1950

A survey to determine the most economic design for concrete runways of a class 4 airport

Yani Triandafilidis

Follow this and additional works at: http://scholarsmine.mst.edu/masters_theses

Department:

Recommended Citation
Triandafilidis, Yani, "A survey to determine the most economic design for concrete runways of a class 4 airport" (1950). Masters Theses. Paper 5037.
A SURVEY TO DETERMINE THE MOST ECONOMIC DESIGN
FOR CONCRETE RUNWAYS OF A CLASS 4 AIRPORT

BY

YANI TRIANDAFILIDIS

----

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in partial fulfillment of the work required for the
Degree of
MASTER OF SCIENCE IN CIVIL ENGINEERING
Rolla, Missouri
1950

-----

Approved by

C. H. Carlton
Professor of Civil Engineering
ACKNOWLEDGEMENT

The author wishes to express his appreciation to Professor E. W. Carlton of the department of Civil Engineering for his help in this investigation.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgement</td>
<td>ii</td>
</tr>
<tr>
<td>List of Illustrations</td>
<td>iv</td>
</tr>
<tr>
<td>List of Tables</td>
<td>v</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Aircraft and Wheel Loads</td>
<td>3</td>
</tr>
<tr>
<td>Stress Repetitions on Runways</td>
<td>6</td>
</tr>
<tr>
<td>Meteorological Data</td>
<td>8</td>
</tr>
<tr>
<td>Drainage</td>
<td>11</td>
</tr>
<tr>
<td>Joints in the Runway Pavement</td>
<td>16</td>
</tr>
<tr>
<td>First Alternative: Plain Concrete Runways</td>
<td>17</td>
</tr>
<tr>
<td>Second Alternative: Reinforced Concrete Runways</td>
<td>27</td>
</tr>
<tr>
<td>Comparative cost of the two Runways</td>
<td>34</td>
</tr>
<tr>
<td>Summary</td>
<td>36</td>
</tr>
<tr>
<td>Conclusions</td>
<td>38</td>
</tr>
<tr>
<td>Bibliography</td>
<td>40</td>
</tr>
<tr>
<td>Vita</td>
<td>41</td>
</tr>
<tr>
<td>Appendix</td>
<td>42</td>
</tr>
</tbody>
</table>
LIST OF ILLUSTRATIONS

Runway lengths (Fig. III) ........................................... 9
Transverse section of runway 1st Alternative (Fig. VI) .... 25
Plan of transverse joints 1st Alternative (Fig. VII) .... 26
Transverse section of runways 2nd Alternative (Fig. VIII) 32
Longitudinal section of the runways 2nd Alternative (Fig. IX) .................................................. 33
Safety factor in concrete (Fig. I) .................................. 44
Wind Rose (Fig. II) .................................................... 45
Graphical determination of the thickness of pavements (Fig. IV) .................................................. 46
Pressure distribution on subgrade (Fig. V) ..................... 47
LIST OF TABLES

Types of planes (Table I) ........................................ 42
Classification of soils (Table II) ............................... 43
INTRODUCTION

This study is for the purpose of determining the most economical design for the runways of the Yesilkoy airport in Istanbul, Turkey. The discussion will include different design methods for the runways and the longitudinal and transverse joints that will be used in each case to provide crack control in the runway surfacing.

The city of Istanbul has a population of about one million. It is a growing city, being the industrial center of Turkey, and it also serves as a terminal for transcontinental airway systems. For these reasons it was decided to construct a class 4 airport for the city.

Yesilkoy is 28 miles from the center of Istanbul, but it is the only possible location for the airport because a site suitable for the construction of an airport does not exist any nearer to the city.

An obsolete airport in Yesilkoy now serving the city of Istanbul will be abandoned as soon as the new airport is ready. A two lane highway and a double track railroad provide the communication between Yesilkoy and Istanbul.

