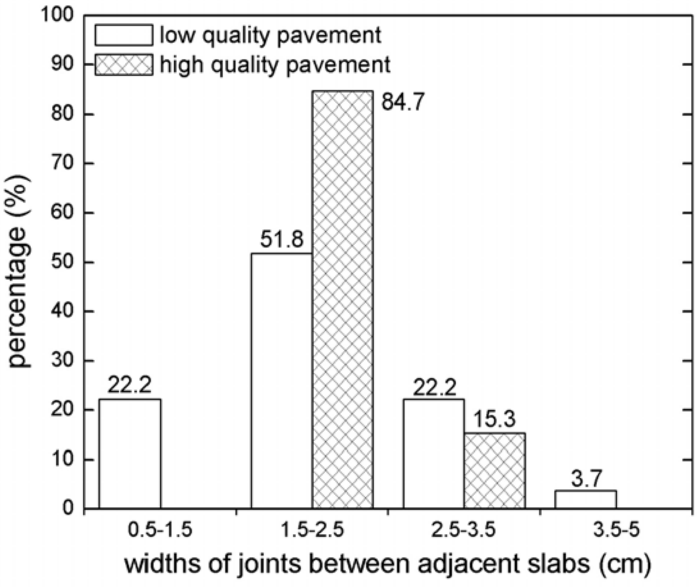

Fig. 7: Frequency distribution of the joint width in the two pavements; those of the high quality have a smaller spread.

5.5 Rotations

Fig. 8 shows the rotation of the plates for the "low" and the "high quality" pavement along a vertical axis. It is evident that the plates of the "low quality" pavement deviate from the mean plane due to rotations along a vertical axis in the range of 0^o to 2.3^o. In the "high quality" pavement, on the contrary, only one or two cases of slightly rotated plates (maximum 0.5^o) were indentified.

As far as tilting of the plates is concerned, in the "low quality" pavement, rotation of plates in the range of -3^o to 1^o along the longitudinal axis Y of sidewalk and in the range of -2^o to 3^o along the transverse axis X of sidewalk were identified. On contrary, occasional, slight tilting (0^o – 0.1^o) was found for the plates of the high quality pavement, X and Y (fig. 9a, 9b).
An indicative, 3-D view of the rotations of a part of the "low quality" pavement, relative to the best fitting mean plane is shown in Fig. 10. No comparison figure for the plates of the "high quality" pavement is presented because of the very small value of their rotations.

