

DETERMINATION OF k FOR RIGID PAVEMENT WITH CAKAR AYAM SYSTEM USING HEAVY WEIGHT DEFLECTOMETER (CASE STUDY: SOEKARNO-HATTA AIRPORT)

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ABSTRACT

One of the important parameter in determining the Aircraft Classification Number/Paement Classification Number (ACN/PCN) of rigid pavement is the modulus of subgrade reaction (k). The current popular way to find the site modulus of subgrade reaction under the rigid pavement is by using the non destructive test with HWD (Heavy Weight Deflectometer). However, the program used to analyze the collected data from the site is only applicable for conventional rigid pavement. This paper discusses the necessary step-by-step procedure to apply the HWD using its accompanied program called ELMOD4 to calculate k in the study of Soekarno-Hatta Airport, where the rigid pavement uses Cakar Ayam system. From the study it is suggested that the k value of the subgrade is 15 MN/m^3 . Therefore the subgrade category of the Soekarno-Hatta Airport is D according to the ACN/PCN method.

BACKGROUND

The International Civil Aviation Organization (ICAO) in 1977 established a study group to develop a single international method of reporting pavement strength [FAA AC. No. 150/5335-5 (1983)], which is called the ACN/PCN method (Aircraft Classification Number/ Pavement Classification Number). ACN is a number which expresses the relative structural effect of an aircraft on different pavement types for specified standard subgrade strength in terms of a standard single wheel load. PCN is a number which expresses the relative load carrying capacity of a pavement in terms of a standard single wheel load. This method is structured so that a pavement with a particular PCN value can support without weight restrictions for an aircraft which has an ACN value equal to or less than the pavement's PCN value.

The ACN/PCN is determined based on the critical aircraft and some other factors as follows.

1. Pavement type: Flexible Pavement (F) or Rigid Pavement (R).
2. Subgrade strength in terms of California Bearing Ratio (CBR) for flexible pavement and modulus of subgrade reaction (k) for rigid pavement.
3. Tire pressure (main landing wheel).

Modulus of subgrade reaction for rigid pavement is divided into 4 categories and is coded as A, B, C and D that depend on the value of modulus of subgrade reaction, k , as follows.

Table 1. Subgrade Strength Category
(FAA-AC 150/5335-5, 1983).

Category	Modulus of Subgrade Reaction (k)		Code Designation
	lbs/in ³	MN/m ³	
High	> 400	> 120	A
Medium	201 – 400	61 – 120	B
Low	100 – 200	25 – 60	C
Ultra Low	< 100	< 25	D

Some methods can be used to find the value of modulus of subgrade reaction in the site. One of the method which is recently popular is by using results from Heavy Weight Deflectometer (HWD) test that has the following advantages:

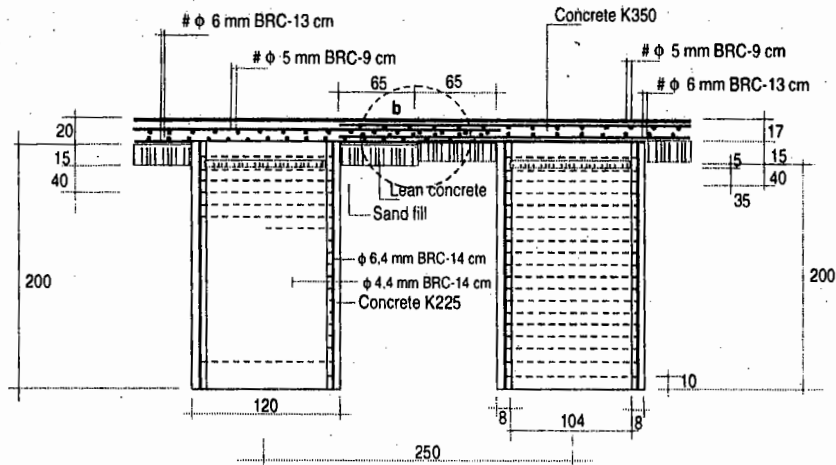
1. a non-destructive test device,
2. one man operational,
3. accurate and fast (up to 60 test points per hour),
4. wide loading range (30 – 240 kN),
5. designed for multi-purpose pavement application,
6. excellent repeatability.

