EVALUATION OF BEARING CAPACITY AND PCN OF NORTH RUNWAY CAKAR AYAM SYSTEM IN SOEKARNO-HATTA INTERNASIONAL AIRPORT USING FINITE ELEMENT MODELING (Case Study: To Operate the B777-300ER Aircraft)

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Abstract

In 2013, one of the Indonesiaairlines planned to operate a new type of aircraft: B777-300ER in Maximum Take-off Weight (MTOW) condition, but North Runway of Soekarno-HattaInternational Airport (SHIA) wasclaimed not able to support the aircraft due to low bearing capacity. The provider suffered financial lose by restricting 39 passengers and containing no cargo.North Runway Soekarno-Hatta was built in 1977-1978 using unconventional pavement system called "CakarAyam" by Prof. Sedyatmo. After more than 25 years of operation, the runway has never been carried out any major evaluation.This studytries to evaluate the runway by modeling the pavement system using 3D Finite Element Method. It is analyzed two models: (1) Model HWD load; and (2) model of the B-777-300ER (MTOW). Both of these models analyze the effect of the deflection and bending moment due to the load. The first model is simulated to verify and validate the model. The second model is simulated to check whether the aircraft load is still able to be supported by the pavement. The results of the first model show that the deflection (mm) and moment (kNm/m') response is compatible with the HWD and B747 test results on the field. The second model (Boeing B-777-300ER) shows that the applied moment (ranged from 21.92 to 22.38 kNm/m') is larger than the moment capacity (Mu) of the North Runway of SHIA which is 19.35 kNm/m'. It is concluded that North Runway of SHIA is not able to support the Boeing 777-300ER in MTOW condition. The Boeing 777-300ER with Restricted Take-off Weight (RTOW): 320 tons,is allowed to take off in North Runway of SHIA. Using the FAA method, the current PCN of North Runway of SHIA is estimated: 114/R/D/W/T.

Keywords: CakarAyam System, Soekarno-Hatta Airport, B777-300ER, Finite Element Modeling, PCN

INTRODUCTION

Air transportation demand in Indonesia is growing very rapidly in the last 10 years (Airports Council International (ACI), 2013). This requires a better and more efficient air transport infrastructure.One of the efforts to improve transportation facilities is carried out by PT. Garuda Indonesia, one of the nat. Reported by ACN News Wire (2013), on 2 November 2013 PT. Garuda Indonesia planned to operate flights B777-300ER aircraft on route from Jakarta to London. However, this plan should be delayed, because the bearing capacity of the runway of Soekarno-Hatta International Airport (SHIA) allegedly not been able to be used by the aircraft. This delay is related to Pavement Classification Number (PCN) of North Runway of SHIAwhich remains lower than the Aircraft Classification Number (ACN) B777-300ER aircraft for the flight from Jakarta to London non-stop in MTOW (Maximum Take-off Weight) condition.

Garuda team stated that: if the aircraft operating at full capacity by transporting 314 passengers and 11 tons of cargo, then its MTOW become 351,534 kg. To pass the B777-300ER aircraft MTOW conditions, runway should at least have PCN 132/R/D/W/T. Currently the North Runway of SHIA (subgrade category D) claimed to only have PCN 120/ R/D/W/T.North Runway of SHIAwas built in 1977-1978 using “CakarAyam” System by Prof. Sedyatmo. After more than 25 years of operation, the runway has never been carried out anymajor evaluation.

This study tries to evaluate the runway by modeling the pavement system using 3D Finite Element Method. Theevaluation is done by conducting more than 600 HWD (Heavy Weight Deflectometer), core drill, PCI, UPV and Hammer Test in North Runway of SHIA. After verification and validation using the field data, the North Runway then modeled by using 3-DFinite Element Method for “CakarAyam” system with SAP2000 structural analysis tools. This model is expected to analyze the bearing capacity and the current PCNof North Runway of SHIA and also determine whether the aircraft (B777-300ER) load is still able to be supported by the pavement (CakarAyam system).

