

EMERGENCY REHABILITATION OF CONCRETE
PAVEMENT SECTION OF AN
AIRPORT RUNWAY

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SECTIONS OF AN AIRPORT RUNWAY

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SYNOPSIS The E-W runway of the Taipei International Airport was constructed some 20 years ago. Due to heavy usage and poor subgrade condition underlying the runway, certain critical sections of the concrete pavement have deteriorated badly and required urgent replacement. The most critical requirement for the replacement work was that the runway must be kept in operation every day. Less than seven hours per night was available for the construction work. All operation including removing of the damaged pavement, replacing subbase, compaction of subgrade, placing and curing of the new concrete must be completed within this short time period. This paper describes a successful design and construction procedures adopted for such an operation in 1976.

1. INTRODUCTION

The E-W runway which is the major runway of the Taipei International Airport was constructed in 1956. At the time of construction, the runway was designed to handle DC-7 class of loading and other light aircrafts. In recent years, the Taipei Airport becomes a major international airport in the Far East with its rapidly increasing amount of traffic. The average traffic volume increased from 50 flights per day to well over 200 and the loading class also increased several folds from DC-7 to DC-8 and Boeing 747. The runway pavement has shown distresses and deteriorations in numerous places. In addition to the overloading, heavy traffic volume, and aging, the poor subsoil conditions and general subsidence of the area further contributed to the acceleration of deterioration of the pavement structure in recent years. Traffic safety became a major problem to the airport authority.

During the past few years, regular inspections of the pavement condition have been made. Various types of epoxy resins were utilized to mend small cracks and damages. In July 1976, a comprehensive evaluation of the pavement condition of the existing runway was undertaken by the Moh and

Associates under the commission of the Taipei Airport Authority. This paper reports the results of the investigation, an emergency rehabilitation program and the performance of the replaced sections.

2. EXISTING CONDITIONS OF THE RUNWAY

To evaluate the runway pavement condition, the program of investigation included a detailed topographic survey, boring and sampling of the pavement, base and subgrade materials, in situ plate loading tests, measurement of pore water pressures in the base and subgrade, and laboratory testing on the soil samples obtained.

The runway lies in an E-W direction, and is 3,000 m long, 60 m wide. The original design of the pavement structure include a 35 cm thick plain concrete surface and a 34 cm thick layer of graded base course overlying compacted clayey subgrade. Fig. 1 shows a typical cross section of the pavement. The concrete pavement surface was poured in 6 m by 3.75 m size panels. Six different types of joint systems were used. The main drainage system in the runway area consisted of two drainage ditches running parallel to the runway. No subsurface drainage system was provided.

3. FIELD AND LABORATORY INVESTIGATION

A total of 15 bore holes was drilled along or near the center line of the runway. Concrete cores were taken from the pavement and soil samples were obtained from the underlying subgrade. Nine observation wells and nine piezometers were installed at various depths in the base course and subgrade for the purpose of measuring the groundwater condition and variations of excess pore pressure. Fig. 2 shows the locations of the bore holes, observation wells, and soil profile along the runway center line deduced from the boring data.

4. CONDITION OF CONCRETE SURFACE

Fig. 2 shows that the actual thickness of the concrete surface of the pavement varied from 30 cm to 58 cm. A series of compression tests was performed on the concrete cores obtained from drilling. Results in Fig. 3 show that the concrete strength decreased with depth from the surface. Ten centimeters below the pavement surface, the concrete had an average compressive strength of only 8.83 MN/m^2 . Even at a

