Third International Workshop on Concrete Block Paving, Cartagena de Indias, Colombia, May 10-13, 1998
Tercer Taller Internacional de Pavimentación con Adoquines de Concreto, Cartagena de Indias, Colombia, Mayo 10-13, 1998

AN EXAMINATION OF THE APPLICATION OF CONCRETE BLOCK PAVEMENTS TO HEAVY - ROAD FIELDS [1] [2]

Akihiko KARASAWA
Central Research Laboratory
CHICHIBU ONODA CEMENT CORPORATION
Kumagaya, Japan

Shigetoshi SEKINE

CHICHIBU ONODA CEMENT CORPORATION
Kumagaya, Japan

Mamoru KAGATA

KAJIMA ROAD CO., LTD.
Tokyo, Japan

Shigeo HIGASHI

KAJIMA ROAD CO., LTD.
Tokyo, Japan

1. INTRODUCTION

About twenty years have elapsed since the introduction of the concrete block pavement in Japan, and the area of about 8,2 million m^2 has been developed by this method by 1995, since this method is excellent for the view and durability of the pavement including excellent follow-up and maintenance toward uneven settlement. This method finds its application in the light traffics such as public place park, walking road and strolling road, which accounts for 80 % of its use. Recently, however, this method is expanding its use year by year for a car road pavement of traffic level A and B, and the future development as expected in such pavement of traffic level C and D as airport, harbor bay, and industrial yards where a heavy load work. Different from other pavement, the concrete block pavement is a pavement in which there is a layer of bedding course sand between the base and pavement material and individual segments are combined and the jointing sand is filled to constraining each block, leading thereby to a load-dispersion. Accordingly, when a heavy load works, the jointing sand, bedding course sand and the base are important factors which are involved in the durability of the pavement. In spite of their significance, their functions and required conditions have not yet been elucidated.

The purpose of the series of study of the writer of this paper, including the contents of this paper, is to clarify the functions of the base structure, bedding course sand and jointing sand and the conditions required of them, and use them as the basic material of the design of concrete block pavement under a heavy load.

We examined the jointing sand and various types of the base structure under a heavy load with a load simulator which can evaluate pavement under a condition similar to the actual car load condition, on the basis of the result of examination of the base structure, bedding course sand and jointing sand under an indoor static load condition.

2. RESULT OF THE PAST STUDY

As the result of the past study, we concluded that it is important for higher load-dispersing effect of the concrete block pavement and restriction of functional breakage and higher durability the stiffness (deflection) of the base structure, thickness of the bedding course sand layer, and quality and working condition of the bedding course sand and jointing sand should be combined most properly. Under the indoor test condition up to now, we have concluded that the thickness of the bedding course sand layer should be minimized as long as working is possible (about 20 mm) and sand containing less silt should be used as the bedding course sand and jointing sand.

3. EVALUATION OF JOINTING SAND AND VARIOUS BASE STRUCTURES UNDER A MOVING LOAD

The above described study was only an indoor study. Since the static load is applied repeatedly, uniformly and in a circular pattern to a fixed point and the paved area is only 2 m x 2 m, it is different in many points from the load of actually running cars. Then, as the next step, we evaluated the jointing sand and various base structures under a moving

1 The editors used the International System of Units (SI) in this book of Proceedings, and the comma ", " as the Decimal Marker. Each paper is presented first in English and then in Spanish, with the Tables and Figures, in both languages, placed in between.

2 This is the original version of this paper.

load near the full-scale, supposing the run of actual cars.

3.1 OUTLINE OF THE TEST

3.1.1 TESTING EQUIPMENT

We performed the test with a load simulator shown in Photo 1. The specifications of this equipment are shown in Table 1. It can evaluate the behavior of various types of pavement under a moving load and a condition similar to the actual running condition of cars. Since this equipment is installed outside, the climate conditions such as temperature, humidity, amount of rainfall, etc., depend on the time when the test is used.

3.1.2 BASE STRUCTURE

We used blocks of Uni-system-N type (222 mm long, 109,5 mm wide, 100 mm thick) in this study, and applied the settlement-pattern of stretcher bond shown in Figure 2. We settled the blocks so that the tires will run in the lengthwise direction of the blocks, different from the common settlement, so that the behavior of the blocks against the load would be indicated clearly.

We used the three types of the upper base structure shown in Table 2, similarly to the static load test in the room. We did not employ a base structure of material stabilized with bitumen this time, since the blocks may be settled locally or creep may occur when cars run slowly or stopped on the concrete block pavement at high temperature in summer.

Since the design method of concrete block pavement of traffic levels C and D had not been established yet, we determined the thickness of pavement at each point by the CBR-T_A method for the asphalt pavement of traffic level D.

We tested each pavement structure with and without the jointing sand and set the thickness of the bedding course sand to 20 mm for each pavement structure according to the result of the indoor static load test. From the result of the above test, we used crushed sand of continuous grain size containing less silt.

We embedded earth pressure gauges in the top of the upper base structure, top of the lower base structure and top of the subgrade, and embedded strain gauges in the top of the top and bottom of the upper base structure. We did not embedded a strain gauge in the base structure of granular with a controlled particle size, however.

3.1.3 MOVING LOAD CONDITION

We moved a traversing wheel load of 7 t/double wheel in the range of 400 mm on each side from the center of the pavement (pavement width: 0,8 m), considering the dispersion of the running position of actual cars. We set the running frequency so that it will draw an almost normal distribution curve around the center line. We moved the load 0 ~ 10 000 times without jointing sand. After finishing this tests, we laid the bedding course sand and blocks again and filled them with jointing sand, then moved the load 0 ~ 40 000 times. We set the moving rate of the load to 1 500 times/day. Where, 50 000 runs of a 7 t/double wheel is almost equivalent to the runs of 190 000, five ton wheels. If the total number of five ton wheels of traffic level D in the design period of 10 years is 35 million wheels, the above value is equivalent to the use of about 20 d.