The site selected for the airport lies in the center of a level stretch of ground which extends to about 5 miles in one and 8 miles in the other direction. The ground slopes gently in a N-S direction but the slope does not exceed 1%. The site selected is capable of providing for the expansion of the proposed airport if this becomes necessary in the
future. Another advantage of the site is the fact that there are fields available for emergency landings immediately adjacent to the proposed landing fields. This lessens the danger of serious accidents in landing and in taking off.
AIRCRAFT AND WHEEL LOADS

As stated before the airport under consideration is a class 4 airport. This airport is to serve a major industrial center and is to be used as a terminal on an airways system as well. It is because of these facts that the airport has to be designed to accommodate the largest planes now in use as well as those planned for the immediate future. In view of the C.A.A. specifications, the airport must be designed to accommodate the largest planes that can be expected to come into use in the next 10 years.

Class 4 airports are being designed at the present time for planes having a gross weight of 74,000 lbs and over, or having a wing loading (lbs/sq. ft.) times power loading (lbs./hp) of 230 and over.

Table I was compiled from a study of the largest commercial planes in use. It is anticipated that a class 4 airport like the one under consideration will not be called upon to accommodate any planes heavier than the Lockheed Constitution (89) in the next 10 years. The gross weight of this plane is 184,000 lbs; however, the design of the runways have to be made for a gross weight of 300,000 lbs in order to comply with the Civil Aeronautics Administration standards. This load, if it is ever applied to the pavement, will be applied

(1) "Airport Design Information", Airport Section Technical Development Division, Civil Aeronautics Administration, Washington, D. C.
through the wheels of the landing system of a plane. The landing systems of the largest planes must therefore be investigated.

The Lockheed Constitution is equipped with a tricycle landing system but this system consists of a group of four wheels for each main wheel and two wheels on the nose. That is to say the maximum static load, which is 81,500 lbs (See Fig. I), will act on 4 wheels. If the weight of the 300,000 lb imaginary plane is assumed to act through the landing system of the Lockheed Constitution we would have 132,000 lbs acting on each main wheel. As each main wheel consists of two dual tires, each dual tire would be subjected to a 66,000 lb load. It is quite evident that this assumption would give an underdesigned pavement that would fail if subjected to loads of present 140,000 lb planes that have main wheels consisting of a single dual tire.

In designing the runways for a plane having a gross weight of 300,000 lbs the load will be assumed to be transferred to the runway through the landing system of the Boeing Stratocruiser 377. This type of loading will be used to assure the greatest possible loading on the runway. It will be assumed however that the tires used in the landing system will consist of 38 x 10 tires that have a footprint area of 500 square inches.

It is assumed that the 300,000 lbs of the gross weight of the imaginary plane which would be accommodated by this
airport in the near future will have a loading on the main wheels directly proportional to the loading produced by the Boeing Stratocruiser 377. This would give 135,000 lbs on the Main, and 30,000 lbs on the nose wheels.

There are three forces that act on an airport pavement: Impact, Dynamic and Static loads. The load that acts on the pavement when the airplane is standing with its motors dead, is the static or gross load. When the airplane is stationary but its propellers are operating at high speeds, or when the plane is taxiing, landing, or taking off, the dynamic and impact loads that are produced on the pavement are always less than the static or gross loads.

This is due to the fact that when the propellers are operating, or when the plane is partially airborne, the aero-dynamical forces that act on it tend to lift the plane. This makes the dynamic and impact loads less critical than the static load. It is because of this fact that loads only were taken into consideration in this design.
STRESS REPETITIONS ON RUNWAYS

In designing pavements for the runways fatigue under flexural stress must be considered. With a given load the tensile and compressive stresses are equal, but the ultimate strength of concrete in flexure is much less than the ultimate strength in compression. The fatigue behavior of the concrete pavement is therefore very important in the design of runways when no steel reinforcement is used.

An airport can handle only about 30 operations per hour. It is an established fact that the maximum daily traffic is less than ten times the maximum for a peak hour. This assumption gives us 300 scheduled operations per day. As half of these operations will be landings, and the other half will be take-offs, we have 150 operations to be distributed between the three runways. This gives 100 landings per runway, if we assume that because of prevailing winds one runway may have twice its share of scheduled flights. It is quite evident that not all of the 100 planes will land on the same spot.

The Civil Aeronautics Administration conducted a test on this subject. A highly skilled pilot flying a comparatively small plane, which was more maneuverable than a large transport plane, was able to hit the same spot on a runway only once in a hundred attempts.