LITERATURE REVIEW

Since discovered by Prof. Dr. Ir. Sedyatmo in 1961, the "CakarAyam" system has been widely used in practice as: (a) hundreds of high-voltage transmission tower foundation, (b) the foundation dozens of multistory buildings, power stations, swimming pools, warehouses, oil tanks, and hangar, (c) airfield pavements (runways, taxiways and aprons) at various airports, and (d) the highway pavement on various highways, all of which are built on soil that is relatively soft to moderate and with the quitedeep/thick of soft soil.

In general, "CakarAyam" pavement system is made of thin reinforced concrete slab (thickness 10-20 cm) that nailed by concrete pipes with a diameter of 120 cm, 8 cm thick, and length of 150-200 cm, which is embedded in a layer of soft subgrade below it, the distance between the pipes of 200-250 cm. Under the concrete slab, there is a layer of lean concrete thickness of 15 cm (made of low quality concrete) and a layer of gravel about 40 cm thick, which serves as the main temporary pavement so that heavy equipment can cross it during the implementation/ construction and that the top surface of the subgrade can be even so that the concrete slab "CakarAyam" can be made on it (Suhendro et. al, 2006) [1].

Considering that “CakarAyam” pavement system is a special system which consists of a reinforced concrete slab that relatively thin (17 ~ 20 cm), the pipes are connected with the monolithic slab, and existing soil/embankment under the slab and between the pipes, it means the analysis and design of conventional rigid pavement cannot be applied.Therefore, structural analysis methods need to be developed specifically for this “CakarAyam” system, so that the influence of the load acting on the top slab on each component of the system can be analyzed accurately.

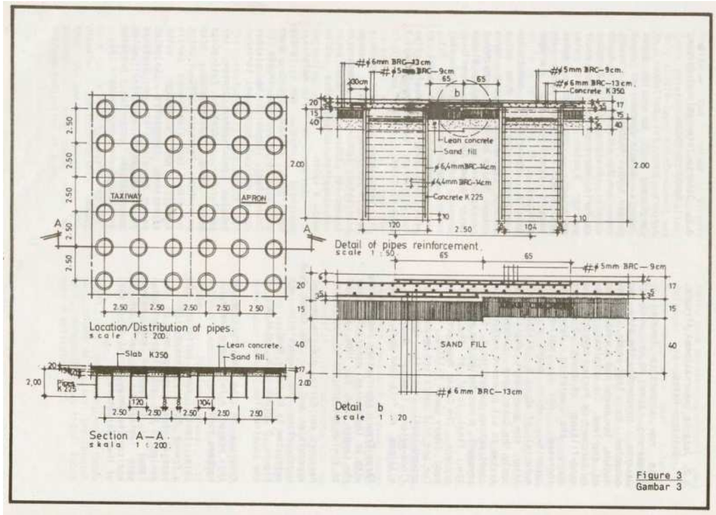


Figure 1 Cross-section and detail drawing of “CakarAyam” System (Suhendro, 1999)

The most reliable method so far for this purpose is the Finite Element Method 3-Dimensional. Finite element modeling for analysis of “CakarAyam” pavement system at Soekarno-Hatta has been developed numerically since 1989 [2], and has been regularly refined to improve the accuracy, through the verification of the results of the analysis of the model using full scale trials at the time of the pavement was new (1985) and the results of the testing deflection response FWD (Falling Weight deflectometer) and HWD (Heavy Weight deflectometer) are regularly conducted every 5 years on the runway, taxiways and apron Soekarno-Hatta airport (1991, 1996, 2001, 2009) [2].

Several studies of “Cakar Ayam” system has also been carried out massively as it is done by: Hardiyatmo (2006) [3], Romadhoni (2008) [4], Nawanggalam (2008) [5] and Firdiansyah (2009) [6].