3.1.4 EVALUATION ITEMS AND MEASURING METHOD

We measured the vertical stress and strain under static and dynamic loads after the moving load was applied under the condition described above. We applied the static load by three methods. First, we applied the load with the center of a steel disc 300 mm in diameter matched to the pavement surface just above the earth pressure gauge as shown in Figure 4 (hereinafter, this method will be referred to as the steel-plate-loading method). Second, we applied the load with the center between the double wheel of the load simulator matched to the pavement just above the earth pressure gauge as shown in Figure 5 (hereinafter, this method will be referred to as the both-wheel-loading method). Third, we applied the load with the center of one of the double wheel of the load simulator matched to the pavement just above the earth pressure gauge as shown in Figure 6 (hereinafter, this method will be referred to as the single-wheel-loading method).

As an example of results of the above three static loading tests, the distribution of the vertical stress on the top of the base structure of material stabilized with cement is shown in Figure 7. As the result of these tests, we confirmed that the level and position of the maximum vertical stress depended on the loading method. Then, we applied a multi-layer elastic structure analysis system (ELSA) to analyze the theoretical maximum vertical stress and its position on each pavement structure under the load of each type, the compared them with the measurement result. Since we got the highest relationship between the analysis result and measurement result by the single-wheel-loading method, we determined to evaluate the pavement structure by the values obtained by this method.

We applied the dynamic load by moving the wheel at the speed of 5 km/h under the single-wheel loading condition described above and measured the vertical stress on the top of the upper base structure as time-series data with seven earth pressure gauge (hereinafter, this method will be referred to as the moving load method).

3.2 RESULT OF EXAMINATION OF EFFECTS OF JOINTING SAND

Figure 8 and Figure 9 show the difference of the deflection and supporting force of the pavement surface with and without the jointing sand. The deflection and supporting force of the pavement surface without the jointing sand in these figures were measured after the load was moved 10 000 times, and those of the pavement surface with the jointing sand were measured after the bedding course sand and blocks were laid again with each base structure left as it was, before the moving load was applied. Accordingly, we assumed that the difference caused by the jointing sand, although the compact condition of the bedding course sand was not the same. These figures show that the deflection of the pavement surface is reduced and its supporting force is increased by the jointing sand.

The test with the moving load simulated to the actually running cars back up the result of the indoor static load test that the jointing sand reduces the deflection of the pavement surface and increase its supporting force. Judging from this result, we suppose that the jointing sand constrains individual blocks and increases mutual biting of those blocks and causes continuos competition to disperse the load.

3.3 RESULT OF EVALUATION OF VARIOUS TYPES OF BASE STRUCTURE

3.3.1 PROPERTIES OF ROAD SURFACE

Table 3 shows the maximum rutting depth of the pavement surface filled with the jointing sand measured with a lateral profile meter after 40 000 runs of the load. The maximum rutting depth of the base structure of granular with a controlled particle size is remarkably large, considering the that the number of runs in this test is little for heavy-load pavement.

After 40 000 runs of the load, the blocks of any pavement structure were not chipped or cracked.

3.3.2 LOAD DISPERSING PERFORMANCE

Figure 10, Figure 11 and Figure 12 show the time-series wave form of the vertical stresses sensed by the seven earth pressure gauges embedded at the top of the upper base structure filled with the jointing sand by the moving load method 10 000 runs. In these figures, the load dispersing performance is heightened as the level of the vertical stress is heightened (the wave is heightened) and the load dispersing angle is widened (the wave is widened) and the vertical stress is evened (the height and width of the wave are evened). Considering these matters, the general level of the vertical stress on the base structure of granular with a controlled particle size is lower and the load dispersion angle is wider in some parts than the case of the concrete base structure, but the height and width of the wave are dispersed and the vertical stress is concentrated partially. On the other hand, the height and width of the wave of the concrete base structure are less dispersed, but the level of the vertical stress is higher and the load dispersing angle narrower than the cases of the base structure of granular with a controlled particle size and base structure of material stabilized with cement. The level of the vertical stress on the base structure of material stabilized with cement is lower and the load dispersing angle is wider than the case of the base structure of granular with a controlled particle size, and the vertical stress is not concentrated partially. Accordingly, the load dispersing performance of the base structure of material stabilized with cement and filled with the jointing sand after 10 000 runs of the load is higher than that of the base structure of granular with a controlled particle size and concrete base structure.

3.3.3 DURABILITY OF BASE STRUCTURE

Figure 13, Figure 14 and Figure 15 show the time-series wave forms of the base structures filled with the jointing sand measured by the moving load method after 40 000 runs. We think that the durability of the base structures can be evaluated by comparing these figures with the time-series wave forms after 10 000 runs described above (Figures 10 to 12).

The wave form of the concrete base structure at 10 000 runs is almost the same as that at 40 000 runs. This indicates that there was not a durability problem in the concrete base structure used for the test.

The wave form of the base structure of granular with a controlled particle size at 40 000 runs is dispersed similarly to that at 10 000 runs, and the vertical stress in each wave form is increased. This fact indicates that the base structure of granular with a controlled particle size is deformed and its load dispersing performance is lowered by the moving load. Accordingly, this base structure cannot be applied to heavy-load fields because of the low durability.

Both height and width of the wave form of the base structure of material stabilized with cement at 40 000 runs are increased and the vertical stress is heightened after 10 000 runs. This implies that the load dispersing performance of this base structure is lowered, similarly to the base structure of granular with a controlled particle size. The possible cause of this phenomenon is that the supporting force of the base structure of material stabilized with cement is lowered gradually by cracking, etc. This can be assumed by the following test result, too.