This is one repetition of stress per day, or if the life of the airport is taken as 30 years, 11,000 repetitions in a
thirty-year life. From Fig I it is evident that a factor of safety of 1.60 is required to handle the 11,000 repetitions.

A higher factor of safety will not be used because all of the planes accommodated by the airport will not be large ones and because a long time will elapse between repetitions. When there is a period of recovery between stress applications, the fatigue action is minimized.
METEOROLOGICAL DATA

The site is located at an average elevation of 35 feet from mean sea level. The temperature varies between -15°C and 38°C. (5°F and 101°F) There is no visibility data available on the country adjoining the site. Bad visibility however does not occur any oftener than about 3% of the year.

The direction of the wind is:

<table>
<thead>
<tr>
<th>DIRECTION FROM</th>
<th>% OF TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>6.0</td>
</tr>
<tr>
<td>NE</td>
<td>34.6</td>
</tr>
<tr>
<td>E</td>
<td>10.6</td>
</tr>
<tr>
<td>SE</td>
<td>2.1</td>
</tr>
<tr>
<td>S</td>
<td>5.3</td>
</tr>
<tr>
<td>SW</td>
<td>22.7</td>
</tr>
<tr>
<td>W</td>
<td>13.5</td>
</tr>
<tr>
<td>NW</td>
<td>3.2</td>
</tr>
<tr>
<td>Calm</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Figure II shows a wind rose constructed from the data given above, and also shows the intensity of the wind.

The rainfall on the site is 29.5 inches per year.
It can be seen from the wind rose in Figure II that the prevailing winds are in an E-W, N-S and NE direction. It is therefore suggested to build three runways parallel to these directions.

According to the specifications of the Civil Aeronautics Administration a runway can be used until cross
winds at 90 degrees to its direction exceed 12 miles per hour. It is therefore evident that a 60 degree pattern will be advisable for the runways.

It is recommended that a runway length of 4510 feet be adopted.
DRAINAGE

In designing the drainage system of an airport the exact location of the runways, and the final layout of the field must be known. This is necessary in order to calculate the acreage served by each drain, and consequently, its capacity. As this thesis is a survey to determine the most economic design for the pavement of the runways, it was only suggested that the 60 degree pattern be used for the runways. Whether this recommendation will be followed or not, has no bearing on the value of the thesis. Evidently the exact acreage served by each drain is not known. The discussion on the drainage system will therefore be limited to the load to which the drains will be subjected, to the method used to compute the flow in the pipes, to the depth below the surface where the drains are located, and to a discussion of the type of soil and of the rainfall.

The average characteristics of the soil are as follows: 36 to 37 percent is retained on a No. 10 sieve. Of the material that is finer than a No. 10 sieve, 30 to 32 percent is retained on a No. 60 sieve, and of the 68 to 70 per cent that passes the No. 60 sieve, 10 to 12 per cent is clay and silt and passes through a No. 270 sieve. (It is evident from Table II that this soil can be classified as a E-2 soil in the CAA classification of soils.) This soil extends to a depth of 3 to 5 meters from the surface. A rock formation of limestone is found at that depth.
"With respect to rigid pavements subgrades are divided into two broad classes \( R_1 \) and \( R_2 \), and each is subdivided into five classes: a, b, c, d, and e. Subgrades are placed in the \( R_1 \) class where the combination of soil, drainage and climatic conditions are favorable; otherwise they are classed as \( R_2 \). Subbase requirements are the same for \( R_1 \) and \( R_2 \) subgrades, but the \( R_2 \) condition requires a concrete pavement one inch thicker than the \( R_1 \)."

Airport Paving, CAA, May 1948, p. 16.

We have to determine the class to which the subgrade belongs, so that by using that on the chart in Fig. IV, we can find the thickness that is required for the pavement and the subbase.

In using Table II we know that the soil under consideration is \( aE-2 \) soil. It is also necessary to know the drainage and frost conditions.

The drainage can be classified as good, because the internal drainage characteristics are such that the subgrade will not develop spongy areas because of accumulations of water; the water table is not situated so as to cause percolation from above or excess capillarity from below; the topography is such that surface water will be removed rapidly.

