CONTAINER PORT EXTENSION—Technical Appendix
ALGECIRAS, SPAIN

PAVEMENT: STEEL FIBRE REINFORCED CONCRETE
Product: Wirand® FF1

Pavement Design

Calculation of the suitability of replacing reinforcement bar with steel fibres was carried out using the Maccaferri pavement design software PAVE. As a result of extensive research, Maccaferri has developed software which uses non-linear fracture mechanics (NLFM) as a design methodology for pavements. In this case concrete reinforced with 35 kg/m^3 H30 Wirand FF1 fibre was shown to withstand the design loading conditions.

The aim of this paper is to describe the method for calculating pavement Wirand metal fibre reinforced soil resting on a Winkler type elastic foundation. The calculation is based on non-linear fracture mechanics (NLFM) that takes into account the resilience of concrete reinforced with steel fibres, highlighting the remarkable resistance that fibre-reinforced concrete is able to offer after matrix cracking. Structural analysis using non-linear fracture mechanics allows the calculation of the ultimate capacity of a steel fibre reinforced concrete panel up to the stage of cracking.

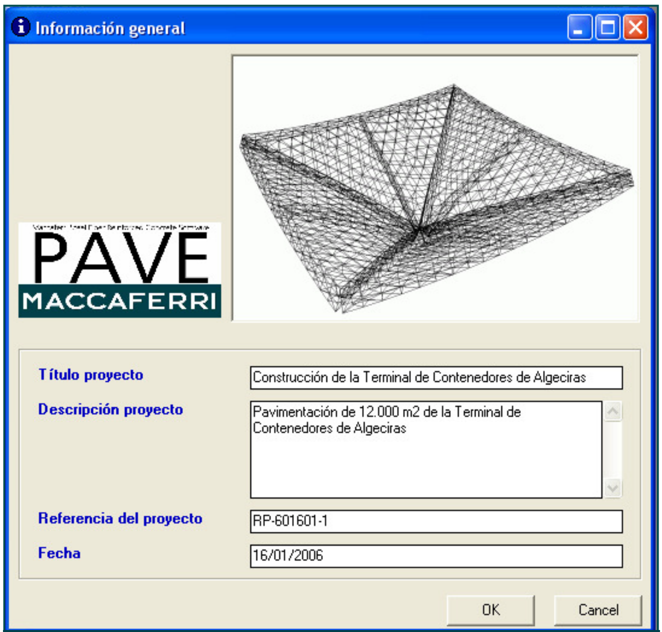


Figure 1: General view of the PAVE Program

Loads on the Structure

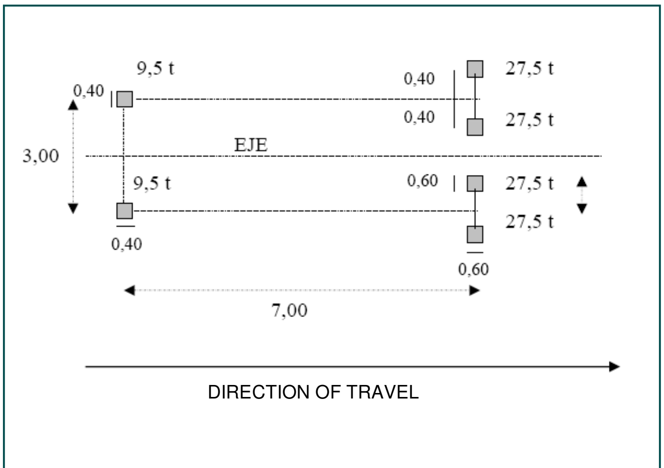
The pavements are designed in zoned areas according to the loads to be accommodated. The following load conditions have been identified:

A. Operation Area - Trucks are the primary load and to a lesser extent, fork-lift trucks
B. Container Storage Area - Containers stacked up to five units high
C. Rolling beam GTR ("Loading Transtainers")