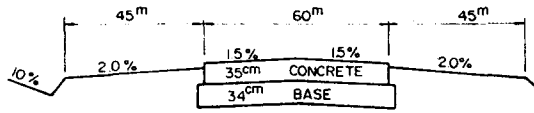


FIG. 1

Fig. 1 Typical Section of Pavement Structure

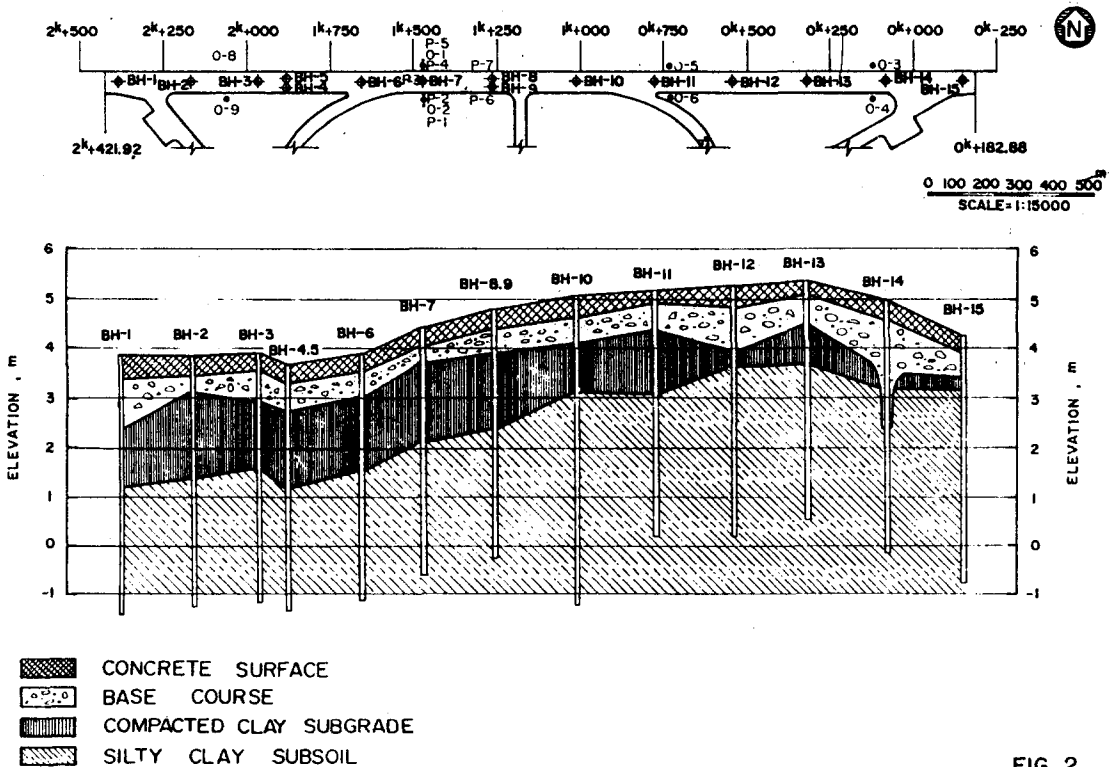


FIG. 2

Fig. 2 Soil Profile along Runway Centerline and Locations of Bore Holes and Piezometers

depth of 40 cm, the concrete strength was still quite low, around 28.44 MN/m². There are several factors which can be considered to be responsible for these low strength values. They include localized overstress, differential settlement, fatigue, aging, weathering action, and also possibly poor quality during construction.

5. SUBGRADE AND SUBSOIL CONDITION

As shown in Fig. 2, the subgrade of the runway pavement consists of mainly a compacted clay, yellowish grey in color, varying in thickness from 20 to 180 cm. According to the original ground profile, the north side of the runway area was filled and the south side was cut area. The subgrade material is of medium to high plasticity with low permeability and thus poor drainage characteristics. According to the Unified Soil Classification System, this soil belongs to the CL to ML group and is a poor subgrade material. According to the FAA Classification System, this soil belongs to E-7 group or higher with class rating as R_p or R_c (SARGIOUS, 1975). The optimum moisture content of this clay as determined by the Modified AASHO compaction is 17%. However, in majority of the cases, the moisture contents of the subgrade samples taken at the time of the field investigation were higher than the optimum, in some cases as high as 45%. The bearing capacity of the subgrade material decreased greatly due to the increase in moisture content after compaction. Furthermore, under continuous heavy impact loading from the aircrafts, the excess pore water pressure developed in the clay subgrade could not dissipate due to its low permeability. Pumping action occurred frequently. It has been observed by the airport maintenance crew that mud pumping occurred along several pavement joints.

