TESTING AND EVALUATION OF CONCRETE AIRPORT PAVEMENTS

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SUMMARY

This report presents a test method by which it is possible to rapidly obtain information on bearing capacity and homogeneity of concrete runways built on cement treated subbase materials. A light vibrator is used for this type of testing, and the measured deflections are brought into a precise relationship with the results of full-scale tests carried out with loads corresponding to those of a B 747 landing gear. The method is based on field experience from the runways of Zurich International Airport. A control of the method was done by comparing the test results from the two methods with the results of a multi-layer computer program simulating both field test conditions. An example is also given for the determination of evaluation criteria in the case of a concrete runway resting on top of an untreated gravel subbase.

INTRODUCTION

The developments and progresses of the last 10 years in the field of road pavement design show an increasing tendency towards a transition from empirical construction to an analytically based science. Mathematically oriented engineers and researchers in the laboratories have indeed made a great step forward in the knowledge of the composite performance of all influencing factors. However, it is not yet possible to define in exact terms the relationship between a chosen model (together with material characteristics developed in the laboratory) on one side and reality on the other side. But this fact provides no real hindrance to the use of the new methods, as a relative interpretation of computation results - i.e. the comparison of the calculated performance of different structure types - is usually possible with sufficient precision due to the long and large practical experience with the materials and structures used. It also must be pointed out that almost no changes - just minor ones if any - occurred as far as the magnitude of loadings on road pavements is concerned.

This premise, allowing consideration of empirical knowledge, is not given in the case of airport pavements. The constant increase in total weight and wheel loads of aircrafts, which will not be dealt with here, and the reduced number of comparable objects explain why most of the methods and publications on design of airport pavements dedicate large portions to the description of structural testing with very heavy loads, which shall be defined as a full-scale test in this report. One of the most common test-oriented design methods, the LCN-Method [1], also has the important advantage of permitting a standard classification not only for airport pavement structures but also for all aircraft types. The required type of testing is combined with a considerable effort in terms of costs, personnel, material and time. The test apparatus must indeed be able to reproduce the loads of landing gears of the heaviest type, to account for possible increases and for breaking tests. This type of testing will, however, still remain a must in the future, considering the high investments in airport pavement construction, the unsufficient theoretical basis, and the reduced possibility of application of empirical knowledge.

A second, very positive development in road pavement construction in the last few years is an increase in measurement and control activity, combined with a statistical analysis of data. This development has been made possible with the construction of new and fast

tools for the non-destructive testing of completed pavements, as well as the single layers thereof.

The adaptation of the first type of new development - theoretical analysis - is not yet possible in a completely satisfactory way for airport pavement construction. Therefore, the application of full-scale testing still must be considered as necessary in the construction of runways. It is the purpose of this report to show how this can be done in the special case of cement concrete runway pavements. Field experiences serving as a background to this report were obtained in 1976 on a new, an old and a renewed runway with cement concrete pavement at Zurich International Airport.

This report deals in particular with a simple way of performing bearing capacity testing of an entire runway pavement immediately after construction, and with the possibility of bringing test results in a defined relation to those of full-scale testing. The information obtained from full-scale testing, which is limited to some few selected points due to the effort involved can be extended to the entire pavement. Possibilities of bearing capacity testing and evaluation for airport pavements already in use are also shown together with interpretation criteria.

DESCRIPTION OF TEST EQUIPMENT

Light Vibrator

The testing device used for the measurements described in this report is a light vibrator placed in a one-axle trailer pulled by a van (Fig.1). It works according to the principle of the Dynaflect, and has been constructed by the Otto-Graf-Institute of the University of Stuttgart in the Federal Republic of Germany [2]. The vibrator produces a vertical dynamic force of ± 2kN through the counter-rotation of four disks with eccentric masses. The force variation has the shape of a sine-wave with a frequency of 8 cps. When operating, the vibrator rests on the surface to be tested by means of an annular, even, steel plate (R = 11 cm, r = 3.8 cm). A geophone is placed on the surface in the center of the annular ground plate and four other geophones are disposed on a line, 30 cm apart from each other. The signal of the sensors is directly proportional to the vertical deflection of the pavement. Thus, the deflection can be easily calculated using a calibration factor.