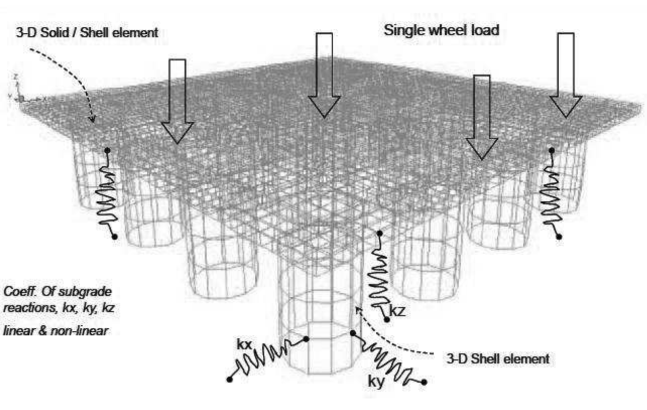


Figure2 Finite element model of “Cakar Ayam” pavement system (Suhendro, 1999).

RESEARCH METHODOLOGY

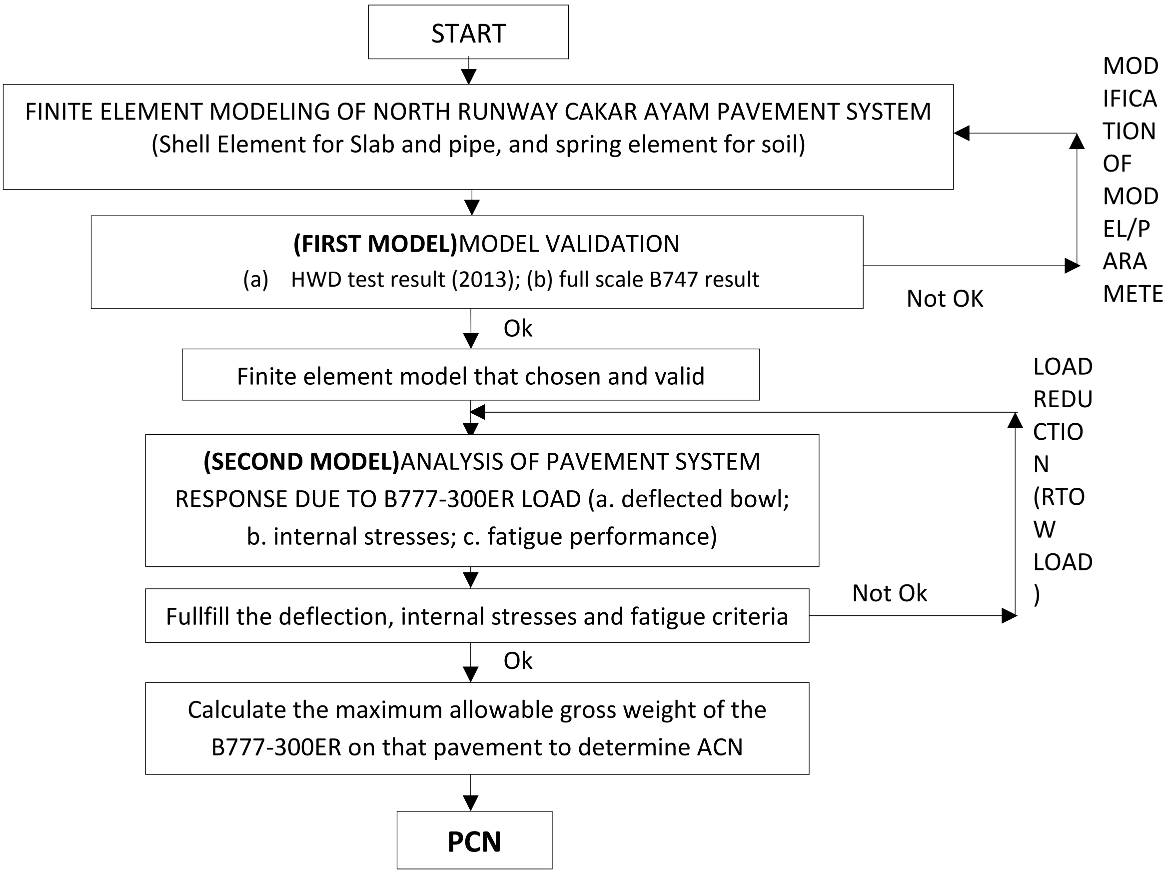


Figure3 Research procedure flowchart

Simulated two conditions: (1) the first model, to simulate the response (deflection and force) of"Cakar Ayam" pavement system due to HWD and the full scale B747 load test, in order tovalidatethe 3D Finite Element models that developed; (2) The second model, after the first model is valid, the model was used to analyze the effect of the load wheel configuration Boeing 777 (MTOW, Maximum Take Off Weight) on the "Cakar Ayam" pavement system, and the response of the deflection and the force will be used to check whether elastic and ultimate bending momentcapacity slab is still not exceeded.

MODEL AND PAVEMENT CHARACTERISTICS

Finite Element models were developed by usingSAP2000 structural analysis and design program. The reinforced concrete slab and pipes are represented as 3D shell elements,while the soil is represented as spring element (compression-only) in the vertical direction under the slab and horizontal direction of subgrade reaction around the pipes, which is put radially to anticipate the rotation of pipes in various directions (**Figure 2**).The pavement characteristics, including the subgrade soil modulus (k), the model dimension and concrete elastic modulus are determined from HWD, core drill, PCI, UPV and