A series of soaked and unsoaked CBR tests was performed in the laboratory on recompacted subgrade material. From the test results, relationship between moisture content and soaked CBR value was obtained. The strength values of the subgrade material in situ were obtained by interpretation from this relationship.

The subsoil underlying the compacted subgrade is a layer of soft clay with low plasticity but high compressibility. The natural moisture content of the soil was around 30% which is near its liquid limit. This type of soil has low bearing capacity, easily to be disturbed and would have large settlement upon loading.

6. SUBSURFACE WATER LEVEL AND PORE WATER PRESSURES

Data obtained from the subsurface water observation wells and piezometers indicated that the pore water pressures in the runway area can be divided into two categories:

(A) Subsurface groundwater level — The groundwater observation wells were installed along the runway edges about 2 to 4 m from the pavement. Fig. 4 shows the static water level during the dry season. The groundwater level appeared to be higher at the eastern end of the runway probably due to the existence of a drainage culvert across the runway in that area. The culvert apparently developed cracks and water often seeped upward onto the pavement through pavement joints.

Within the area of runway pavement, the pore water pressures in the subgrade increased due to the aircraft loading. Due to low permeability of the subgrade and poor drainage condition, the excess pore water pressure could not dissipate easily. Consequently the pore pressures under the pavement were higher than those outside the pavement, as shown in Fig. 5.

(B) Localized excess pore water pressure — According to the pavement design section, the average thickness of the concrete surfacing was 35 cm and the thickness of the base course was 34 cm. Fig. 4 shows that the static groundwater surface existed at a depth of about 1.2 to 1.4 m below the pavement surface. In other words, there should not be any positive pore water pressure existing in the base course. During maintenance and repairing work near Station 1 + 260, water was found flowing upward from the base course. Subsequently installed piezometers in the base course indicated that the pore water pressure level reached 10 to 50 cm below the surface, i.e. there was an excess pore water pressure equivalent to about 1.1 to 0.6 m of water head.

A series of pumping wells was installed at locations where excess pore water pressure was observed or suspected. After continuous pumping for several hours, it was found that in some locations, the piezometric level dropped and in other locations the piezometric level gradually rised again after pumping was stopped. This indicates that there was localized depressions in the subgrade and water was probably trapped in between the base and subgrade.