Figure 1: Light vibrator in operating position.

The shape of the ground plate requires that the tested surface be sufficiently even to provide a stable position for the vibrator and for the geophones. It is also particularly important to be certain that the surface is free from single aggregates. The geophones normally stand on three points, but they were also used with flat bottoms. This was necessary for those parts of the runway which were grooved for better drainage of surface water. The measurement of deflection with the vibrator requires a time of one minute (including moving from one point to another) for the center deflection, and roughly two minutes for the measurement of the deflection basin (5 points).

Full scale test

Full-scale testing in the runways and taxiways of Zurich Airport was carried out statically and dynamically with a total load of 830 kN distibuted over four square contact surfaces (simulating one landing gear of a B 747 jet aircraft). Loading was produced by two hydraulic pistons, and a counterweight of 1000 kN provided by a 10.0 by 3.5 m concrete plate on four buttresses (Fig.2) [3]. With this device it was possible to measure elastic and permanent deformations for center, corner and two edge loadings for up to two slabs per working day. Displacement of the complete test equipment was done using a special trailer built for abnormally heavy loads, with hydraulic controls for adjusting the height of the loading platform. A total of six people are necessary for the complete operation. Costs per load location are about 500 times those for the vibrator, without taking into account equipment expenses. Former bearing tests [4] on experimental structures had been carried out using much heavier equipment (with heavier loads) and considerably higher costs.

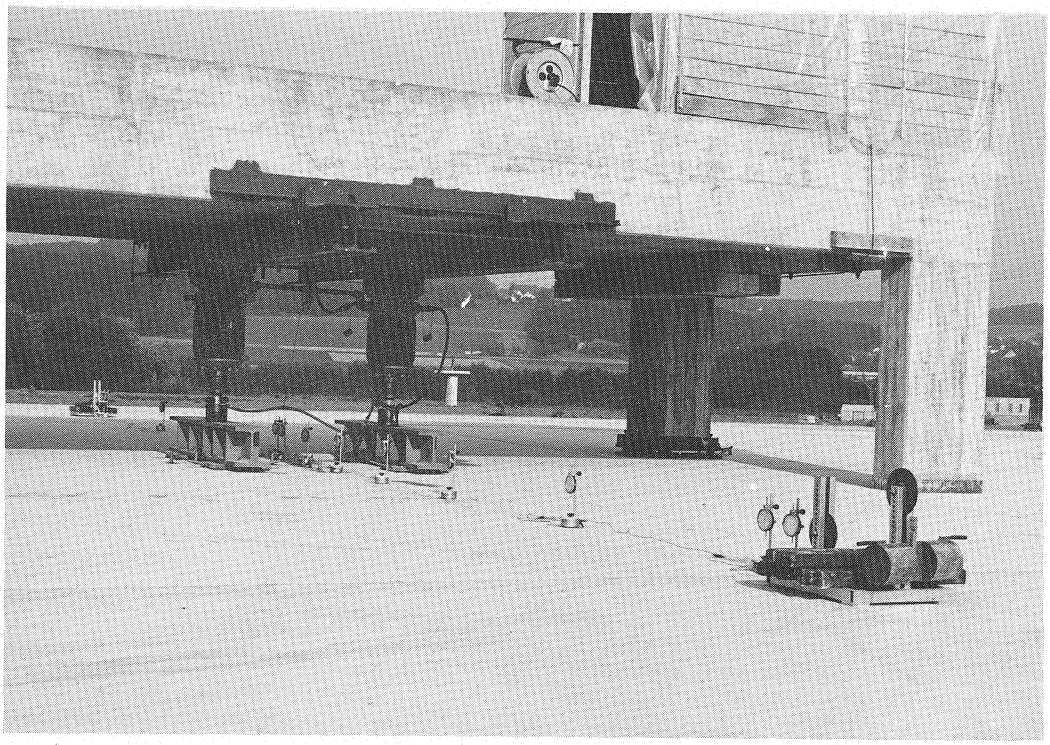


Figure 2: Full-scale test equipment (Photograph courtesy of EMPA)