Figure 16 shows the strain of the top of the upper base structure on which the wheel load of 7 ton was applied by the single-wheel load method. While the strain of the concrete base structure changes little as the number of runs of the load is increased, that of the base structure of material stabilized with cement is increases as the number of the runs is increased. Figure 17 shows the vertical stress on the top of the subgrade on which the wheel load of 7 t was applied by the single-wheel load method. While the vertical stress on the concrete base structure and base structure of granular with a controlled particle size changes little after 10 000 runs, that on the base structure of material stabilized with cement is increased as the number of the runs is increased. We further estimated the number of the loading times to fatigue the base structure of material stabilized with cement used for the test by applying the multi-layer elastic structure analysis system (ELSA). As the result, we confirmed that fatigue was increased after the total runs of about 20 000.

Judging from the matters, the supporting force of the base structure of material stabilized with cement used for the test is probably decreased as the number of the runs is increased and this structure has a problem in reliability.

4. CONCLUSION

The matters proved by the test of this time under the moving load simulated to an actually running car are summarized below.

4.1 EFFECTS OF JOINTING SAND

The effects of the jointing sand to reduce the deflection and increase the supporting force of the pavement surface were confirmed.

4.2 BASE STRUCTURE

1. Since the base structure of granular with a controlled particle size has the problems of increase of the rutting depth, increase of the vertical stress on itself and lowering of the load dispersing performance, it cannot be applied to heavy-load concrete block pavement.
2. Although the concrete base structure has the advantages that the rutting depth is not increased easily and the vertical stress on itself and subgrade changes little, its load dispersing performance is lower. Accordingly, if it is used for a long period, the problems of floating of the blocks, shifting of the joints, local settlement, etc., may occur.
3. The base structure of material stabilized with cement is less rutted and its load dispersing performance is higher until the 10 000 runs of the moving load, but its supporting force is lowered relatively quickly.
4. As the result of examination of the properties of the road surface, load dispersing performance and durability of the concrete block pavement as the requirements for its application to heavy-load fields, we found that a base structure which has proper stiffness and high resistance to deformation and reduction of strength is necessary.

5. SUBJECTS FOR THE FUTURE

The following are the subjects for the future determined from the result of the best of this time.

1. We confirmed that the stiffness of the base structure should be at a middle level between the concrete block pavement and base structure of granular with a controlled particle size. Since we could not confirm the optimum stiffness range by the test of this time, however, it needs to be determined in the future.
2. The base structure must maintain proper stiffness for a long period. We must examine the material and structures of the base to satisfy this condition. We also must examine the new materials and methods for items other than the base structure.
3. This time, we determined the thickness of the pavement at each point by the CBR-T_A method for the asphalt pavement of traffic level D. Considering the above examination result of the durability of the base structure, there may be some problems if this design method is applied as it is for heavy-load concrete block pavement. Accordingly, the design method must be examined too, to proceed with examination of various matters.

6. POSTSCRIPT

As the result of the series of study, including the contents of this paper, it was confirmed that the quality, structure, etc., of the base structure, jointing sand and bedding course sand have large effects on the serviceability and durability of the concrete block pavement. Although we could not obtain a clear conclusion on the structure, we found that it was required to combine to above conditions properly to obtain higher serviceability and durability in heavy-load fields.

We will further continue the study to clearly show the conditions of the base structure, jointing sand and bedding course sand required to apply the concrete block pavement to heavy-load fields, and establish an optimum pavement structure or design method.

Wheel load / *Carga de llanta*	When stopped / *Detenida*: 0 ~7 t During travel / *En movimiento*: 0 ~7 t
Wheel traverse / *Desplazamiento lateral*	Lateral direction / *Dirección lateral*: 500 mm
Speed / *Velocidad*	5 km/h, fixed / *fija*
Type of tire / *Tipo de llanta*	Double wheel for large sized car / *Llanta doble para vehículos de gran tamaño*
Pavement scale / *Tamaño del pavimento*	Width / *Ancho*: 4 m; Length / *Largo*: 16 m

Table 1. Specifications of load simulator.
Tabla 1. *Especificaciones del simulador de carga.*

Test No. / *Ensayo No.*		1	2	3	4	5	6
Block *Adoquines de concreto*	Shape / *Forma*	Uni-system-N block (Figure 1) / *Adoquines de concreto N del sistema Uni (Figura 1)*					
	Pattern *Patrón*	Stretcher bond (Figure 2) Lengthwise direction of block is parallel with travel direction of tires *En hileras (Figura 2). El largo (dimensión mayor) en sentido del desplazamiento de las llantas*					
Jointing sand *Arena de sello*		Supplied *Colocada*	Not supplied *No colocada*	Supplied *Colocada*	Not supplied *No colocada*	Supplied *Colocada*	Not supplied *No colocada*
		Crushed sand / *Arena triturada* (FM = 2,84; 75 µm max. 2,4 %)					
Bedding course sand *Capa de arena*	Type / *Tipo*	Crushed sand / *Arena triturada* (FM = 2,84; 75 µm max. 2,4 %)					
	Thickness *Espesor*	20 mm					
Upper base structure *Estructura superior de base*	Type / *Tipo*	Granular with a controlled particle size M-30 Corrected / *Granular con contenido de Tamiz 30 corregido* CBR = 143 %		Stabilized with cement / *Estabilizada con cemento* E = 5 296 MPa Q_{u7} = 3,43 MPa		Concrete / *Concreto* E = 27 459 MPa σc = 39,23 MPa	
	Thickness *Espesor*	400 mm		300 mm		200 mm	
Lower base structure *Estructura inferior de base*	Type / *Tipo*	None		Crusher run (M-30) / *Triturado (M-30)*			
	Thickness *Espesor*	--		100 mm		200 mm	
Subgrade *Subrasante*		Mountain sand / *Arena de montaña* (CBR = 29%)					
Pavement area *Área del pavimento*		Width / *Ancho*: 4 m x Length / *Largo*: 2 m		Width / *Ancho*: 4 m x Length / *Largo*: 4 m		Width / *Ancho*: 4 m x Length / *Largo*: 4 m	
Travel condition *Condiciones de circulación*		Wheel load: 7 t/double wheel, Travel position: Area of 400 mm on each side of center of pavement *Carga de llanta: 7 t/llanta doble, Posición de circulación: 400 mm a cada lado del centro del pavimento*					
Weather condition *Condiciones del clima*		Average temperature / *Temperatura promedio*: 18 °C, Average humidity / *Humedad promedio*: 66 % Total rainfall in test period / *Lluvia total en el período de ensayo*: 77 mm					