7. SETTLEMENT CONDITION

Since the completion of the runway some twenty years ago,

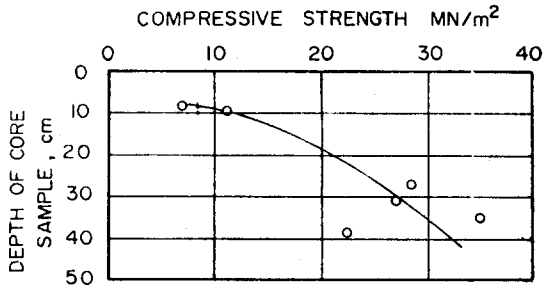


FIG. 3

Fig. 3 Variation of Concrete Strength with Depth of Core Sample

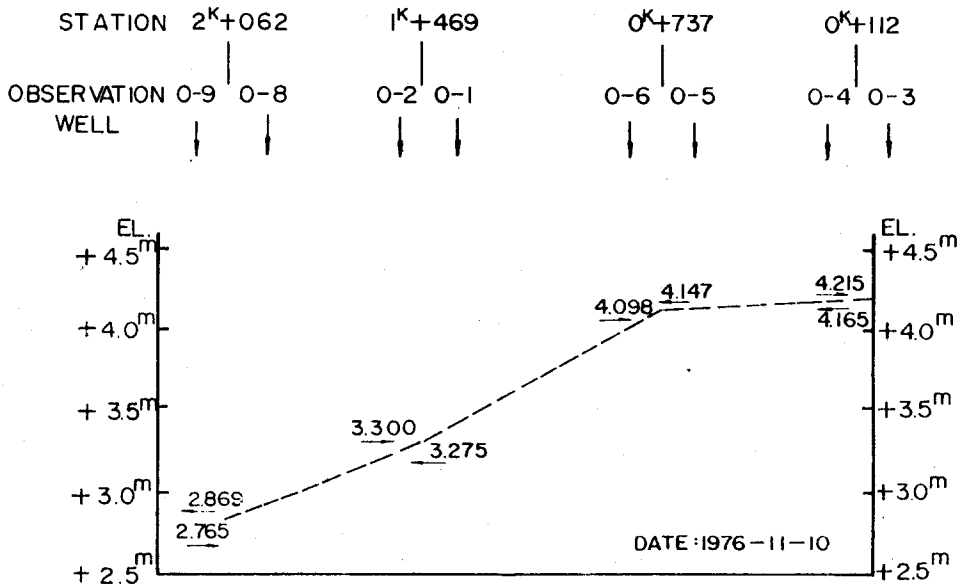


FIG. 4

Fig. 4 Static Groundwater Level during Dry Season

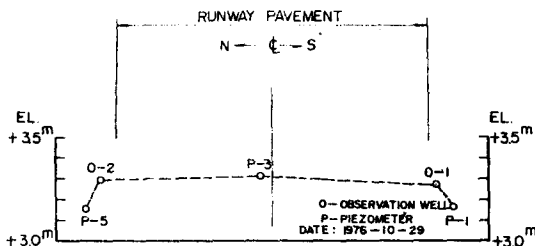


FIG 5

Fig. 5 Pore Water Pressures in Subgrade at Station 1 + 469

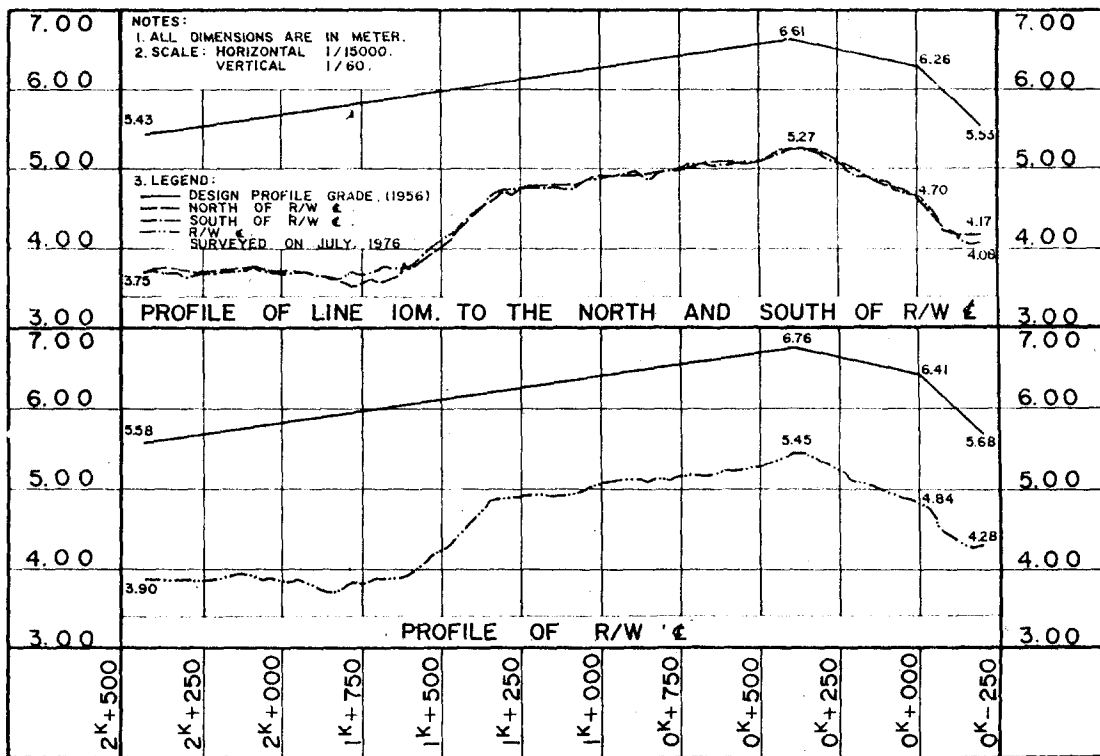


Fig. 6 Runway Profile

the runway elevation has been continuously settling. The settlement can be attributed to two main courses: (i) the general subsidence of the Taipei Basin due to deep well pumping, and (ii) consolidation settlement of the subsoil due to the runway and aircraft loading. Fig. 6 shows the elevations of the runway surveyed in August 1976. Comparing with the elevation at the time of construction (1956), the average settlement of the runway during the 20 years time ranged from 130 to 220 cm. The amount of settlement which can be attributed to subsidence varied from 70 to 100 cm. Therefore, the relative settlement of the runway due to loading ranged from 50 to 130 cm. Table 1 shows the settlement values for the various sections of the runway. It can be seen that considerable amount of differential settlement had occurred. The most serious section was near Station 1 + 750 with a maximum relative settlement of 130 cm. Due to the wind direction, most the take-offs and landings at the Taipei Airport took a west to east direction. The section between Stations 1 + 350 and 2 + 000 is considered to be the most critical area which experiences more concentrated loading (rear wheel) during take-offs and braking forces during landings.

8. BEARING CAPACITY OF THE RUNWAY

(A) Bearing capacity of the pavement surface — The bearing capacity of the pavement surface depends primarily on the flexural strength of the concrete. Due to difficulties in obtaining specimen of the existing pavement for flexural test, the flexural strength was estimated from compressive strength by using the following relationship:

$$MR = k \sqrt{f'_c}$$

where MR = modulus of rupture
 k = coefficient of correlation, from 8 to 10
 f'_c = compressive strength

Table 2 lists the average values of the computed flexural strengths. All the values are much lower than the currently used design value of 4.55 MN/m² for carrying DC-8 type of aircraft.

(B) Bearing capacity of base and subgrade — The original design thickness of the base course was 34 cm, however the boring data showed that the actual thickness of the base course varied considerable over the runway length. In several locations, it was found that fines from the subgrade has intruded into the base course. The effective thickness of the