DESCRIPTION OF TESTED STRUCTURES

Runway 14/32

The new runway 14/32 was constructed from 1972 to 1975, and was cleared for use on April 1,1976 [5].The pavement structure of the 3300 m long runway (Fig.3) consists of 30 cm thick concrete slabs resting on a cement stabilization of the mixed-in-plant type. The thickness of the cement stabilization is variable (25 to 45 cm), according to the bearing capacity of the subgrade. The upper 20 cm of the subgrade have been stabilized with cement for the whole length of the runway. The concrete pavement was constructed in 8 lanes with a slip-form paver. The slabs are 7.5 x 7.5 m wide and have no reinforcement. Load transfer in transverse joints is done by aggregate interlock (no dowels), whereas longitudinal joints are of the keyed type with tongue and groove. Transverse joints were sawed before the cracking occurred. Different types of gravel materials (GW, GP, GM) were used for the upper cementstabilized layer, with a cement content of 65 to 75 kg/m³. Silty and clay materials (GM-ML, GM-GC, GC-CL) were used in the lower layer, with a cement content of 70 to 90 kg/m³. Bearing capacity ranges for the different structure types of the runway are also shown in Fig.3.

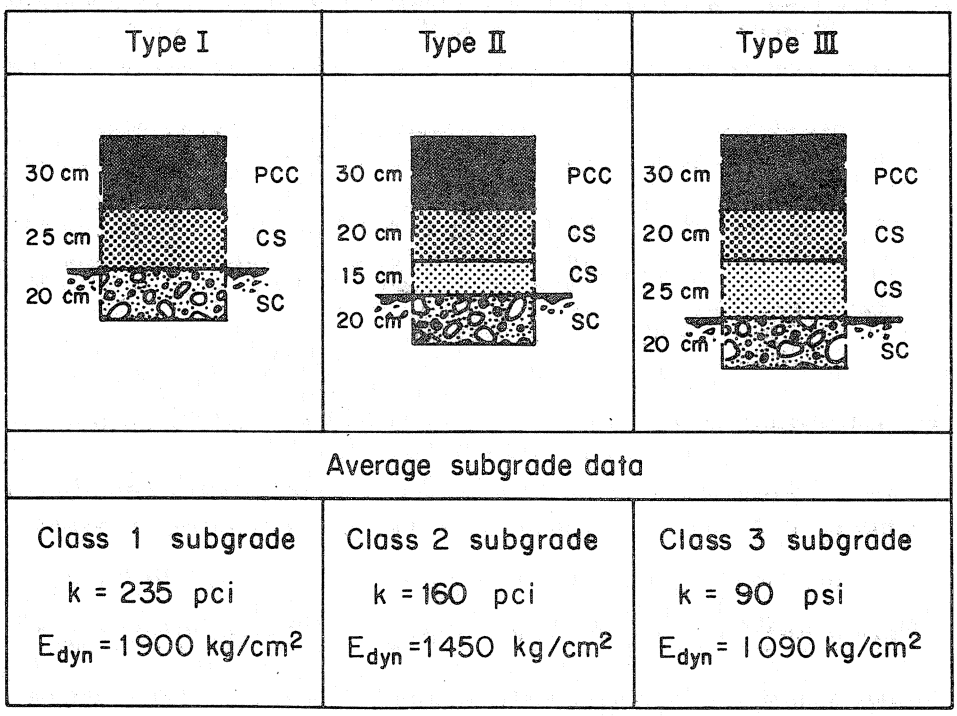


Figure 3: Zurich International Airport.
Structural sections of runway 14/32.
(PCC: Portland cement concrete; CS: cement stabilisation, mixed in plant; SC: soil cement, mixed in place).