Table 2. Test condition.
Tabla 2. *Condiciones de ensayo.*

Granular	5,5 mm	**Stabilized with cement**	2,8 mm	**Concrete**	0,8 mm

Table 3. Maximum rutting of pavement surface.
Tabla 3. *Ahuellamiento máximo de la superficie del pavimento.*

Photo 1. Load simulator.
Foto 1. *Simulador de carga.*

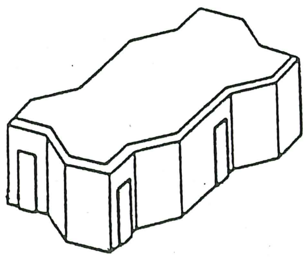


Figure 1. Shape of block (Uni-system-N block).
Figura 1. *Forma de los adoquines (Adoquines de concreto N, Sistema Uni).*

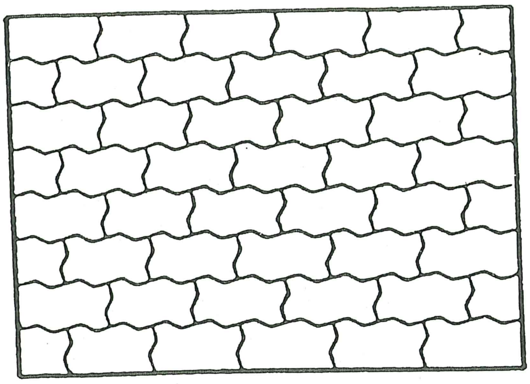
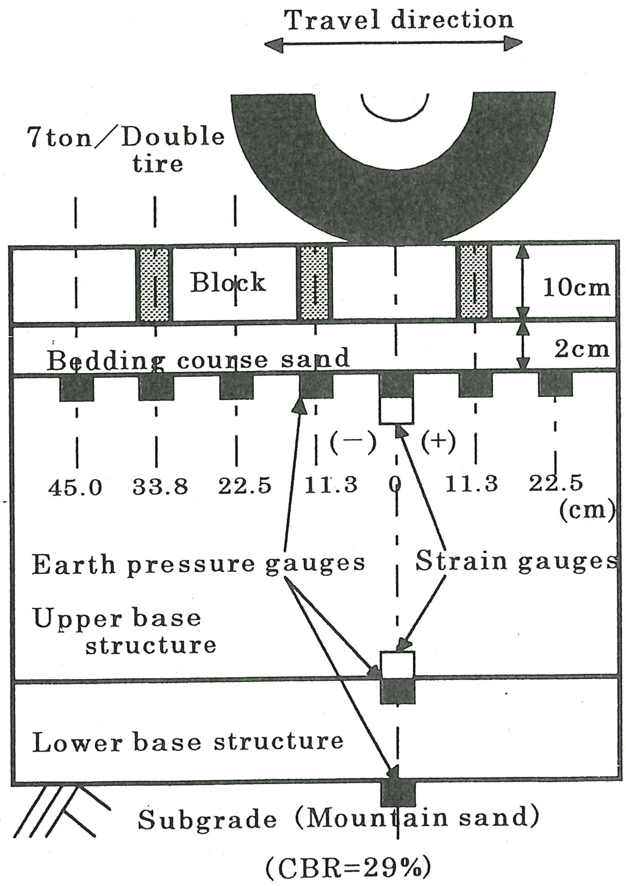
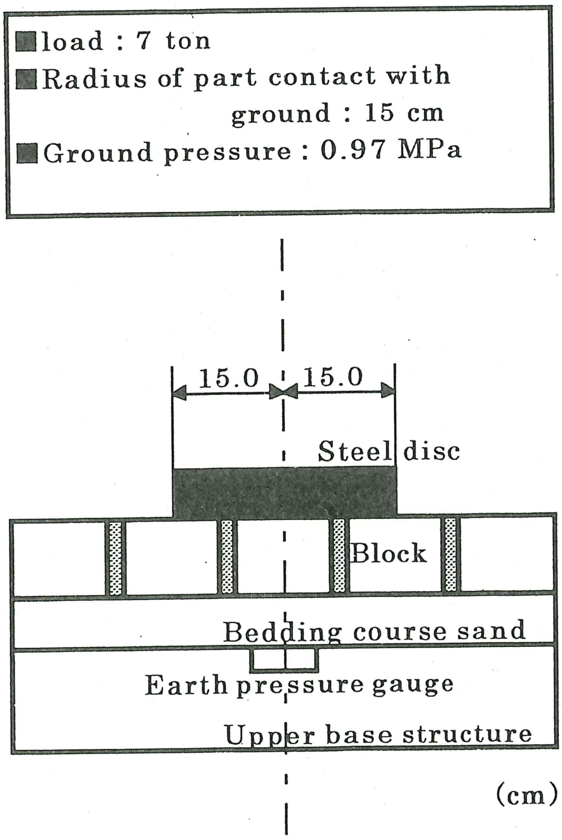