Hammer Test. From analysis and corelation method, the characteristics is obtained and shown in **Table 1** and **2**.

Table 1 Model dimension “Cakar Ayam” pavement system (analysis result).

No.	Parameter	Value	Unit
1.	Pipe dimension		
	Length	2,00	m
	Diameter	1,20	m
	Thickness	0,08	m
	Distances between pipes	2,50	m
2.	Slab Dimension		
	Length	20	m
	Width	10	m
	Thickness	0,20	m

Table2 The pavement characteristicsof North Runway of SHIA (analysis result)

No	Parameter	Nilai	Satuan
1.	Modulus of Subgrade Reaction (k_v)	40 ~ 45	MN/m^3
2.	Concrete f’c	25,3	MPa
3.	Young’s Modulus (E_c)	23.452	MPa
4.	Slab thcikness	0,20	m

ANALYSIS AND RESULTS

Validation Model

The first stage of validation step, as shown in **Figure 4**, where the “Cakar Ayam” pavement system slab is represented by an area of 10 mx 10 m (in which there are 16 pipes) with the load of HWD (31 tonnes) is located at the center of the loading plate slab with a diameter of 30 cm. This model involves 6193nodal, 6776 shell elements 3D, and 6193 spring compression-only elements.

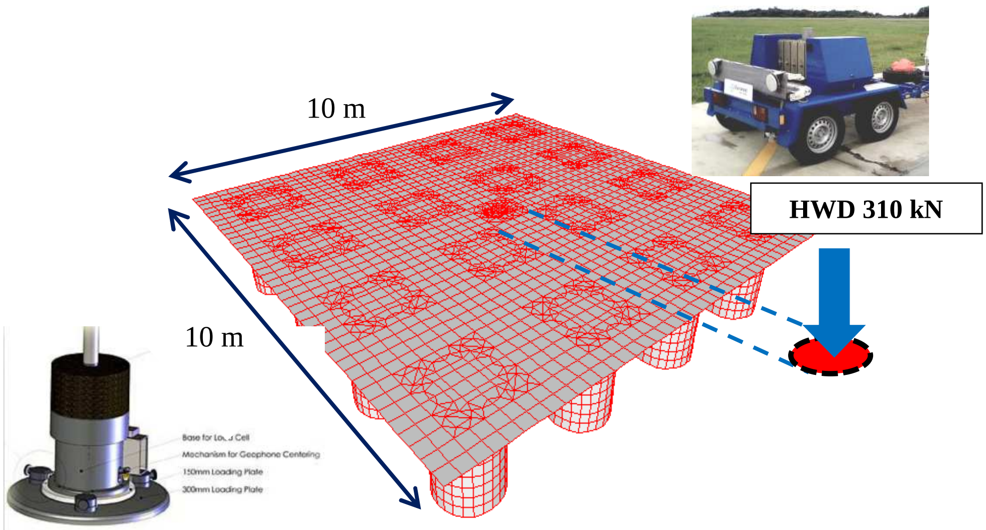


Figure4 The first model, to analyze the response of system due to HWD load/impact load (analysis result).