Runway 16/34 (old)

Runway 16/34 was built from 1947 to 1949 and lengthened at both ends in 1959/1960. Tests described in this report were carried out on the part of the runway built in 1947/1949. The structure (Fig.4a) consists of a concrete pavement resting on a sand-gravel subbase course. The 5.5 x 7.0 wide concrete slabs (some have different dimensions) were constructed in two layers with a total thickness of 27 cm. Transverse joints have round dowels for load transfer, and a light reinforcement was used in the interface of the two concrete layers (reinforcement 1.8 kg/m^2). The subbase has a thickness of 53 cm. This runway was built originally considering a Lockheed Constellation as the heaviest type of aircraft at that time. The conditions of the runway became worse with the use by heavier aircraft. The quality decreased rapidly after 1970 to the point where larger repair work or reconstruction was considered necessary. In 1975, over 50% of all the slabs in the 23 m wide central portion of the runway were cracked, mostly with transversal or corner cracks [6].

Runway 16/34 (new)

The reconstruction of the damaged runway 16/34, carried out from April 1 to September 30, 1976, involved the central 23 m over a total length of 3300 m. The reconstructed part (Fig.4b) has a 35 cm thick concrete pavement which was laid in a similar way and with the same equipment (slipform paver) as the new runway 14/32. Slab size is 5.75 x 7.0 m. The concrete pavement rests on two cement-stabilized layers with a total thickness of 45 cm. The material for these layers was taken from the existing subbase, which was excavated and brought to a mixing plant. Extensive control was done on the subgrade, with a required minimal k-value (plate load test, 76 cm diameter) of 120 pci. Subgrade material was replaced where this condition was not met.

PROCEDURES AND FINDINGS OF FIELD TESTING

Runway 14/32

As part of a contract with the Department of Construction of the Canton Zurich, deflection measurements with the vibrator were carried out on a total of 880 slabs of runway 14/32 in March, 1976. Deflections were measured only on the loading axis of the vibrator in the center of each second slab of the 4 central lanes. Additional deflection measurements were carried out for 19 loading locations, where full-scale testing had been accomplished (center, edge and corner loading). The entire testing required 4 working days for a two-man team.

Table 1 shows statistical results for the whole runway, as well as for the various sections with different structure.

		Type I	Type II*	Type III	Type II*	Entire Runway
$\bar{x}$	mm·10^{-3}	1.10	1.01	1.11	1.20	1.08
S	mm·10^{-3}	0.27	0.31	0.19	0.25	0.25
CV		0.25	0.30	0.17	0.21	0.23

Table 1: Zurich International Airport, Statistical data of deflection measurements with the vibrator on runway 14/32. $\bar{x}$ = mean deflection value; s = standard deviation; CV = coefficient of variation.

*: Type II was used in two different locations of the runway.

These results show that the whole runway, as well as the different sections, are very homogeneous as far as deflections are concerned. This fact also proves that the adaptation of the structure to bearing capacity conditions of the subgrade (by variation of number and thickness of cement stabilized layers) has been quite successful. Table 2 shows the deflections for the vibrator and for the full-scale tests [3] at 19 different locations. Results from the full scale test are the difference of total and permanent vertical deformation after the third static load cycle (the location of the maximum value is dependent on loading position and lies either in the center of the simulated landing gear or between two "wheels").

①	②	③	④	⑤
	Vibrator deflection $[mm \cdot 10^{-3}]$	Vibrator deflection extrap. 830 kN $[mm \cdot 10^{-2}]$	Full-scale test deflection $[mm \cdot 10^{-2}]$	Ratio ④/③
$\bar{x}$	1.24	51.5	70	1.39
s	0.21	8.72	13.77	0.36
CV	0.17		0.20	0.26

Table 2: Zurich International Airport. Elastic deflection data for vibrator and full-scale test on runway 14/32.