Figure 2. Settlement-pattern - stretcher bond).
Figura 2. *Patrón de colocación - hileras.*



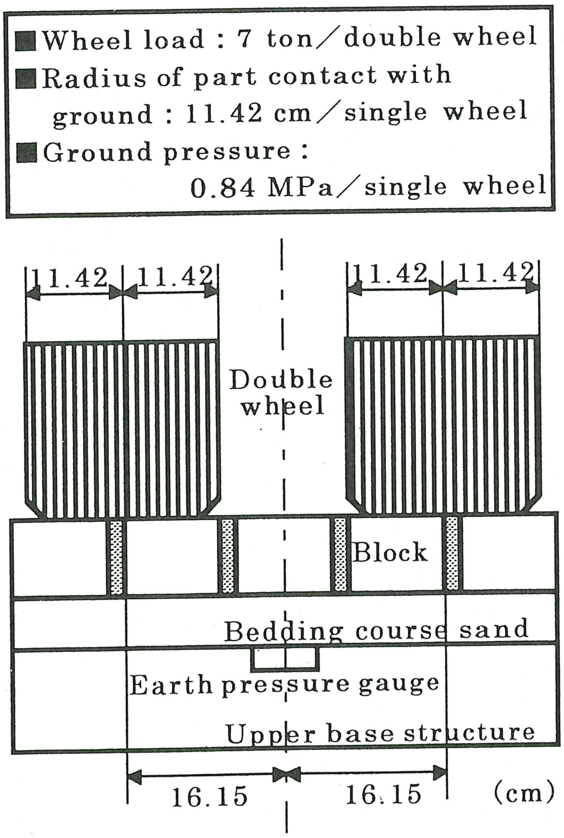
Travel direction / *Dirección de desplazamiento* - Double tire / Llanta doble - Block / *Adoquines de concreto* - Bedding course sand / *Capa de arena* - Earth pressure gauges / *Medidores de presión* (*empuje de tierra*) - Strain gauges / *Medidores de deformación* (*deformímetros*) - Upper base structure / *Capa superior de la base* - Lower base structure / *Capa inferior de la base* - Subgrade (Mountain sand) / *Subrasante (Arena de montaña).*

Figure 3. Arrangement of earth pressure gauges and strain gauges in pavement structure.
Figura 3. *Disposición de los medidores de presión y de deformación en la estructura del pavimento.*



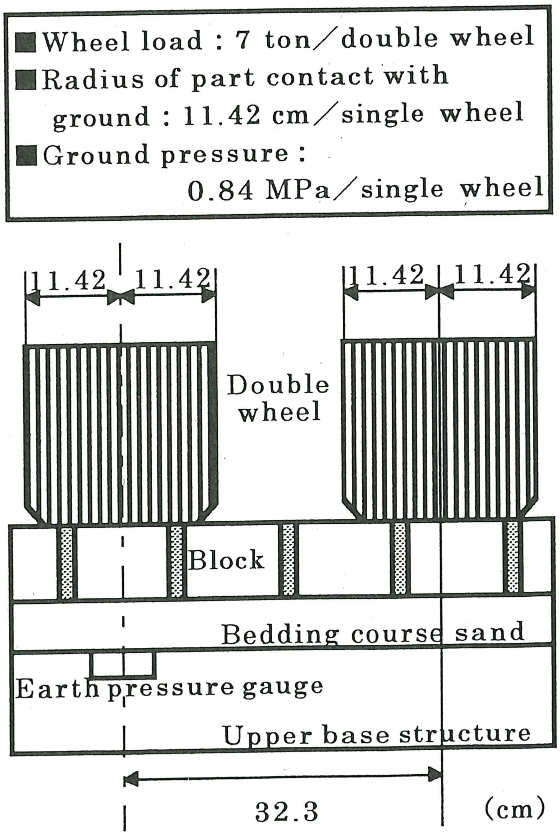
Load / *Carga*: 7 t - Radius of part contact with ground / *Radio del área de contacto con la superficie*: 150 mm - Ground pressure / *Presión bajo la arena*: 0,97 MPa - Steel disc / Disco de acero - Block / *Adoquines de concreto* - Bedding course sand / *Capa de arena* - Earth pressure gauge / *Medidor de presión* - Upper base structure / *Capa superior de la base.*

Figure 4. Measuring method of vertical stress and strain (steel plate loading method).
Figura 4. *Sistema de medición del esfuerzo y la deformación verticales (método de carga sobre disco de acero).*



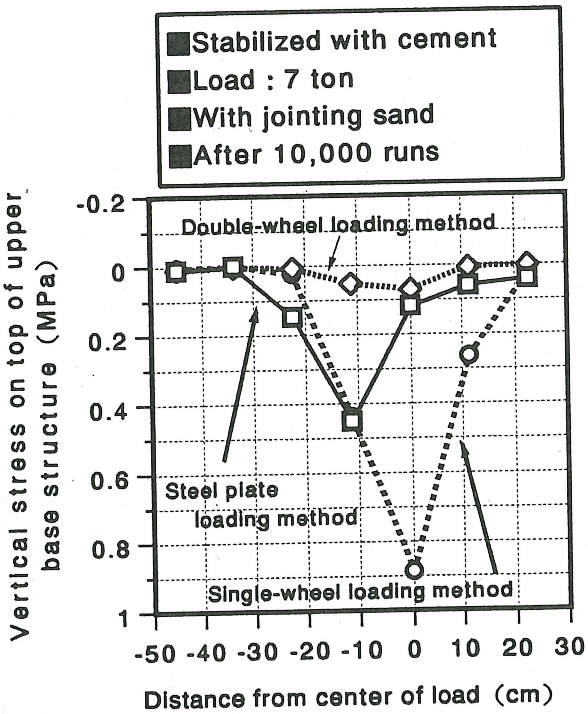
Wheel load / *Carga de llanta*: 7 t/double wheel / 7 t/*llanta doble* - Radius of part contact with ground: 114,2 mm / Single wheel / *Radio del área de contacto con la superficie*: 114,2 mm / *Llanta sencilla* - Ground pressure / *Presión bajo la arena: 0,84 MPa* - Double wheel / *Llanta doble - (ver Figura 4).*