It appears from **Figure 5** that both the maximum deflection and deflected bowl shape that produced is already in accordance with deflection response from HWD test results.

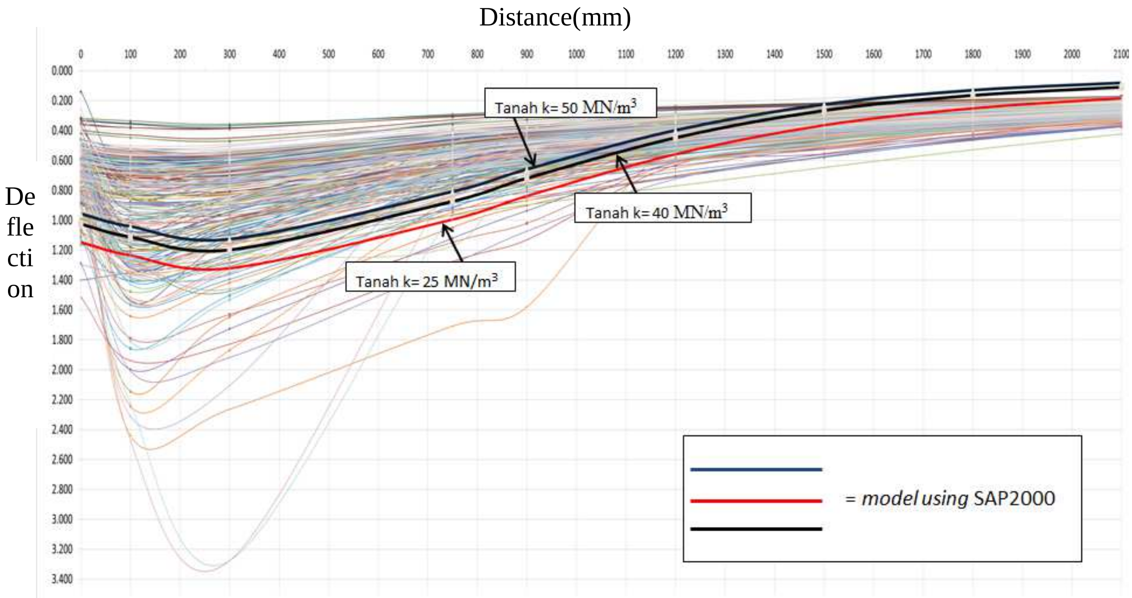


Figure5compatibilitybetween deflected bowlof model and HWD test (analysis result)

The maximum bending moment due to HWD load that occurs in the slab, 29.743 to 30.273 KNm/m'is still smaller than the capacity of the slab 31,434 KNm/m' (dynamic properties).

The second stage of validation step is using a B-747 bogie full-scale test load performed by Aeroport De Paris, 1983. The load tests is performed using hydraulic jacks on 4 plates representing the tire print of a B-747. Static load test results on two landing gear (which amounted to 90 tons each), resulting deflection of no more than 2.54 millimeters. With the same amount and configuration of load, then modeled the finite element model with size 10 x 20 m (32 pipes), with Boeing B747 tire load. The deflection response of the model results are then shown in Figure 7-21.