It can be seen from Table 2 that the dispersion of deflection values is practically the same for both test methods. A linear extrapolation of the deflections measured by the vibrator to a load corresponding to the fullscale test gives results of the same magnitude, with the ratio of the two mean values being 1.39. These facts allow us to conclude that the vibrator test may be calibrated to the full scale test. Since both test methods show the same level of dispersion for individual measurements, a well defined relationship may be developed between them. This relationship must be established for each individual case, and is not only dependent on the tested structure, but also on loading configuration and arrangement of the measured points.

Runway 16/34 (old)

Deflection measurements were carried out on a 700 m long section of runway 16/34 just before the concrete in the 23 m wide median part was broken and removed to begin reconstruction. The purpose of this test series was to find possible deflection differences between the badly damaged concrete slabs in the central portion and the undamaged and practically untrafficked slabs of the outer construction lanes. These results were meant to furnish the basis for establishing evaluation criteria for that particular type of concrete runway.

The slabs of the two central lanes (without considering the 1 m wide centerline lane) had, as it already has been mentioned, a large number of cracks. In order to get results representative for all the different slab quality conditions, instructions were given to the driver of the van to follow an imaginary serpentine line on each construction lane and to stop once on every other slab. The stopping points were alternately in the near, central and far thirds of the slabs with respect to direction of travel. This procedure helped to obtain a random distribution of measurement locations in the center, edge and corner of the slabs, with varying distances to existing cracks. The same traffic pattern was also followed during the measurements on the undamaged outer construction lanes.

As can be seen from the results in Table 3, no differences between the mean deflection values for the damaged and undamaged sections of the runway were found. However, a very significant difference could be seen as far as homogeneity of the deflections is concerned.