However, the included ELMOD4 software in HWD test to conduct the analysis can only be used for conventional rigid pavement. Therefore it is necessary to develop a procedure to carry out the HWD test in the rigid pavement using Cakar Ayam system. This paper discusses how this procedure works in Soekarno-Hatta airport where the specification of the Cakar Ayam system is depicted in Figure 1 (Anonim, 2002).

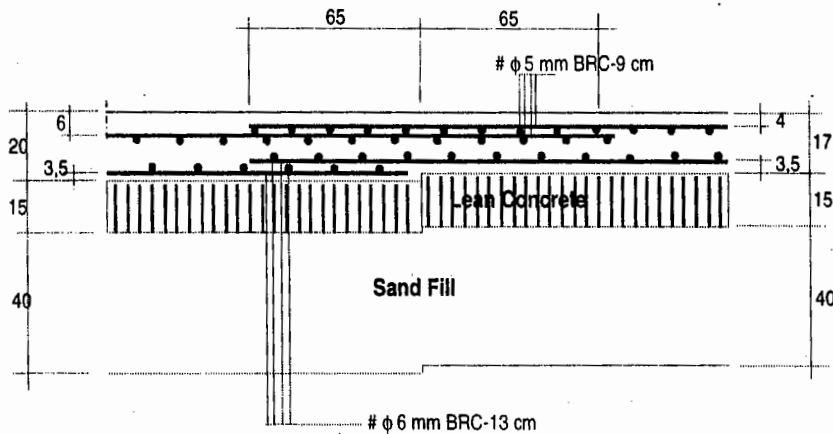
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(a) Detail of Pipes Reinforcement



(b) Detail b

Figure 1: Rigid pavement with Cakar Ayam system.

THEORY

The soil modulus of subgrade reaction, k , should actually be determined through plates commonly 30.5 x 30.5 cm or round plates from 30.5 to 76 cm in increment of 15 cm. The plate thickness is commonly 2.5 cm to reduce bending. From plate-load test data, the value of k is determined as follows (Bowles, 1977):

$$k = \frac{q}{\delta} \quad (1)$$

where q = stress due to load on standard plate radius (760 mm).

δ = displacement at center of the plate

The above load test is commonly carried out before constructing the slab. If rigid pavement is already constructed on the subgrade, the standard test directly to the subgrade under the rigid pavement could be very difficult to be carried out and can be very costly. Therefore, the determination shall be carried out on the rigid pavement and the value of k is determined using such as Westergaard's theory. In this method a load P is applied on the rigid pavement using a circular plate of diameter a , and the occurred displacement is measured. Theoretically, the correlation between deflection at the center of loading plate δ and the applied load P , for example, can be calculated as follows (Ullidtz, 1987):

$$\delta = \frac{P}{(8kl^2)} \left\{ \left(1 + \frac{1}{2\pi} \left[\ln \left(\frac{a}{2l} \right) + \tau - \frac{5}{4} \right] \left(\frac{a}{l} \right)^2 \right) \right\} \quad (2)$$

where

$$l = \left\{ \frac{Eh^3}{[12(1-\mu^2)k]} \right\}^{0.25} \quad (3)$$

In the above equations P = load, h = thickness of the slab, E = modulus of concrete, μ = Poisson's ratio of concrete, k = modulus of subgrade reaction, a = radius of loading plate, τ = Euler's constant (0.57772). Currently, the above process is commonly carried out by using a HWD test as will be explained below.

HEAVY WEIGHT DEFLECTOMETER TEST

Heavy Weight Deflectometer is the development from Falling Weight Deflectometer (FWD), which is developed by Dynatest 8000 (Ullidtz (1987), www.dynatest.com/hardware). The configuration of HWD is depicted in Figure 2. The device works by using force impulse, which is obtained by dropping a weight on a specially designed spring system. The impulse can produce an impact loads of up to 250 kN, which is corresponding to the load of one wheel of a fully loaded Boeing 747 aircraft. This impulse loads then produce a deflection basin or deflection bowl as can be seen in Figure 3. The deflections are measured with geophones, normally at seven different distances from loading plate of 400 mm in diameter.