Figure 5. Double-wheel loading method.
Figura 5. *Sistema de carga sobre llanta doble.*



Wheel load / Carga de llanta: 7 t/double wheel / 7 t/llanta doble - Radius of part contact with ground: 114,2 mm / Single wheel / *Radio del área de contacto con la superficie*: 114,2 mm / *Llanta sencilla* - Ground pressure: 0,84 MPa/single wheel / *Presión bajo la arena: 0,84 MPa / Llanta sencilla* - Double wheel / Llanta doble - (ver Figura 4).

Figure 6. Single-wheel loading method.
Figura 6. *Sistema de carga sobre llanta sencilla.*

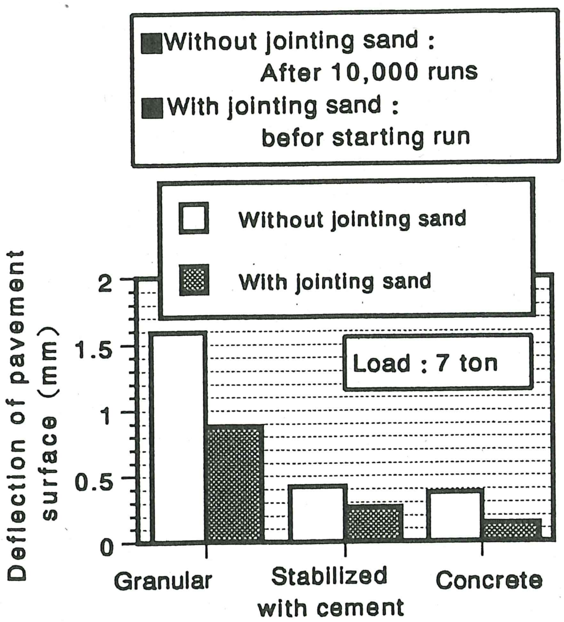


ESFUERZO VERTICL vs DISTANCIA AL CENTRO DE CARGA

Stabilized with cement / *Estabilización con cemento* - Double-Wheel loading method / *Método de carga con llanta doble* - Single-wheel loading method / *Método de carga con llanta sencilla* - Load: 7 t / *Carga: 7t* - With jointing sand / *Con junta llena* - After 10 000 runs / *Después de 10 000 pasadas.*

Figure 7. Distribution of vertical stress on top of upper base structure.

Figura 7. *Distribución de esfuerzos sobre la capa superior de la base.*

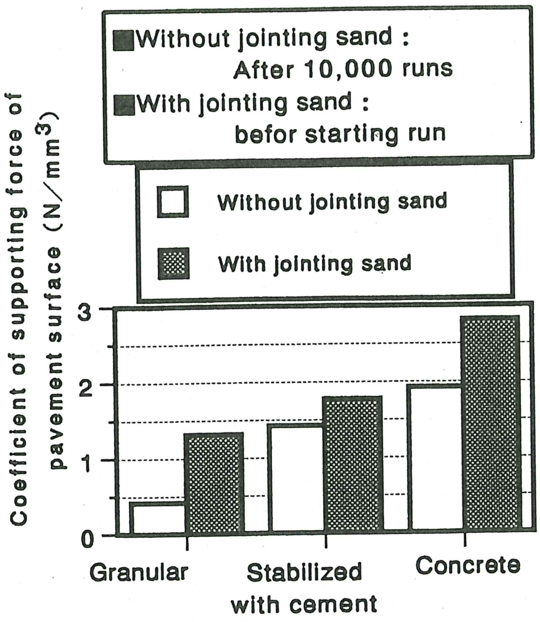


DEFLECCIÓN (mm) vs (GRANULAR - ESTABILIZADA CON CEMENTO - CONCRETO)

Without jointing sand: After 10 000 runs / *Sin arena en la junta: Después de 10 000 pasadas* - With jointing sand: Before starting run / *Con arena en la junta: Antes de comenzar las pasadas* - Load: 7 t / *Carga: 7t.*

Figure 8. Deflection of pavement surface measured with Benkelman beam.

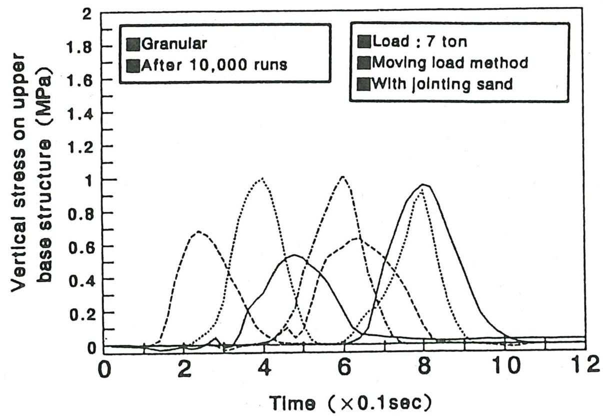
Figura 8. *Deflexión en la superficie del pavimento medida con la viga Benkelman.*



CAPACIDAD DE SOPORTE (N/mm²) vs (GRANULAR - ESTABILIZADA CON CEMENTO - CONCRETO)

Without jointing sand: After 10 000 runs / *Sin arena en la junta: Después de 10 000 pasadas* - With jointing sand: Before starting run / *Con arena en la junta: Antes de comenzar las pasadas.*