Table 1 Settlement of Runway Pavement
from 1957 to 1976

Station	Total Settlement, cm	Settlement due to Regional Subsidence, cm	Settlement due to Runway Loading, cm
0 - 150 to 1 + 350	140 to 150	70 to 90	50 to 80
1 + 350 to 1 + 600	140 to 205	85	55 to 120
1 + 750	220	90	130
1 + 950 to 2 + 350	170 to 200	90 to 100	70 to 110

Table 2 Average Strength of Concrete Core Samples

Sample Depth, cm	Compressive Strength, MN/m ²	Flexural Strength, MN/m ²	
		k = 8	k = 10
0 - 15	6.83	1.74	2.14
15 - 35	28.43	3.54	4.41
Weighted Ave.	19.19	2.91	3.63

base was therefore greatly reduced. After considering all the factors concerned, it was assumed that the overall effective thickness of the base course under the conditions at the time of investigation was probably in the order of 25 cm. By using this value and the concrete strength values listed in Table 2, the minimum required values of the coefficients of subgrade reaction, K (i.e. for a factor of safety equal to 1.0), for the base course and subgrade material could be calculated as shown in Table 3. The actual in situ K values of the subgrade material were very close or even smaller than these minimum required values. This means that the pavement subgrade was at the point of incipient failure as far as load carrying capacity is concerned.

As shown in the subsoil profile, the subgrade material primarily consisted of clayey soil. This soil had relatively high strength when compacted to the maximum dry unit weight at optimum moisture content. Upon contact with water, the soil absorbed water, swelled, and softened. Laboratory test results showed that the CBR values dropped from 40 to 80 for as-compacted specimens to only 2 to 3 after soaking. When this type of soil were used as subgrade material, it is necessary to have adequate subsurface as well as surface drainage system to prevent water saturation of the soil. In the present case, due to lack of subsurface drainage and poor surface drainage system, water seeped into the subgrade. The in situ moisture content ranged from 25 to 45% which was much higher than the optimum moisture content, in fact it was even higher than the moisture content of laboratory compacted specimens after 96 hours of continuous soaking. Due to the nonuniformity and the large variation of the moisture content distribution along the runway, the loading carrying capacity and also compressibility of the subgrade varied considerably. These factors led to serious differential settlement and damages to the concrete surface.