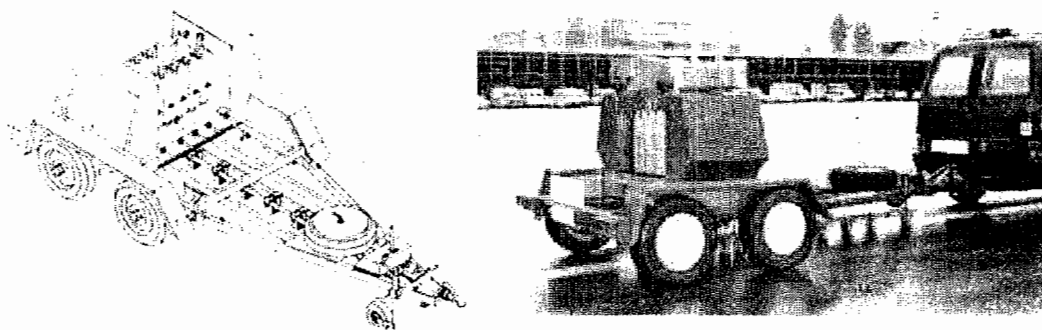


Figure 2. Heavy Weight Deflectometer device (www.dynatest.com/hardware).

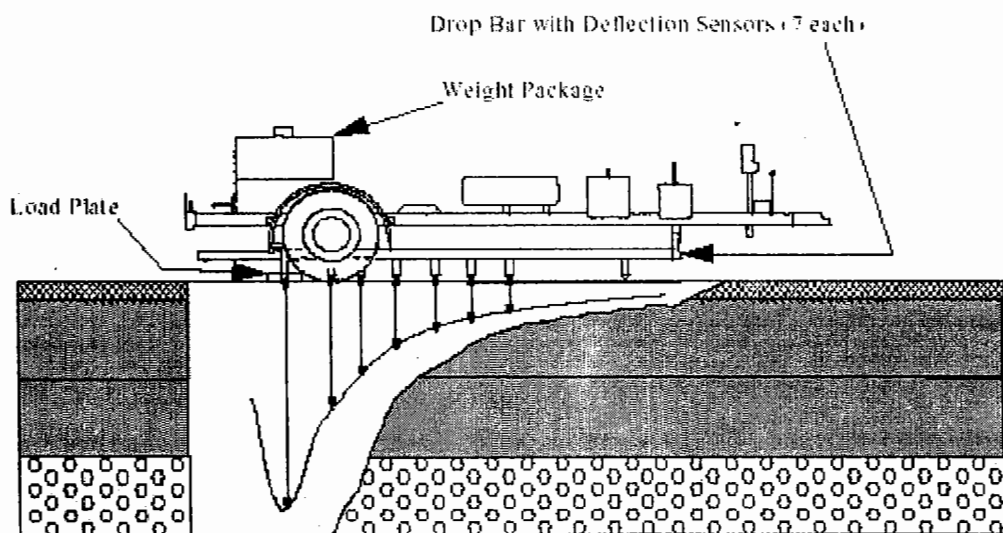


Figure 3: Deflection bowl (AFCEA, 1998).

The total test sequence can be controlled from the driver's seat and the results are automatically stored in a computer hard disk or in a floppy disk for later uploading and processing with ELMOD4 software. Two mathematical models are used in the ELMOD4 method, they are the Westergaard solution for a loaded elastic plate on a winkler foundation for rigid pavements, and the Boussinesq solution for stresses and displacements in a homogeneous isotropic elastic half-space under surface loading for flexible pavements. Using the collected deflection bowls and the two mathematical models above the ELMOD4 will find modulus of subgrade reaction k for rigid pavement and modulus elasticity of each layer for flexible pavement.