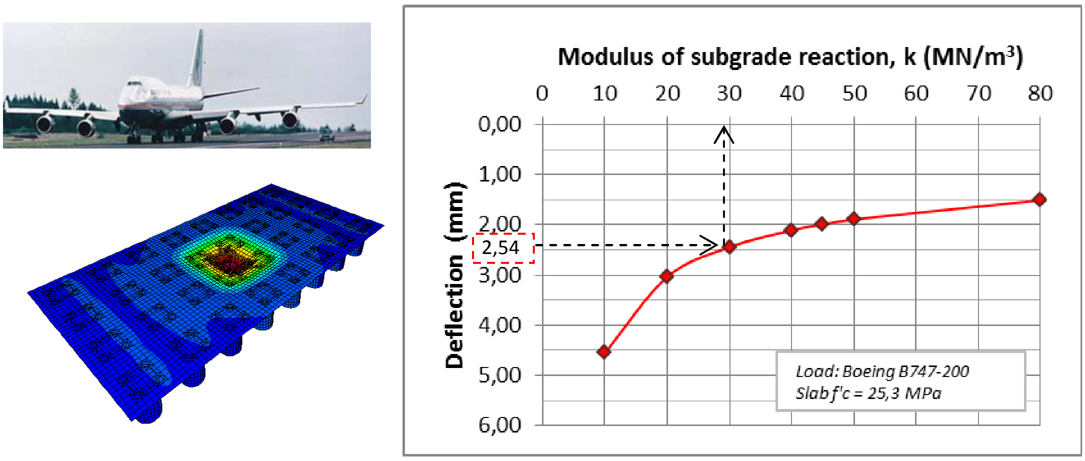


Figure6 Compatibilitybetween the FE model and Full-scale load test (analysis result)

The results (**Figure 6**) show that the maximum deflection due to the 1 boogie B-747 load is 2.5 mm for $k_v$around 30 MN/m^3.This result is in accordance with a deflection on the field test results that conducted by Aeroport de Paris in 1983. Thus, the finite element model proposed acceptable, and ready for the next stage of the simulation.

Analysis Model

The analysis model, as shown in **Figure 7**, is used to analyze the effect of Boeing 777-300ER aircraft Maximum Take-off Weight Load (MTOW) load which is transfered through the configuration of the wheels of the plane. “Cakar Ayam” pavement system is represented by an area of 20 mx 10 m slab (it consist of 32 pipes) with weights MTOW (352 tonnes) is positioned at the most critical position.

Themaximum deflections and bending momentsresult is used to check whether the concrete compressive stress and tensile stress on the steel reinforcement due to B777-300ER load is still able to be supported by the material.

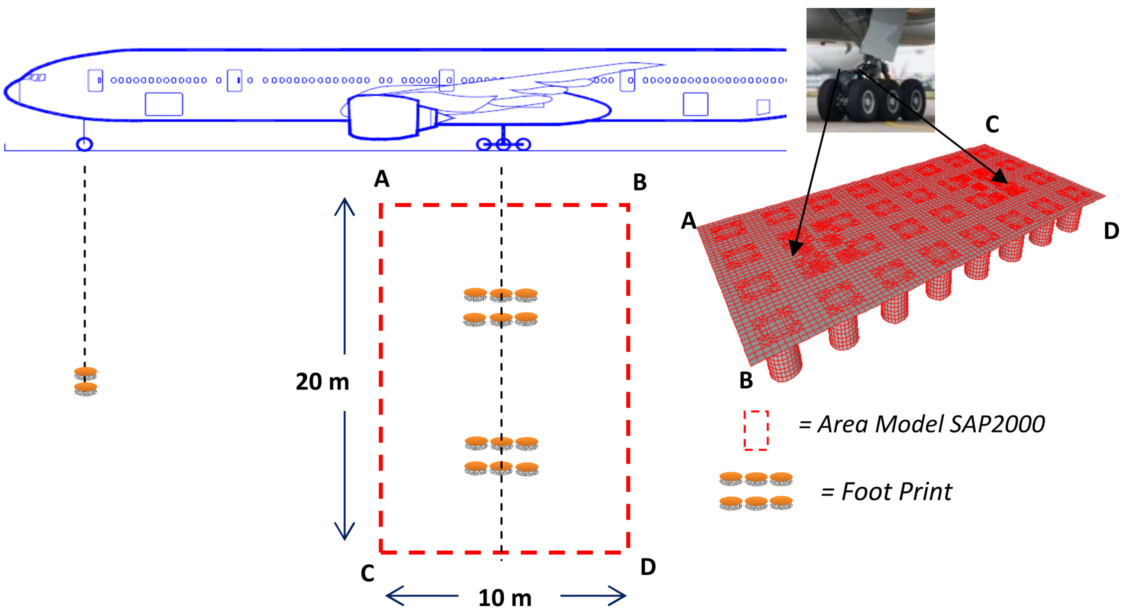


Figure 7 The second model to simulate the effect of load Boeing 777-300ER (analysis result).