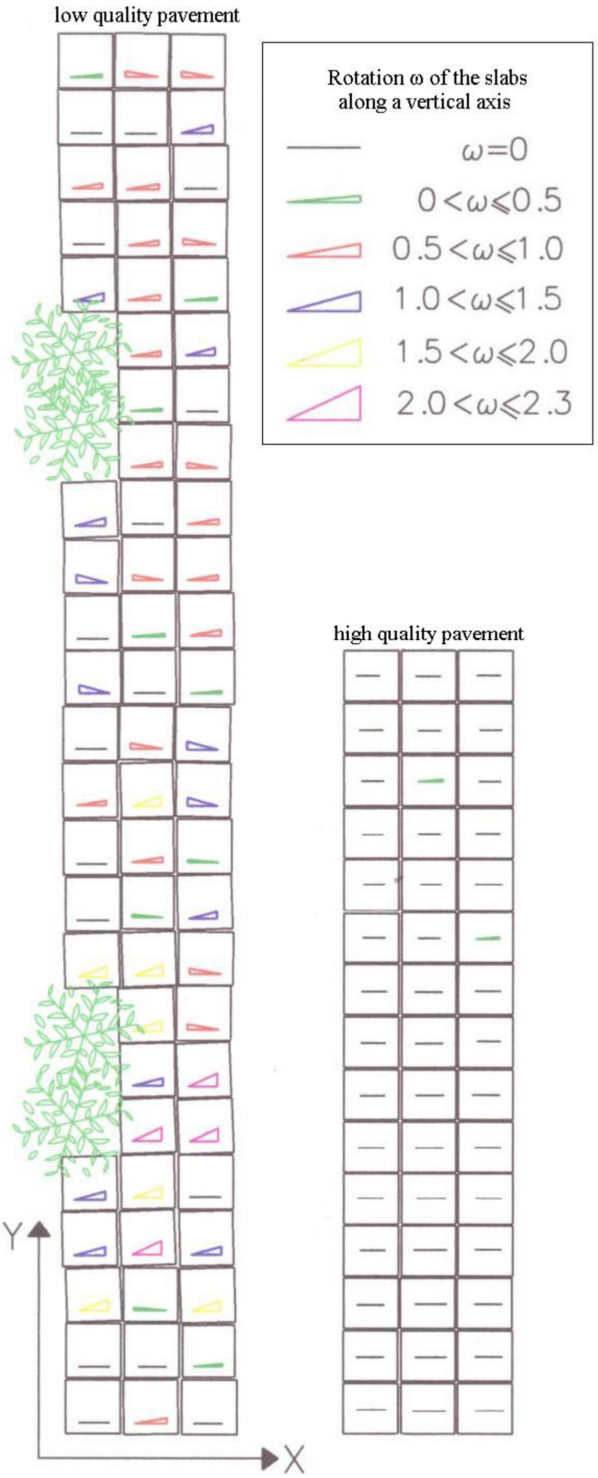

Fig. 8: Rotation of the plates for the "low" and the "high quality" pavement along a vertical axis. The majority of the plates in the low quality pavement are rotated by up to 2.3°, while in the high quality pavement, only two plates with a maximum rotation of 0.5° were noticed.

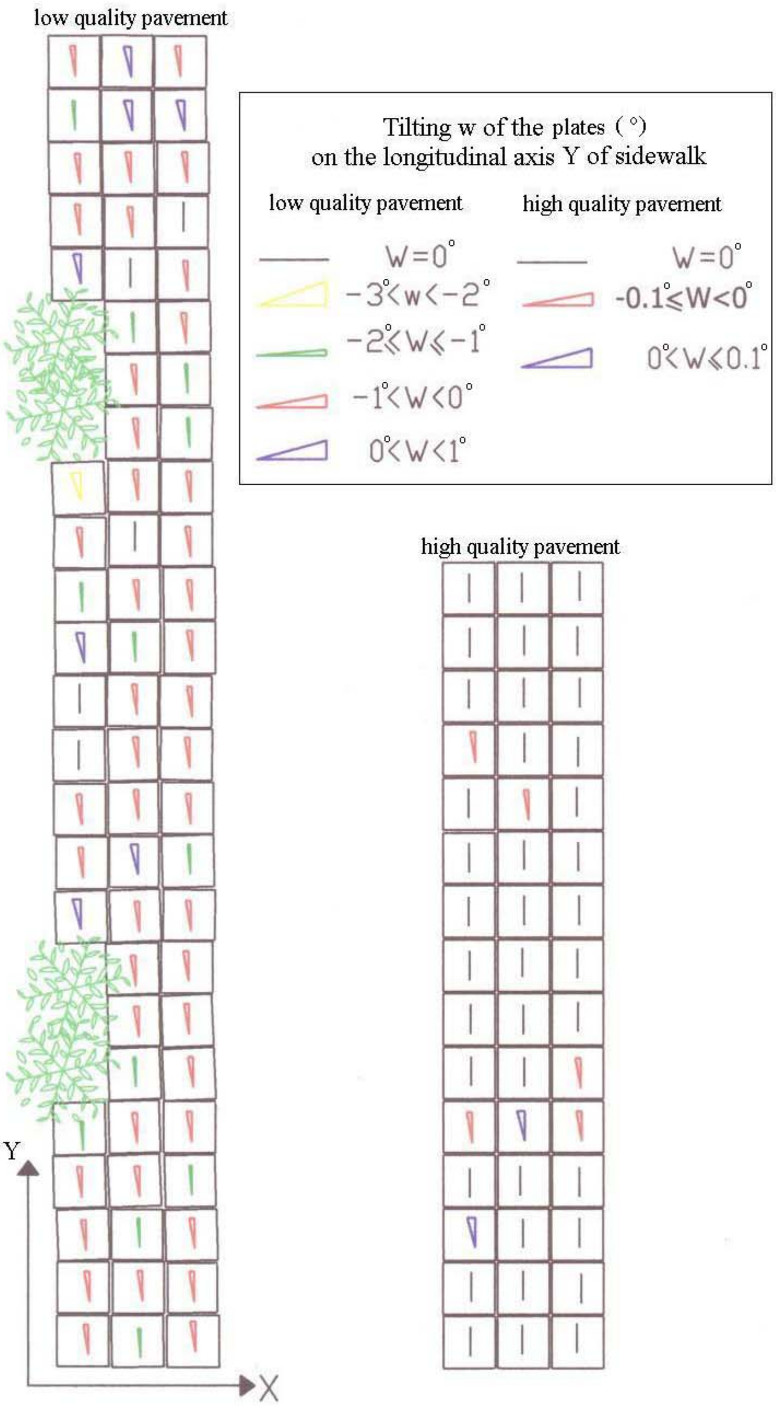

Fig. 9a: Tilting of plates of the "low" and "high quality" pavements along the longitudinal axis of sidewalk. Almost all plates of the low quality pavement are significantly tilted, in contrast to the plates of the high quality pavement which practically coincide with the mean plane.