METHODOLOGY

As explained above, the ELMOD4 in HWD test can only be used to determine k for conventional rigid pavement. In this case a user need to provide the thickness of the slab of that conventional rigid pavement. However, in the rigid pavement with Cakar Ayam system as shown in Figure 4, the rigid pavement also has "pipes" that are connected to the slab which change the supporting mechanism. The application of the real slab thickness of Cakar Ayam system in the ELMOD4 is inappropriate. Therefore it is necessary to firstly convert the Cakar Ayam system into the conventional rigid pavement system having an equivalent slab thickness as input data for ELMOD4. This equivalent slab thickness is determined by assuming that the maximum flexural stress developed in the slab of Cakar Ayam system equals to the maximum flexural stress developed in

the slab of conventional rigid pavement. Having this assumption it means that the Cakar Ayam and the conventional systems will have the same loading capacity. The calculation of flexural stress is carried out using SAP 90 (Wilson and Habibullah, 1995), where the step-by-step procedure is explained as follows.

STRUCTURAL MODEL

The structural model of Cakar Ayam system and conventional rigid pavement system using SAP 90 is shown in Figure 4. The slab thickness and other dimensions of Cakar Ayam system can be seen in Figure 1, but the thickness of the conventional rigid pavement system as the conversion of Cakar Ayam system is to be determined by trial and error method as will be explained later. The support from subgrade as modulus of subgrade reaction k is modeled by spring member. From previous study it was found that modulus of subgrade reaction for Cakar Ayam system in horizontal direction could be taken around ten times for that of vertical direction (Suhendro, 1992). In the model therefore, the spring stiffness is calculated as follows.

$$k_z = kA_z \quad (4)$$

$$k_x = 10kA_x \quad (5)$$

$$k_y = 10kA_y \quad (6)$$

where A_x , A_y , and A_z = tributary element area in X, Y and Z directions, k = modulus of subgrade reaction that should be firstly assumed, k_x , k_y and k_z = spring stiffness in X, Y and Z directions.

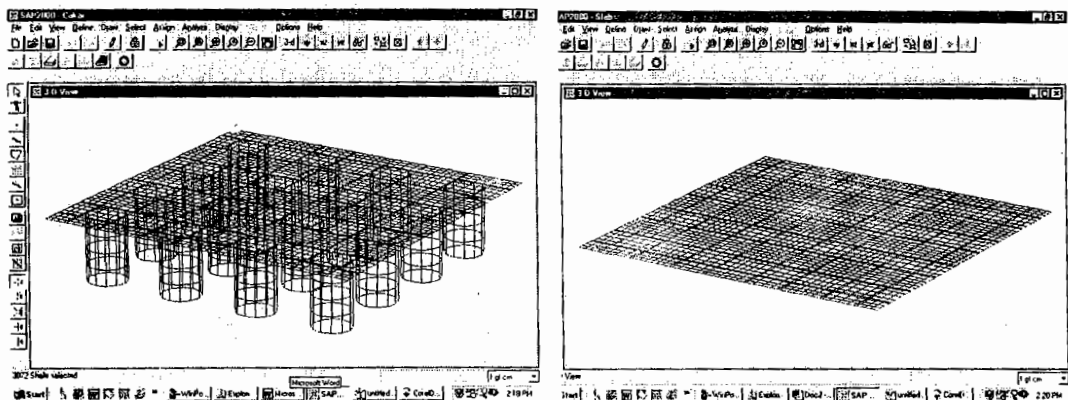


Figure 4: Structural models of Cakar Ayam and conventional rigid pavement systems.