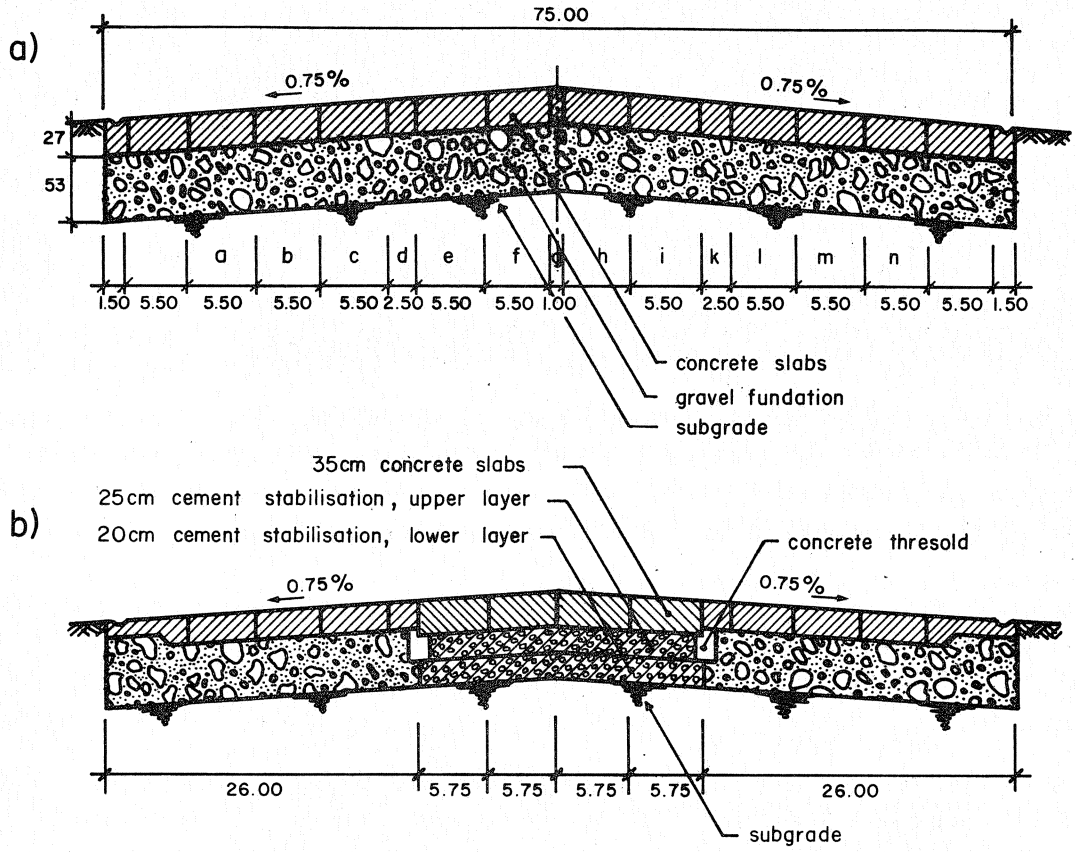


Figure 4: Zurich International Airport. Cross-section of the runway 16/34
a: original construction 1947
b: reconstruction of the central part 1976

		Lanes f + h (damaged)	Lanes b + m (undamaged)
$\bar{x}$	mm · 10^{-3}	4.84	4.67
s	mm · 10^{-3}	2.81	1.12
CV		0.58	0.24

Table 3: Zurich International Airport. Vibrator deflection data for damaged and undamaged sections of runway 16/34.

It is generally known that one of the prerequisites for the good performance of a concrete pavement lies in a homogenous supporting layer [7]. For this reason, the use of treated materials immediately below the concrete layers is increasing. The results obtained on runway 16/34 led to the assumption that the dynamic influence of traffic caused a postcompaction, associated with the displacement of material and the creation of cavities under the concrete slabs in the untreated gravel subbase. The conclusion fol-

lows that the observation of changes in the coefficient of variation of deflection measurements is necessary for the control of the performance of concrete runways under traffic. This conclusion is limited to structures corresponding to that of runway 16/34, i.e. a concrete pavement resting on a thick untreated gravel subbase. No pumping effect was observed with this subbase material at Zurich Airport.

Some full-scale tests, using the same equipment and loading conditions as for the new runway 14/32, were also carried out in 1975 on the runway 16/34. The ratio of the mean values of deflections between the results of the full-scale test and the extrapolated (linearly from 2 to 830 kN) vibrator deflections was 0.6. The restricted number of individual measurements (a total of 8) and the influence of the choice of test locations on the damaged runway for the full-scale test must be considered when interpreting the value of the ratio of deflections. Therefore the value given above is not representative for average conditions of runway 16/34.

Runway 16/34 (new)

The test method with the vibrator, proven to be successful on runway 14/32, will also be applied on the reconstructed portion of the runway 16/34, which will get the same type of structure as the new runway. Due to the progress of construction work, some measurements have already been carried out. Deflections were measured on one central construction lane in the same portion of the runway which had been measured previously in the damaged condition. The concrete pavement had an age of 35 days at the time of the vibrator testing.

The results, shown in Table 4, are slightly higher as far as deflections are concerned in comparison to runway 14/32, whereas the homogeneity is better. The latter can be partially explained by the fact that the measurements were made before the surface was grooved giving an ideal contact surface for both the ground plate of the vibrator and the geophone.

		Concrete Pavement	Stabilized Layers
$\bar{x}$	$mm \cdot 10^{-3}$	1.28	5.28
s	$mm \cdot 10^{-3}$	0.13	1.61
CV		0.10	0.30

Table 4: Zurich International Airport. Deflection data obtained by the vibrator on the concrete pavement and on top of the cement-stabilized subbase of the reconstructed runway 16/34.