The maximum deflections that occur in the slab for various $k_v$are shown in **Figure 8**, while bending moments are shown in **Figure 9**.

Table3 The maximum Deflection due to B-777-300ER (MTOW)load (analysis result).

Slab f'c: 25,3 MPa	
k_v (MN/m^3)	Deflection (mm)
10	3,8810
30	1,8838
40	1,5741
45	1,4661
60	1,2283
80	1,0352

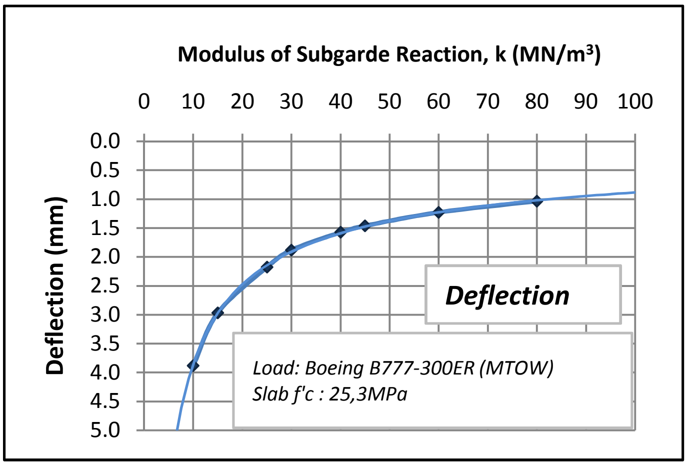
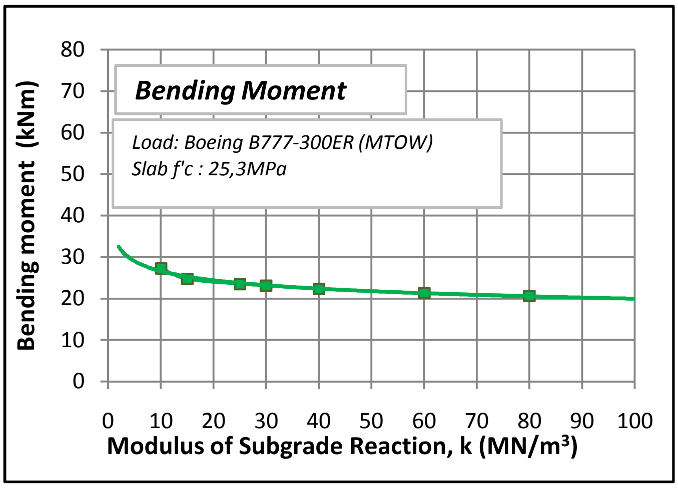


Figure8 Deflection due to B-777-300ER (MTOW) load (analysis result)

Table4 The maximum bending momentdue to B-777-300ER (MTOW) load (analysis result).

Slab f'c: 25,3 MPa	
k_v (MN/m^3)	Bending moment (kNm/m')
10	27,285
30	23,136
40	22,379
45	21,923
60	21,400
80	20,706



Gambar9 Bending moment due to B-777-300ER (MTOW) load (analysis result)

The result shows that the maximum deflection that occurs in slab is 1.575 mm, while the maximum bending moment ranged from 20.70 to 23.54 KNM / m '(**Figure 8** and **Figure 9**). Considering that the moment that is able to be supported by the slab in this review (stress working conditions) is 19 KNm/m', thereby the B-777-300ER MTOW load (with bending moment: 20.70 to 23.54 KNm/m') **can not be operated** in North Runway Soekarno-Hatta International Airport.

Maximum Allowable Gross Weight

To find out how much the Boeing 777-300ER reduced load that can be served by the existing pavement, then conducted a simulation with RTOW (Restricted Take Off Weight) load less than 352 tonnes, ranged from 320 tons to 315 tons. The results of thissimulation are presented in **Table 5** and **6** (deflection response and response at the moment of slab).