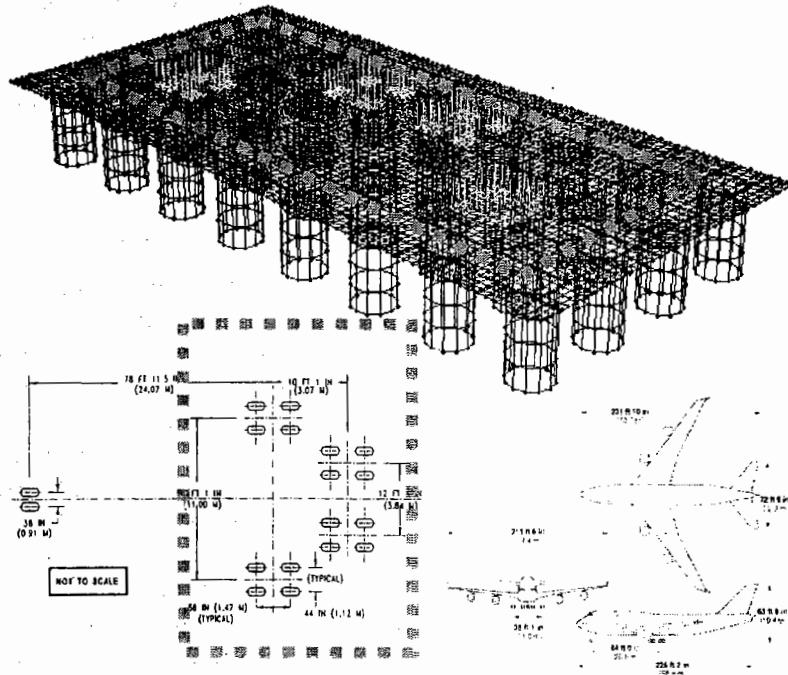


Figure 5: Aircraft wheel load model.

LOADING MODEL

The load to be considered in the analysis is merely the load from aircraft wheels. Figure 5 shows the wheel configuration of the critical aircraft B-747 that to be applied in the structural model. In the analysis, only main wheels are taken into account and the load can be taken as 95 % of Maximum Take Off Weight, which is 396890 kg. Therefore the applied load in the analysis is 95 % x 396890 kg = 377046 kg. From Figure 5 it can be seen that the main wheels consist of 4 bogeys or 4 unit dual tandem wheels, then the load for each wheel will be $377046/16 = 23565$ kg.

FLEXURAL STRESS ANALYSIS

Using the above structural and loading models, it can be found that the maximum flexural stress developed in the slab of Cakar Ayam system is 4.88 MPa. At the same time it is also necessary to find the maximum flexural stress developed in the slab of conventional rigid pavement system as a the conversion of Cakar Ayam system. The equivalent slab thickness of the conventional system is determined by trial and error to produce the same flexural stress as developed in the slab of Cakar Ayam system. It was found that the equivalent slab thickness

of conventional rigid pavement system must be around 450 mm to produce the same maximum flexural stress as in the slab of Cakar Ayam system.

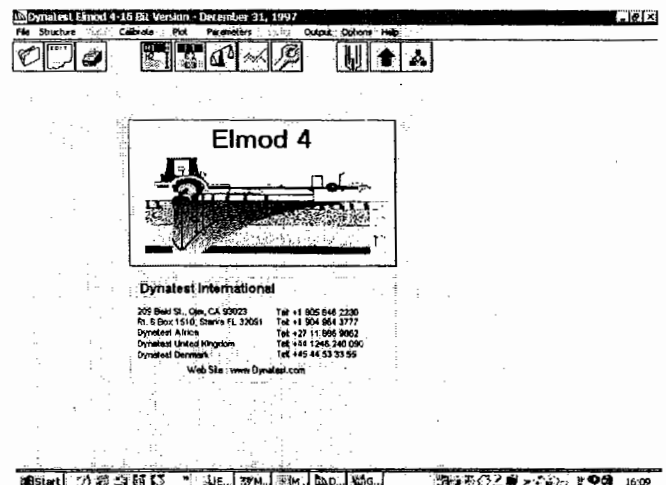


Figure 6. ELMOD4 program for processing HWD test data.

ANALYSIS RESULTS

Using equivalent slab thickness of 450 mm and deflection bowls data from HWD tests, then run the ELMOD4 as shown in Figure 6. The analysis results from ELMOD4 for the runway area can be seen in

Figure 7. In this figure each slab number represent a typical area of 7.5 m x 15 m. The value of modulus of subgrade reaction for the entire region of pavement is determined using confidence level. If the confidence

level is taken to be 98%, then the value of modulus of subgrade reaction is 15 MN/m³ as can be seen in Figure 8.