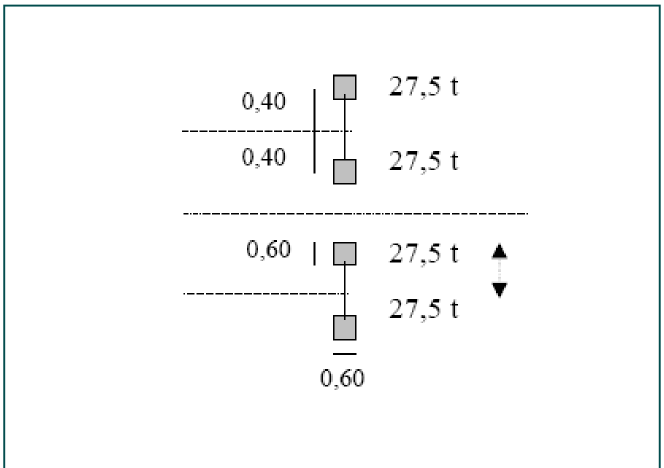
In the analysis, a single concentrated cyclic load in the middle of the paving slab is determined. This equivalent load is obtained through the Westergaard methodology, in which a central load is calculated from the sum of the contributions of local loads.

A. Operation Area

In this case, only the loads positioned on the right will be taken into account, since the separation between the saw cut joints is six meters, the loads will never all act on the same panel at any time.



Operational area / layout



Load distribution considered for Zone A

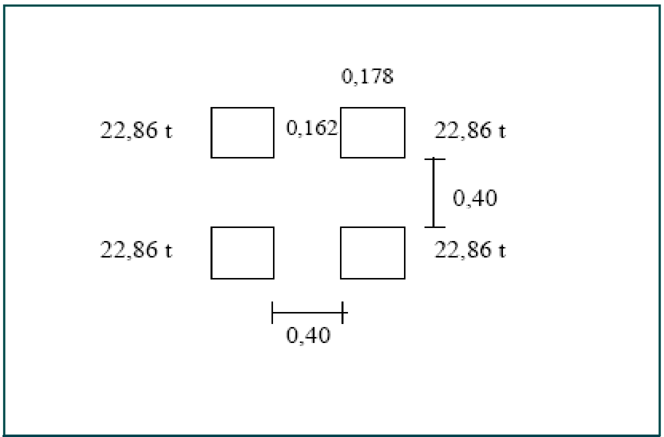
This load distribution for Zone A corresponds to an equivalent static, concentrated load (on the center of the paving slab) of;
Fe = 322.35 kN.

Considering the safety coefficient included (γ_{min} Dynamic) the ultimate load used was ;
Fu = 967.05 kN over an area of 0.36m2 (0.6m x 0.6m)

B. Container Storage Area

The loading on Area B corresponds to an equivalent static, concentrated load (on the center of the paving slab) of:
Fe = 395.3 kN.

Considering the safety coefficient included (γ_{min} Static) the ultimate load used was:
Fu = 632.5kN over an area of .0288m2 (0.178m x 0.162m)



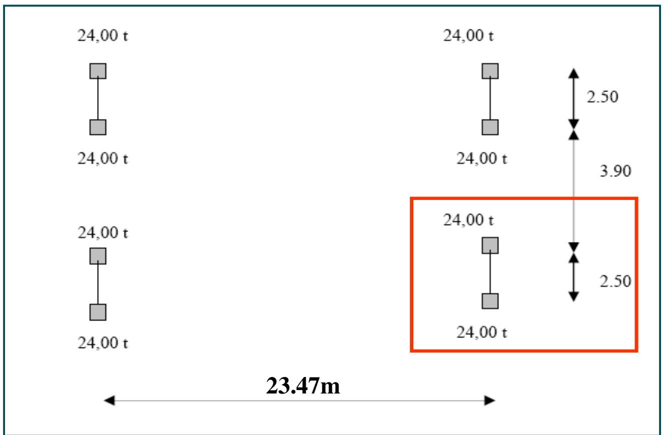
Corner Details - Area B

C. Rolling beams GTR ('Transtainers')

In Case C, only the pair of loads closest together need to be taken into account; the separation between the joints is six meters and therefore at no time will more of these loads act on the same panel. The load distribution considered for this zone is represented by the area boxed in red on the diagram opposite.

This corresponds to an equivalent static, concentrated load (on the center of the paving slab) of:
Fe = 248 kN.