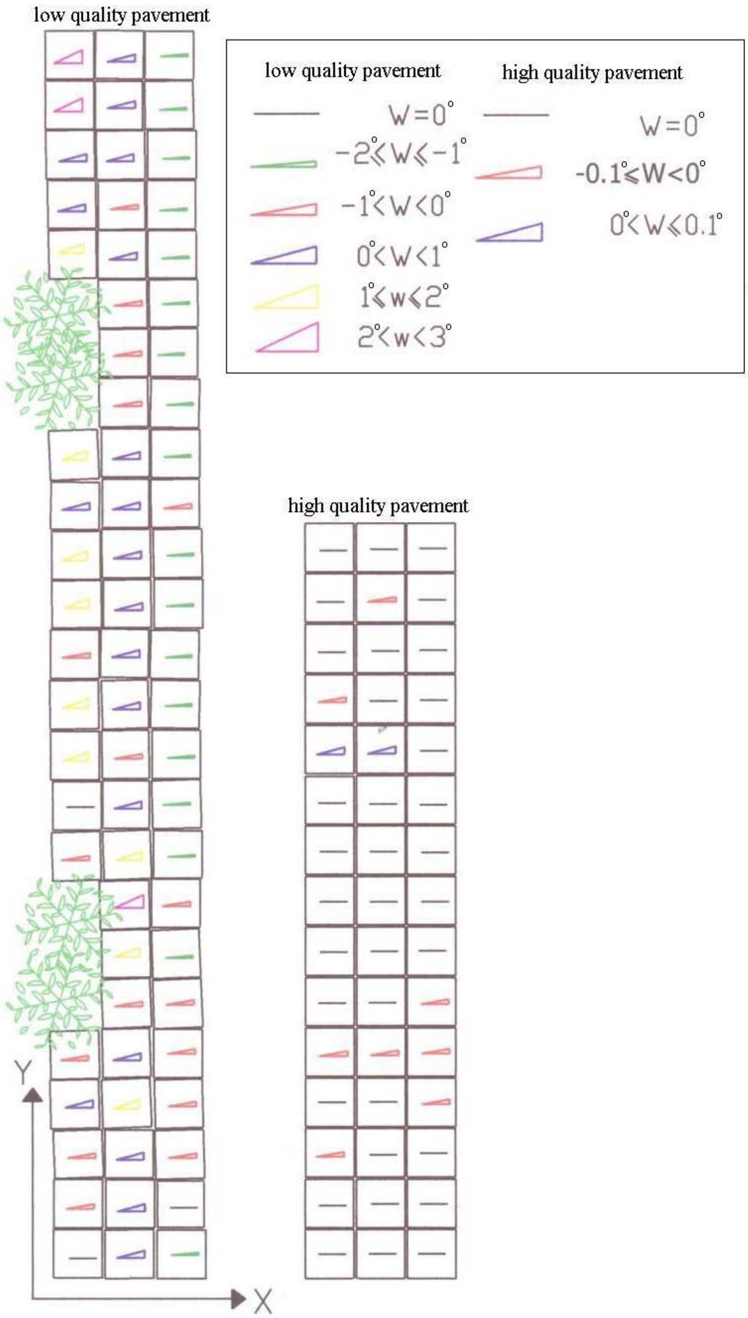

Fig. 9b: Tilting of plates of the "low" and "high quality" pavements along the transverse axis of sidewalk. Almost all plates of the low quality pavement are significantly tilted, in contrast to the plates of the high quality pavement which practically coincide with the mean plane.