Tabel5 The maximumbending moment due to B-777-300ERRTOWload (analysis result).

k_v (MN/m^3)	The maximumbending moment (kNm/m'):		
	320 ton	318 ton	315 ton
35	19.76	19.64	19.18
40	19.37	19.12	18.86
45	18.84	18,70	18.53

Tabel6 The maximumdeflection due to B-777-300ERRTOWload (analysis result).

k_v (MN/m^3)	The maximumdeflection(mm):		
	320 ton	318 ton	315 ton
35	1.59	1.58	1.57
40	1.46	1.45	1.44
45	1.36	1.35	1.34

The result show that for RTOW: 320 tons, the maximum deflection that occurs in slab is about 1.36 mm to 1.46 mm, whereas the maximum bending moment that occurs in slab is about 18.84 to 19.37 KNm/m'. The range of the maximum deflection and bending moment is **still able to be supported** by the existing slab (19.35 KNm/m'). From these analysis, can be concluded that the B777-300ER is restrictively able to beoperated inNorth Runway Soekarno-Hatta International Airportwith RTOW load: 320 tons, while the Maximum Take-off Weight (352 tons) of B777-300ER cannot be operated.

Pavement Classification Number (PCN) of North Runway Soekarno-Hatta Airport

The Aircraft Classification Number (ACN) of B777-300ER can be determined using the ACN-Rigid Pavement Graph for B-777-300ER model (Boeing,2009) [7].With the maximum allowable gross weight: 320 tons and the subgrade category D, thenthe ACN = 114. Usingthe FAA method and procedure (1998) [8], the current Pavement Classification Number (PCN) of North Runwayof Soekarno-Hatta International Airport is 114 R/D/W/T.

Table7 ACN for rigid pavement for aircraft category 4E and 4F.

No.	Aircraft Type	MDTW (kg)	MOTW (kg)	% Load on MLG	Tire Pressure (MPa)	Subgrade Category			
						A	B	C	D
1.	B-777-300ER	352.441	351.535	92,50	1,55	66	85	109	131
2.	B-777-200LR	348.358	347.452	91,80	1,50	64	82	105	127
3.	B-747-400ER	414.130	412.770	93,60	1,58	59	69	81	92
4.	B-747-8	449.056	447.696	94,80	1,52	65	77	90	102
5.	B-787-8	228.384	227.930	91,20	1,57	61	71	84	96
6.	A-340-600	366.200	365.000	93,50	1,61	61	71	83	96
7.	A-350-900	268.900	268.000	93,60	1,66	64	71	83	96
8.	A-380-800	577.000	576.000	94,24	1,50	56	70	91	113

Based on the current Pavement Classification Number (PCN),The North Runway of Soekarno-Hatta International Airportcan operate the entire aircraft in Maximum Take-off Weight (MTOW) condition,except the B777-300ER and B777-200LR aircraft (**Table 7** for subgrade category D).

CONCLUSION

North Runway Soekarno-Hatta currently can not operate (take-off)The B-777-300ER in Maximum Take-off Weight(MTOW).The bending moment that occurred at the slab ranged from 21.92 to 22.38 KNm/m' is greater than the moment capacity (Mu) that able to be supported by the slab (19.35kNm/m'). The B-777-300ER with Restricted Take-off weight (RTOW); which is 320 tons,is allowed to be operated in the North Runway Soekarno-Hatta Airport. The Analysis shows that thePavement Classification Number (PCN)of North Runway Soekarno-Hatta is currently: PCN: 114/R/D/W/T. From this study, it can be concluded that the B-777-300ER and B-777-200LR is permitted to take off with the maximum allowable gross weight or RTOW of 320 tons, while for other aircrafts types namely B-747-400ER, B-747-8, B-787-8, A-340-600, A-350-900 and A-380-800 are permitted to take off with Maximum Take Off Weight (MTOW), because of their ACN are smaller than PCN = 114/R /D/W/T.

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