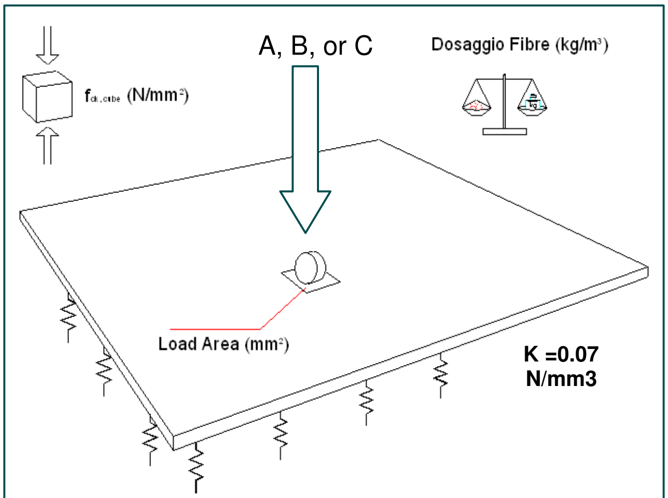
Considering the safety coefficient included (γ_{min} Dynamic) the ultimate load used was:
Fu = 744 kN over an area of 0.160m2.



Load distribution considered for Zone C

Soil Reaction Model

The pavement design has considered a vertical reaction coefficient under the pavement of K = 0.07 N/mm^3 (plate diameter 760 mm), equivalent to a CBR = 20 (under these specific conditions).



Soil reaction model

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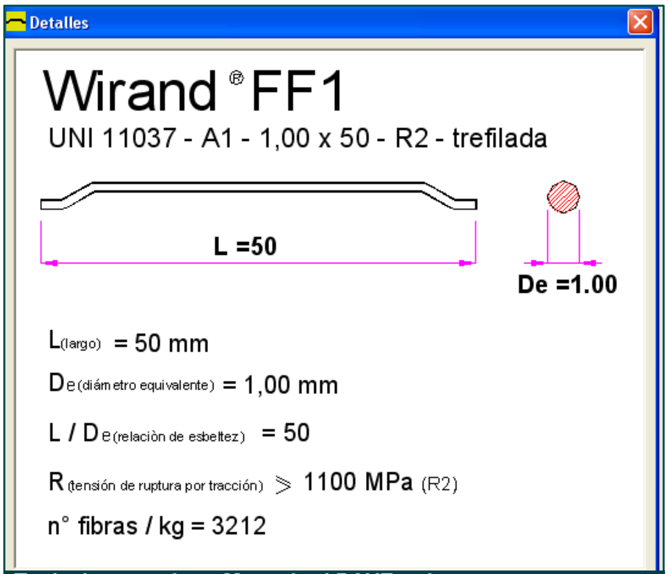
Characteristics of Concrete Reinforced with Fibres

The pavement slab is made from concrete of class H30 (F = 30 MPa) reinforced with 35 kg/m^3 FF1 Wirand fibre. Through experimental and theoretical research with the University of Brescia, Italy, many variations of Wirand reinforced concrete have been created and tested. Mix variables included:

- Concrete strength
- Wirand dosage
- Wirand fibre type
- Fibre dosage

The results are applicable for the use of these composite materials in both industrial paving and shotcrete.

The Maccaferri PAVE design software has been developed for the design of concrete slab floors as a result of the research and experimentation carried out.