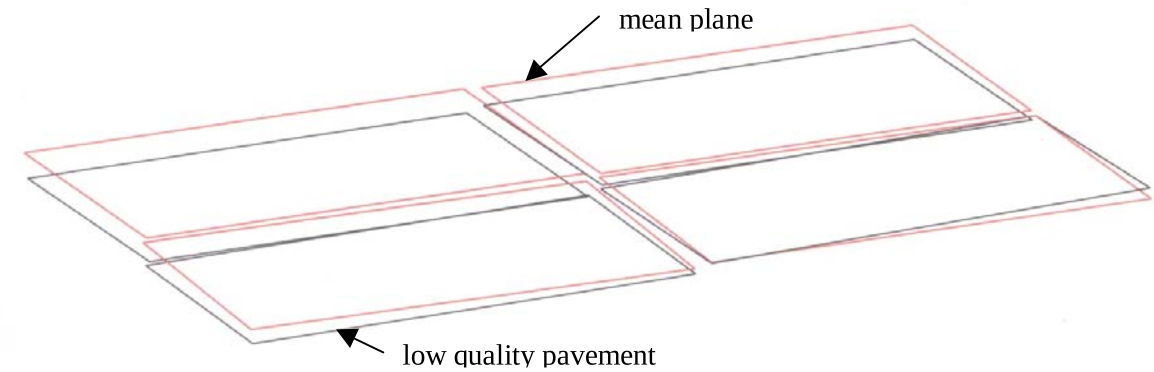

Fig. 10: 3-D sketch showing the diversion of plates from the plane best fitting to the pavement. The higher the quality of construction, diversion is smaller.

6. DISCUSSION

The analysis of the coordinates x, y, z of the four edges of 69 and 45 plates on a "low" and a "high quality" pavement respectively indicated that there are significant differences in several structural characteristics among the two types of pavements.
According to the construction instructions of Hellenic Ministry of the Environment Physical Planning & Public Works for paving, the inclination of a pavement along the longitudinal axis of sidewalk (Y axis), should be maximum 12% while along the transverse axis of sidewalk (X axis) the respective percentage is 4% (Law for basic Urban Design by Hellenic Ministry of the Environment Physical Planning & Public Works). Both "low quality" and "high quality" pavements satisfy the above specifications (max values observed 3.4% and 2.2% along the longitudinal axis of sidewalk and 1.7% and 1.6% along the transverse axis respectively).

The range of the dimensions of the sides of the plates on the "low quality" pavement is 0.48 to 0.51m with the ideal dimension of 0.50m covering about 79% of the total number of the examined plates. The percentage of the plates with ideal dimensions for the "high quality" pavement is much higher, 98.9%.
The width of the joints varies between 0.78 and 4.32 cm for the "low quality" pavement and 1.7 to 3 cm for the "high quality" pavement.
The rotation of the plates along a vertical axis are between 0^{o} and 2.3^{o} and 0^{o} and 0.5^{o} for the "low" and the "high quality" pavement respectively.

The angle between each plate and the mean plane on the transverse axis of sidewalks (X axis) varies in the range of -1.66^{o} to 2.24^{o} on the "low quality" pavement and -0.1^{o} to 0.06^{o} on the "high quality" pavement. The corresponding angles on the longitudinal axis of sidewalks (Y axis) lie between the values -2.94^{o} to 0.29^{o} ("low quality" pavement) and -0.06^{o} to 0.10^{o} ("high quality" pavement).

6. CONCLUSIONS

This study revealed that the results from the comparison between a high and a low quality pavement permits to distinguish from a quantitative point of view between a "high quality" and a "low quality" pavement (Table 2), and even present, possibly for the first time in Greece, geometric quality standards for pavements. The latter can be based on the results of our analysis of the sample pavement classified as of "high quality" by visual inspection.

In particular, it was shown that for the study pavements, the specifications of Table 3 can be defined.

Table 2: Results of the Quality Control Study of the Two Pavements

		Low Quality Pavement	**High Quality Pavement**
Percentage of the plates that have the identical dimensions 0.50×0.50m		79%	99%
Width of the joint between adjacent plates		0.78 – 4.32cm	1.7 – 3.0cm
Rotation/tilting	**X-Y**	$0 - 2.3^{o}$	$0 - 0.5^{o}$
	X-Z	-1.66 to 2.24^{o}	-0.1 to 0.06^{o}
	Y-Z	-2.94 to 0.29^{o}	-0.06 to 0.10^{o}

Table 3: Specifications for high Quality Pavements

Dimensions of the plates	0.499 ± 0.001 m
Percentage of the plates that have equal (ideal) dimensions	99%
Width of joints	2.110 ± 0.311 cm
Maximum rotation of the plates along a vertical axis	$0^{o} \pm 0.25^{o}$
Maximum tilting of the plates along the longitudinal axis of sidewalk (referring to the mean plane)	$0^{o} \pm 0.03^{o}$
Maximum tilting of the plates along the transverse axis of sidewalk (referring to the mean plane)	$0^{o} \pm 0.05^{o}$

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BIOGRAPHICAL NOTES

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