On this runway, it has also been possible to measure deflections with the vibrator on the surface of the upper cement-stabilized layer. The results, obtained on the same runway location as the later tests on the surface of the concrete slabs, are also shown in Table 4.

CONTROL OF RESULTS IN A MULTILAYER MODEL

The good, nearly linear correlation between the deflections obtained from the vibrator and from the full-scale test is one of the essential points of this report. The performance of the tested structure under two extremely different loads can be explained by the fact that the concrete pavement, and to a large extent also the cement treated materials in the stabilized layers, behave like an elastic body following Hook's law. It was thus quite natural to verify field observation through theoretical analysis. As already mentioned in the introduction, characterization of materials is still one of the points which bring uncertainty in to the results of computer programs based on elastic solutions. The difficulties associated with determining appropriate material moduli lie in

the fact that each modulus depends on the particular test equipment used and, in the case of materials which actually do not behave elastically, on the imposed stress level. In this particular case, the material with a non-elastic behaviour was the subgrade soil. Now it is possible to obtain reasonable results in a computer program if an appropriate modulus for the subgrade can be found for a particular load condition. In the course of different experiences with vibrator testing, where it was possible to carry out measurements on top of each single layer of a pavement structure including the subgrade, a set of appropriate Young's moduli (E) for different soils was found. This was accomplished by an iterative computation process which was stopped when equality of calculated and measured deflections was obtained. A similar approach was used by the consulting engineers in charge of the design of the new runway at Zurich Airport [5]. They considered the loads imposed by aircraft landing gears, i.e. the same as used in the full-scale tests.

In each one of these two approaches, a different value of Young's modulus (E) for the subgrade was found. Each value is valid for the loading conditions and the stress level under which it was determined.

Calculations were made with the BISAR computer program [8], developed by the Shell Company primarily for flexible pavement analysis. BISAR is an elastic multilayer program permitting the calculation of stresses, strains, and displacements in any point under the action of one or more circular loads. A three-layer structure was used to simulate runway 14/32, and all cement-stabilized materials were considered as one homogenous layer. A full bond was assumed between the layers. Tables 5 shows the material data and dimensions. Loading conditions, calculated deflections, and the comparison with measured values are given in Table 6.

Layer	Thickness [cm]	E (load 2 kN) [N/mm²]	E (load 830 kN) [N/mm²]	ν
1	30	40000	40000	0.35
2	55	4000	4000	0.35
3	∞	700	150	0.35

Table 5: Data for a three-layer computer model of runway 14/32.

①	②	③	④	⑤	⑥
	Load kN	Load radius cm	Deflection calculated [mm · 10^{-2}]	Deflection measured [mm · 10^{-2}]	Ratio ④/⑤
Vibrator	2	11	0.118	0.108	1.09
Full-scale test	4x208.75	22.39	79.5	70.0	1.14

Table 6: Comparison of calculated and measured deflections for runway 14/32.

The results show a very good agreement between measured and calculated values for both test procedures. Geometric assumptions for the pavement model were the same for both cases, whereas the different subgrade moduli were determined independently from each other.

CONCLUDING REMARKS

The results of field experience with vibrator testing on the new runways of Zurich International Airport have shown that this testing device is suitable for bearing capacity and quality control of a cement concrete pavement. The almost linear correlation values with the full-scale test are confirmed by the results of a computer model utilizing an elastic multilayer system. These conclusions are strictly valid only for a particular type of structure, as used in runway 14/32 and in the reconstructed part of runway 16/34. These structures consisting of cement concrete slabs resting on a thick cement-stabilized layer, show nearly elastic behaviour. It is assumed that the reported test method could also apply to other types of pavement structures.

Measurements carried out on a concrete runway in operation for over 25 years - where the subbase consisted of a thick layer of untreated gravel - have shown that changes in the coefficient of variation of deflections are the criterion to be observed in pavement evaluation.

ACKNOWLEDGEMENT

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