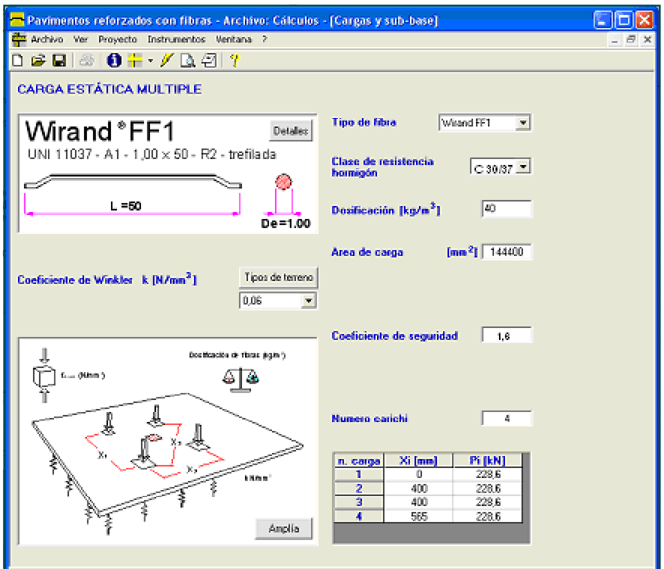


Typical extract from Maccaferri PAVE software

Factors of Safety Coefficients

Structural analysis with nonlinear fracture mechanics directly indicates the Ultimate Strength of a pavement slab constructed with fibre reinforced concrete. This corresponds to the formation of a crack / collapse mechanism. The working load applied to the pavement is determined according to the ultimate load which must take into account partial safety factors for loads and materials to which a coefficient which considers the cyclical nature of the loads (often present in industrial flooring), is applied. Such a coefficient depends on the specific case to be solved but cannot be less than the Value indicated below;

Static γ_{min} = 1.6
Dynamic γ_{min} = 3.0



Typical extract from Maccaferri PAVE software

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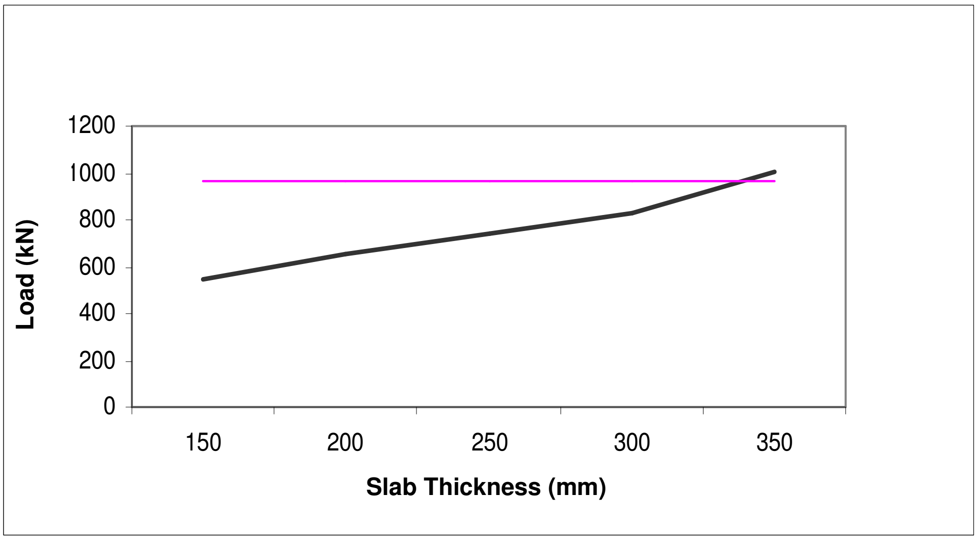
Tension Verification

The minimum thickness of concrete is determined by the graph containing results of numerous structural analyses, based on non-linear fracture mechanics, on slabs of different thickness founding upon soils characterized by different moduli of subgrade reaction (kw).

A. Operating Area

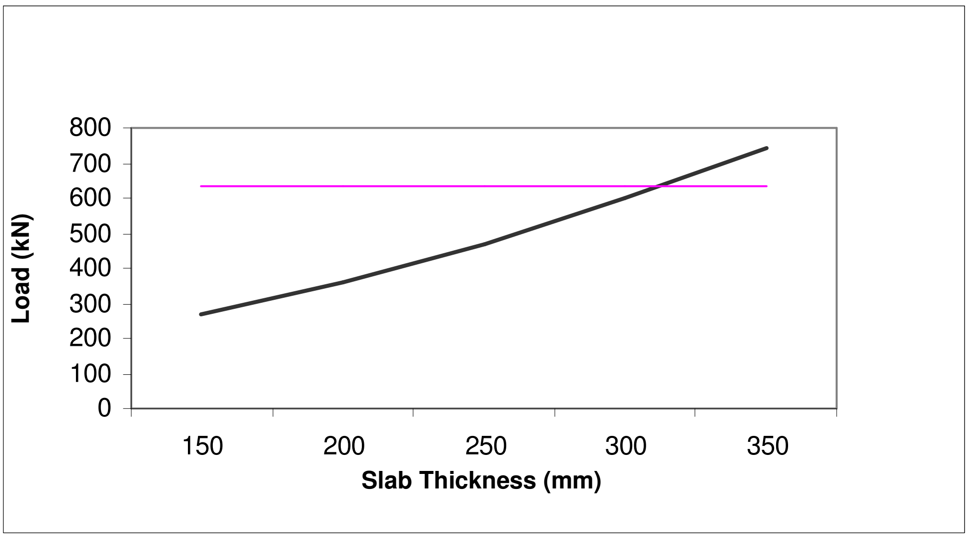
The graph for a concrete mix, Class H30, with 35 kg/m^3 Wirand fibre FF1, on a loading area of 360 000 mm^2 and coefficient kw = 0.07 N/mm^3, is illustrated in Figure 2.