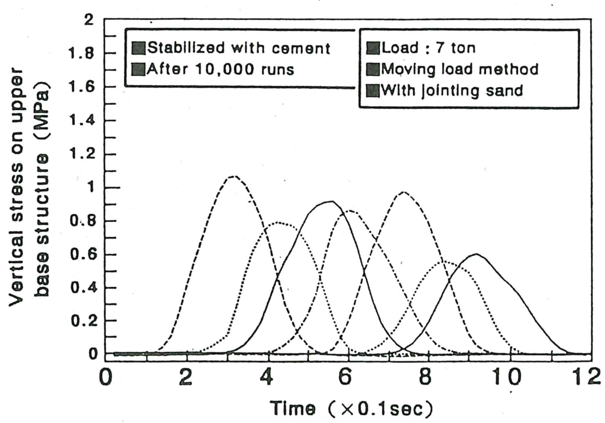
Figure 9. Supporting force of pavement surface measured by plate loading test.
Figura 9. *Capacidad de soporte de la superficie del pavimento medida con el ensayo de placa metálica.*



ESFUERZO VERTICAL SOBRE LA CAPA SUPERIOR DE LA BASE (MPa) vs TIEMPO (x 0,1 s)

Granular / *Granular* - After 10 000 runs / *Después de 10 000 pasadas* - Load: 7 t / *Carga: 7 t* - Moving load method / *Método de la carga* móvil - With joint sand / *Con junta llena de arena.*

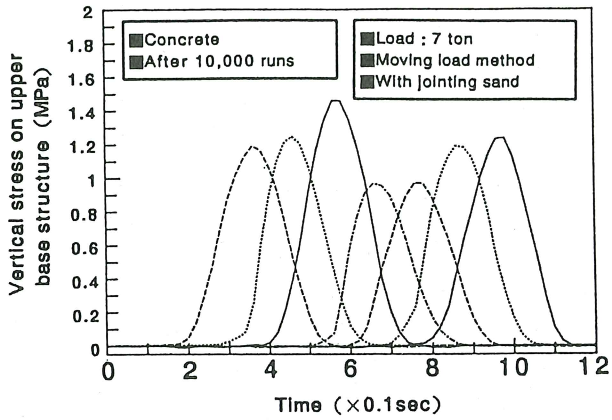
Figure 10. Vertical stress on upper base structure measured by moving load method.
Figura 10. *Esfuerzo vertical de la capa superior de base medida con el método de carga móvil.*



ESFUERZO VERTICAL SOBRE LA CAPA SUPERIOR DE LA BASE (MPa) vs TIEMPO (x 0,1 s)

Stabilized with cement / *Estabilizado con cemento* - After 10 000 runs / *Después de 10 000 pasadas* - Load: 7 t / *Carga: 7 t* - Moving load method / *Método de la carga móvil* - With joint sand / *Con junta llena de arena.*

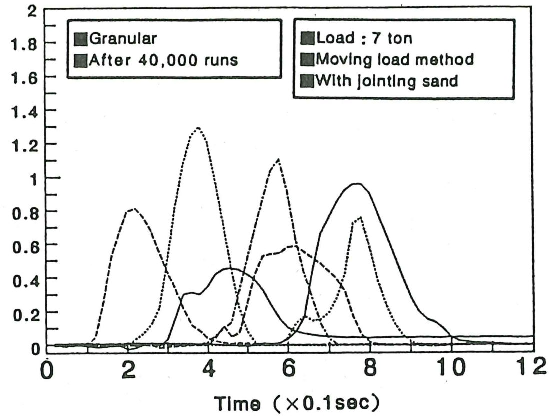
Figure 11. Vertical stress.
Figura 11. *Esfuerzo vertical.*



ESFUERZO VERTICAL SOBRE LA CAPA SUPERIOR DE LA BASE (MPa) vs TIEMPO (x 0,1 s)

Concrete / *Concreto* - After 10 000 runs / *Después de 10 000 pasadas* - Load: 7 t / *Carga: 7 t* - Moving load method / *Método de la carga móvil* - With join sand / *Con junta llena de arena.*

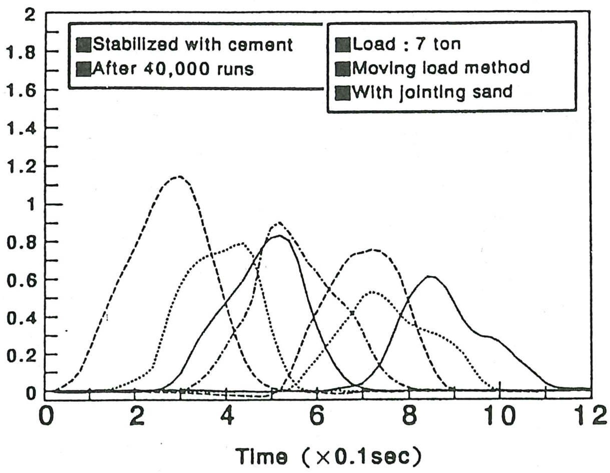
Figure 12. Vertical stress.
Figura 12. *Esfuerzo vertical.*



ESFUERZO VERTICAL SOBRE LA CAPA SUPERIOR DE LA BASE (MPa) vs TIEMPO (x 0,1 s)

Stabilized with cement / *Estabilizado con cemento* - After 40 000 runs / *Después de 40 000 pasadas* - Load: 7 t / *Carga: 7 t* - Moving load method / *Método de la carga móvil* - With joint sand / *Con junta llena de arena.*