9. EXAMINATION OF PAVEMENT SURFACE DAMAGES

A detailed examination of the pattern and distribution of pavement damages was made throughout the entire runway. In general, cracking patterns could be divided into four types. They are: (i) corner cracks, (ii) joint cracks, (iii) diagonal cracks, and (iv) deterioration after minor repairs. Fig. 7 shows schematic diagrams of the deterioration conditions of some of the pavement panels. Survey results further showed that majority of the cracks and damages concentrated within the range of the mid-third width of the runway. The most serious condition occurred in 8 panels at Station 1 + 265 which had cracks distributed over the entire panels and were

beyond regular repairing. These panels located in an area generally referred to as the "landing zone" where brakes of the aircrafts are applied after landing. Heavy loading, high moisture content (about 44%) in the subgrade, large settlement and deterioration of concrete quality (the concrete core from this area has lowest strength value) all contributed to the poor condition of the pavement. In order to maintain flight safety, it was decided that an emergency rehabilitation program must be devised for this area.

10. EMERGENCY REHABILITATION PROGRAM

Since the E-W runway is the only major runway at the Taipei International Airport, and the airport itself is the major international communication center for Taiwan, the airport could not be closed for a complete overhaul before the opening of the new Taoyuan International Airport in 1979. Therefore any emergency repair program must meet the following conditions:

(i) The airport cannot be closed for operation even for one day.

(ii) The seriously damaged parts of the concrete runway surface must be rehabilitated in order to maintain traffic safety.

(iii) Any repair work must be carried out under the condition of not interfering the normal operation of the airport. The maximum length of working time each day is only 6 hours after midnight. The runway must be opened for traffic after 7 o'clock every morning.

(iv) The repaired product must last as long as possible, at least for a period of six months.

Three possible solutions were considered and investigated for this purpose. They were the use of polymer concrete, asphalt concrete and rapid-set portland cement concrete. Polymer concrete is a newly developed product utilizing the polymerization of chemicals to bind aggregates, no cement is used. The strength of the polymer concrete can be very high and the set time is very rapid. It has been used successfully in repairing bridge decks of the Major Deegan Expressway in New York (KUKACKA et al, 1975). However, due to the rapid chemical reaction of polymerization, very strict control of the proportion is necessary. It is most suitable for works involving only small volume of material.

Table 3 Values of Coefficient of Subgrade Reaction K for the Existing Base Course and Subgrade

Type of Aircraft	Concrete Flextural Strength, MN/m ²	Minimum Required K Value for F.S. = 1, MN/m ³		K Value from Plate Bearing Test, MN/m ³	
		Base	Subgrade	Base	Subgrade
B727	2.91	19.0	10.8	-	6.8-27.1
B707		38.0	21.7	-	6.8-27.1
B747		48.9	29.9	-	6.8-27.1
DC-8-63		48.9	29.9	-	6.8-27.1
DC-10		32.6	19.0	-	6.8-27.1
B727	3.63	13.6	6.8	-	6.8-27.1
B707		13.6	6.8	-	6.8-27.1
B747		19.0	9.5	-	6.8-27.1
DC-8-63		19.0	9.5	-	6.8-27.1
DC-10		13.6	6.8	-	6.8-27.1

Table 4 Average Strength of Sika Set Treated Concrete

Curing Time, hour	Compressive Strength, MN/m ²	Flextural Strength, MN/m ²
4	13.79	2.77
5	16.55	3.04
6	25.86	3.25
24	26.20	2.82