Operating Area A: Load vs Slab thickness graph

B. Container Storage Area

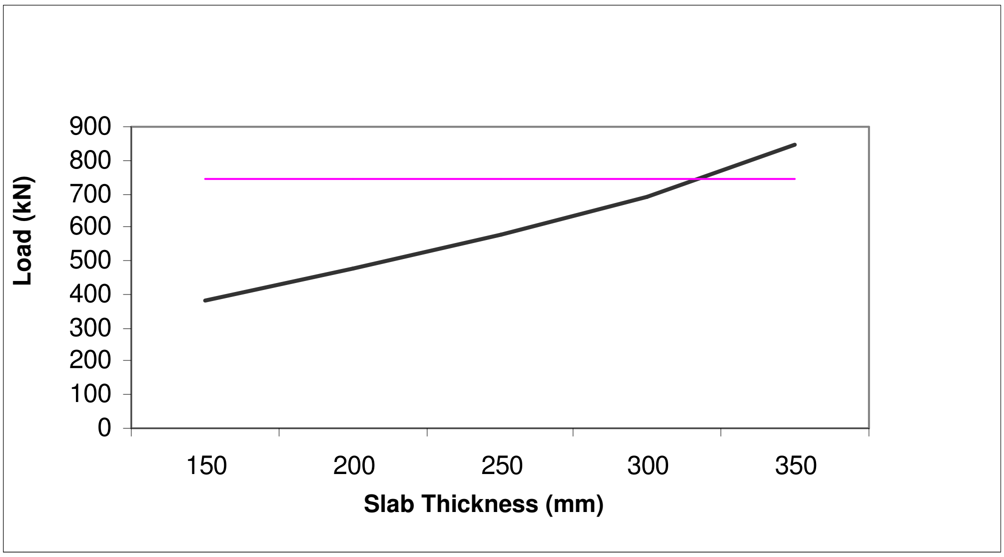
The graph for a concrete mix, Class H30, with 35 kg/m^3 Wirand fibre FF1, on a loading area of 28836 mm^2 and coefficient kw = 0.07 N/mm^3, is illustrated in Figure 3.



Operating Area B: Load vs Slab thickness graph

C. Rolling beams GTR (transtainers)

The graph for a concrete mix, Class H30, with 35 kg/m^3 Wirand fibre FF1, on a loading area of 160000 mm^2 and coefficient kw = 0.07 N/mm^3, is illustrated below.



Operating Area C: Load vs Slab thickness graph

Guidelines for the use of the graphs

- The ultimate load is determined by multiplying the applied load by the global security coefficient (Static γ_{min} = 1.60; Dynamic γ_{min} = 3.0)
- Locate the ultimate load on the graph along the ordinate axis ('Load' axis) and draw a horizontal line to find the locus for the elastic coefficient kw of the soil
- From the coincident point of this horizontal line with the preset curve, a vertical line is drawn to find the minimum thickness of the pavement
- Note that curve on the graph is specific to the concrete grade, fibre type, fibre dosage, loading area and elastic coefficient of the soil listed.

Conclusions

From Figure 2, 3 and 4 it is shown that the minimum thickness of pavement made with 35 kg/m^3 FF1 Wirand fibre in a concrete class H30, appropriate for each of the zone areas is as follows:

Zone Area	Thickness (mm)
A. Operating Area:	320
B. Container Storage Area:	320
C. Rolling beams RTG ('Transtainers'):	320

It is important to note that, the validity of the method used to achieve these thicknesses, is derived from the results of a series of tests conducted in the laboratories of the University of Brescia, Italy.