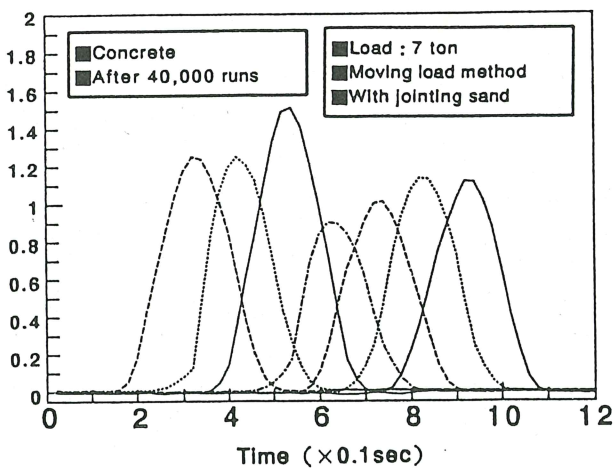
Figure 13. Vertical stress.
Figura 13. *Esfuerzo vertical.*



ESFUERZO VERTICAL SOBRE LA CAPA SUPERIOR DE LA BASE (MPa) vs TIEMPO (x 0,1 s)

Granular / *Granular* - After 40 000 runs / *Después de 40 000 pasadas* - Load: 7 t / *Carga: 7 t* - Moving load method / *Método de la carga móvil* - With joint sand / *Con junta llena de arena.*

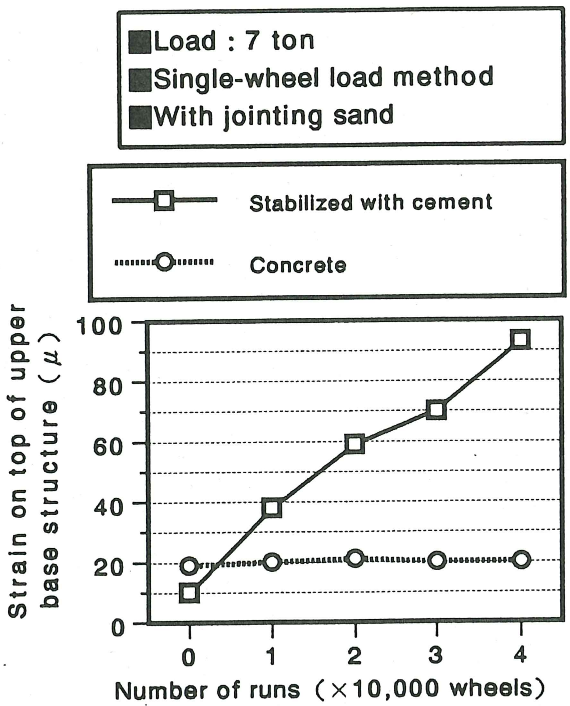
Figure 14. Vertical stress.
Figura 14. *Esfuerzo vertical.*



ESFUERZO VERTICAL SOBRE LA CAPA SUPERIOR DE LA BASE (MPa) vs TIEMPO (x 0,1 s)

Concrete / *Concreto* - After 40 000 runs / *Después de 40 000 pasadas* - Load: 7 t / *Carga: 7 t* - Moving load method / *Método de la carga móvil* - With joint sand / *Con junta llena de arena.*

Figure 15. Vertical stress.
Figura 15. *Esfuerzo vertical.*

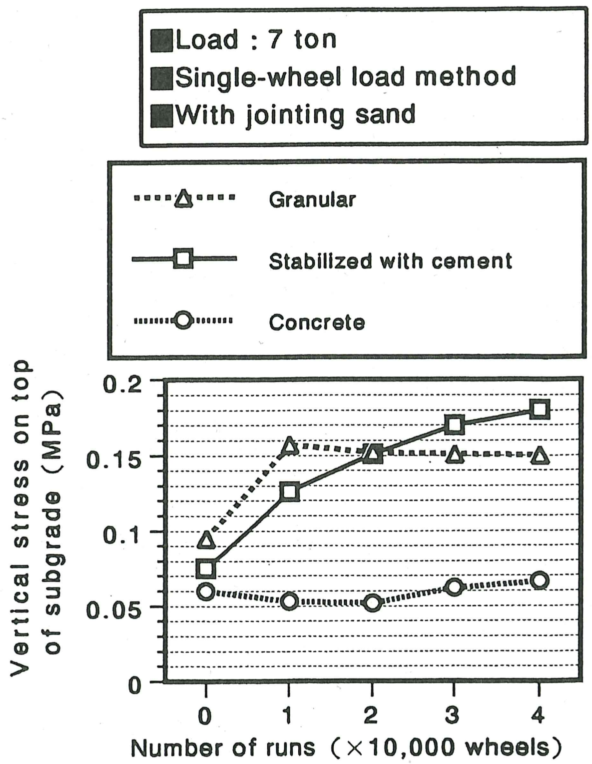


Load: 7 ton
Single-wheel load method
With jointing sand

DEFORMACIÓN (μ) vs NÚMERO DE PASADAS (x 10^4 LLANTAS)

Load: 7 t / *Carga: 7 t* - Single-wheel load method / *Método de la llanta única* - With jointing sand / *Con junta llena de arena* - Stabilized with cement / *Estabilizado con cemento* - Concrete / *Concreto*

Figure 16. Strain on top upper base structure.
Figura 16. *Deformación en la parte de arriba de la capa superior de la base.*



ESFUERZO VERTICAL (MPa) vs NÚMERO DE PASADAS (x 10^4 LLANTAS)

Load: 7 t / *Carga: 7 t* - Single-wheel load method / *Método de la llanta única* - With jointing sand / *Con junta llena de arena* - Granular / *Granular* - Stabilized with cement / *Estabilizado con cemento* - Concrete / *Concreto.*

Figure 17. Vertical stress on top of subgrade.
Figura 17. *Esfuerzo vertical sobre la subrasante.*