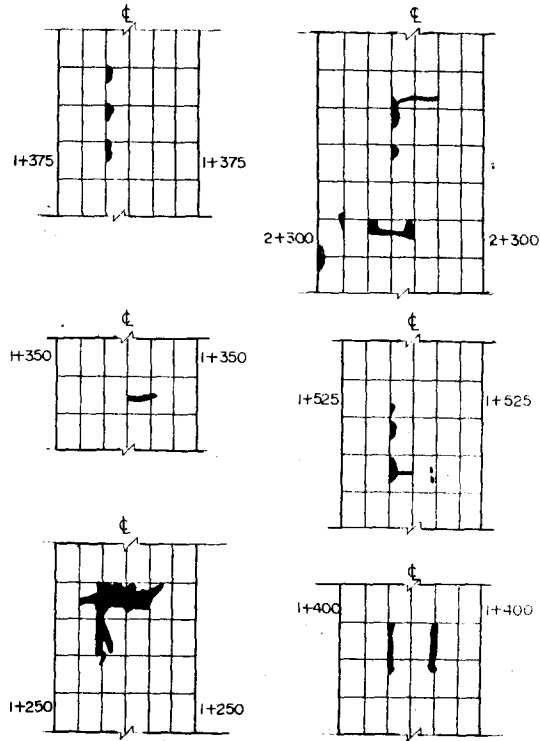


FIG 7

Fig. 7 Damages of Concrete Pavement Surfaces

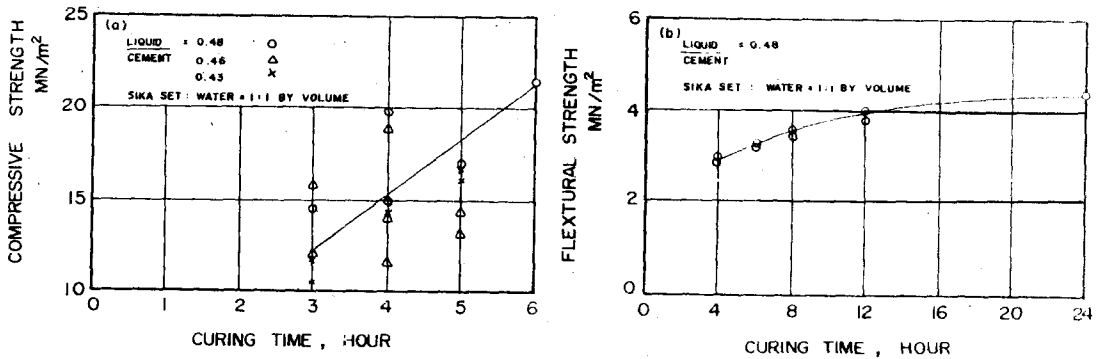


Fig. 8 Strength Development of Accelerator Treated Type III Cement Concrete

Asphalt concrete requires relatively short period of curing time as compare with normal portland cement concrete. However, asphalt concrete must be properly compacted. Furthermore, for the case under consideration, the pavement thickness was about 35 cm, several layers of asphalt concrete will be needed. In view of the small area available for working and difficulty in carrying out proper compaction, asphalt concrete was also considered not to be suitable.

Rapid-set portland cement concrete has the main advantages that it would be relatively easy to construct. Secondly, the finished products would have the same type of material as the neighboring panels which were not being repaired. The main requirement was to find a suitable chemical which will accelerate the setting of the concrete and develop sufficiently high early strength in few hours but will not sacrifice the ultimate strength.

At the time of the investigation, one of such a product became available, i.e. Sika Set manufactured in Switzerland. Past records of the manufacturer showed that Sika Set could accelerate the strength development of concrete using Type III high early strength cement. However, no record was available from anywhere that a concrete pavement could be open for aircraft traffic with less than 24 hours of curing. A testing program was conducted to evaluate the mix design and strength development of Sika Set treated concrete. Fig. 8 shows some of the test results. On the basis of the average strength results of the Sika Set treated concrete (Table 4), the estimated in situ moduli of subgrade reaction of the base course and subgrade (Table 3), the factors of safety of the new concrete pavement after replacing with the Sika Set treated concrete were calculated as shown in Fig. 9.

For the Taipei Airport, the heaviest aircrafts involved are Boeing 747 and DC-8 and the most frequently used type of aircrafts is Boeing 727. Although the commonly used factor of safety for repetitive loading is between 1.5 and 1.7 (PACKARD, 1973), the safety factor required for the concrete after 4 hours curing can be much lower for two reasons. Firstly, at the Taipei Airport, there are only very few civilian airline flights in the early morning hours which use Boeing 747 or DC-8. Secondly, the strength of the new concrete, in other words the safety factor, increases with time. It was therefore concluded that a compressive strength of 13.79 MN/m^2 ($2,000 \text{ lb/in}^2$) after 4 hours curing can be considered to be adequate for the purpose of emergency repairing work provided that the base course is properly recompacted.