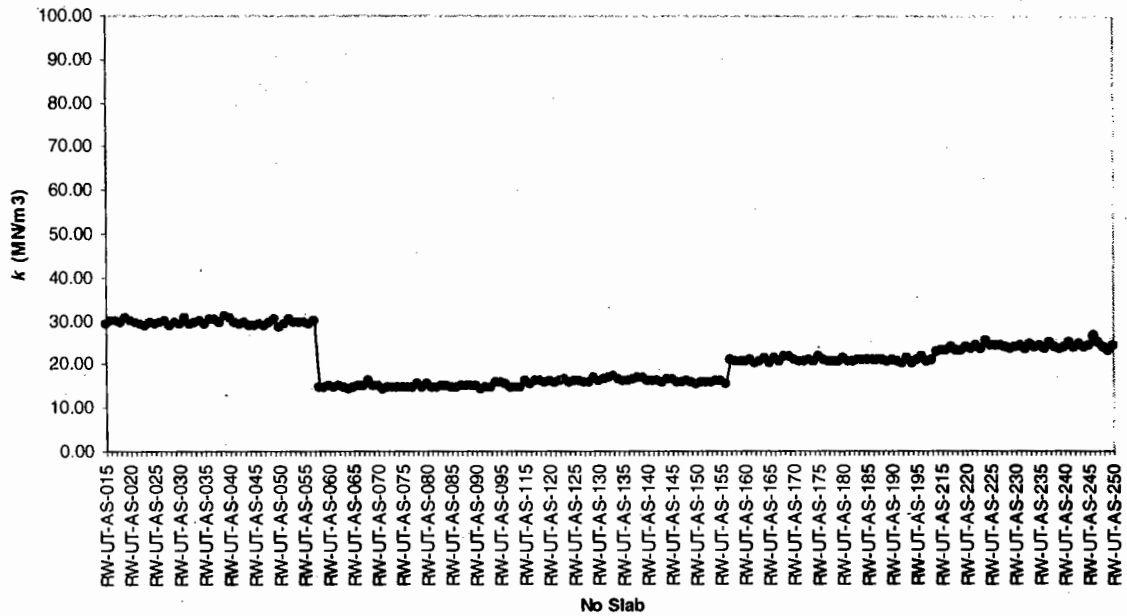


Figure 7. Calculated modulus of subgrade reaction of North Runway-left side.

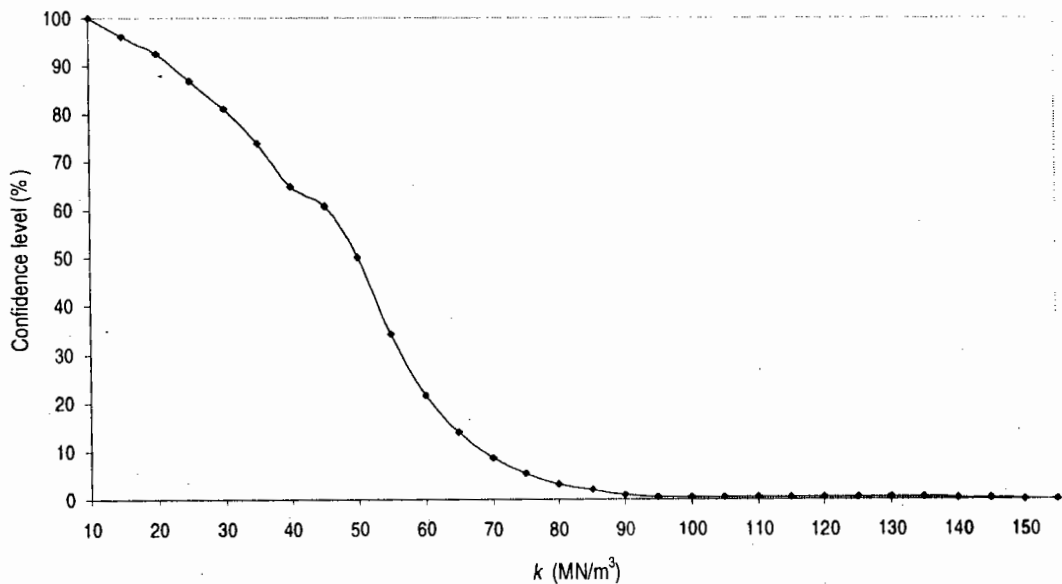


Figure 8. Modulus of subgrade reaction for the whole area.