In order to ensure safety, strict quality control was

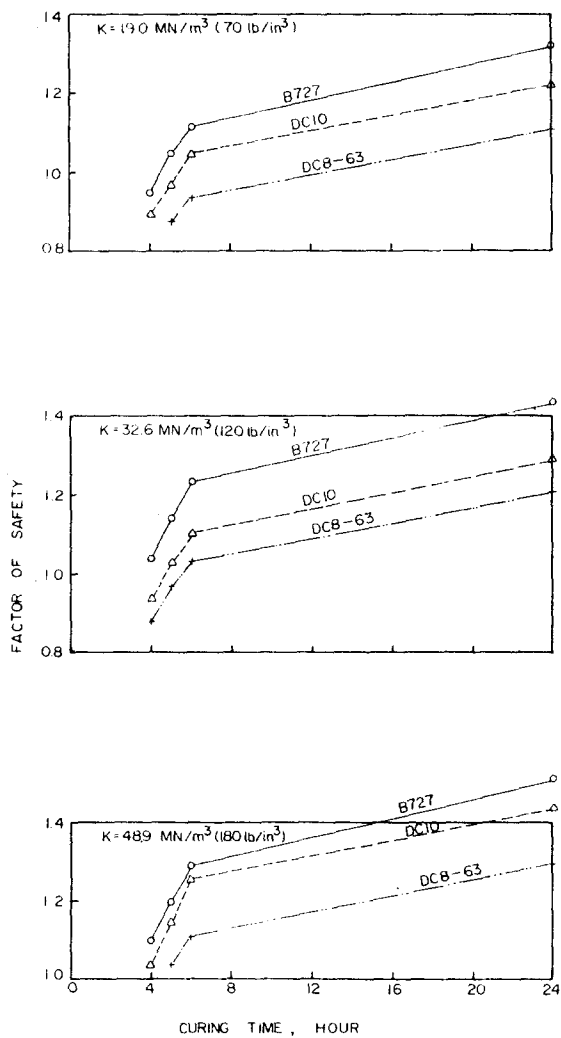


FIG 9

Fig. 9 Relationship between Factor of Safety and Curing Time for Accelerator Treated Type III Cement Concrete

exercised during the construction. The eight panels were replaced during the period of November 4 to 11, 1976. All works were carried out by manual labor. The replacement work involved the following steps:

- (i) Use concrete saw to cut the four sides of each panel — 2 hours.
- (ii) Use backhoe equipped with high pressure drill to break the concrete pavement. Clean the broken concrete — 1 hour.
- (iii) Remove the existing base course and replace with graded material. Compact the replaced base course — 20 minutes.
- (iv) Pump out accumulated water and use water stop agent when necessary.
- (v) Use compressed air to clean the sides of cut — 10 minutes.
- (vi) Place preassembled reinforcing steel cage — 5 minutes.
- (vii) Apply epoxy resin along the four sides of the existing concrete.
- (viii) Use manual labor to mix the cement, aggregate, water and Sika Set — 1 hour.
- (ix) Compact the concrete with vibrator.
- (x) Finish the surface, apply curing compound, clean the area — 30 minutes.
- (xi) Test the concrete by using test hammer after a minimum of 3 hours curing.

The total operation for each panel took $4\frac{1}{2}$ to $5\frac{1}{2}$ hours. After curing the concrete for a minimum of 3 hours, the runway was open to traffic. Due to the rapid chemical reaction, large amount of heat was released during curing. The finished panel generally has many hair cracks which were not considered to be of any detrimental effect. To date (April 1978), eighteen months after the replacement, all of the eight panels are still in service. No serious deterioration has been observed. It appears that these panels will most likely to last for another year or so until a complete overhaul of the runway is to take place.

The most important factor which contributed to the success of the emergency rehabilitation program is strict quality control of the construction which included not only the placement of the concrete itself but also the replacement of the base course. Besides the Sika Set used in the 1976 operation, it was found lately that several other products, such as Protex PDA202H and Thoroguard can also accomplish the same function.

11. ACKNOWLEDGEMENTS

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