Because the frost action does not exceed the combined thickness of surfacing, base and subbase, it can be said that "no frost conditions exist".
The characteristics of an E-2 soil where "good drainage" and "no frost conditions" exist, are $R_1a$. (Table II)

Using these characteristics on the chart in Fig IV we find that the thickness of the pavement must be 15 inches. The thickness of the subbase is shown as zero because this type of soil does not need a subbase.

Eight inches of compacted subgrade will be used below the pavement. This subgrade will consist of clean gravel, sand, and soil taken from the excavations in the airport site. A minimum of 6 inches of subgrade is specified by the CAA for this type of soil.

Airport Paving, CAA, May 1948, p. 27.

Because of the fact that tile drains have to be imported whereas concrete drains can be manufactured locally, it is suggested that concrete pipes be used in parallel drains located at the sides of the runways. These drains will be designed for a direct load of 135,000 lbs. The depth of the ditch that will contain the drains will vary between 20 and 40 inches. This will be decided by the slope and the direction of the slope at each point on the runway. Clay pipe surface drains will be used at the edges of the pavement to collect the surface water.
The formula \( Q = \frac{RiA}{T-t} \) will be used to compute the capacity of the drains, where:

- \( Q \) = required capacity in ft. per second
- \( R \) = Coefficient of run off for ground served by the drain
- \( i \) = rate of rainfall in inches per hour
- \( A \) = Estimated area of ground served by drain in acres
- \( T \) = Duration of rainfall in hours (It is usual to assume 1 hour in designing airports)
- \( t \) = Time allowed for removal of rainfall after the end of a storm

Sharp H. Oakley, Shaw G. Reed, Dunlop A. John, Airport Engineering, p. 27.
JOINTS IN THE RUNWAY PAVEMENT

Joints are used to divide the pavement into slabs of uniform size. This is done to control the cracking of the pavement by reducing the stresses from temperature warping and other natural causes.

The classification of joints as transverse or longitudinal merely refers to the direction of the joint. Joints can be classified according to their functions. This method gives three types of joints: Expansion joints, Contraction joints and warping joints. The purpose of expansion joints is to provide a space that will close when the adjoining slabs expand. This type of joint must either be covered to prevent incompressible material from filling it up or the space between the faces of the joint must be filled with a compressible material. Bitumen, cork, rubber, or treated wood can be used to fill the joint. A metal device can be used to keep out of the joint the incompressible material. As the joint is not poured monolithically, it is necessary to use some method to transfer the load from one slab to the adjoining slab.

Contraction joints are used to relieve tensile stresses that are produced when a decrease in length occurs in adjoining slabs. Theoretically these joints are constructed without any space being left between the joint faces. An arrangement has to be made so that the joint will open as the adjoining slabs contract. Instead of a full joint that would
extend through the whole depth of the slab, a dummy contraction joint can be used. This type of joint consists of a groove in the pavement extending to a depth of about one-third of the thickness of the pavement. This groove is sealed with a bituminous seal to keep off the water. This dummy joint constitutes a plane of weakness in the pavement. Cracking of the pavement takes place along this plane, and has no detrimental effect on the pavement.

A warping joint is a joint that acts as a hinge and relieves the warping that occurs in the slab. An expansion or contraction joint can also serve as a warping joint.

There is a divergence of opinion among engineers as to the spacing and kind of joints to be used on concrete pavements.

The publication, "Principles of Highway Construction as applied to Airports, Flight Strips and Other Landing Areas for Aircraft", Public roads Administration, June 1943, page 259, recommends the following spacing for transverse joints:

Warping Joints--- ---------------15 feet
Contraction Joints-------- 30 or 45 feet
Expansion Joints----------90 or 120 feet

A paragraph on the same page however reads as follows:
"It must be kept in mind that the design of concrete pavements is not an exact science and should be tempered with engineering judgement."
**FIRST ALTERNATIVE: PLAIN CONCRETE RUNWAYS**

The Goldbeck theory modified to apply to dual tires will be used in the design of the plain concrete pavements. (See Fig. V)

This theory states that the thickness required for the pavements is given by the formula:

\[
t = \sqrt{\frac{KW - 2SL_1 - \pi L_1 L_2}{M}} + \sqrt{\frac{2S + L_1 + L_2}{2}} \cdot \frac{2S + L_1 + L_2}{2}
\]

- **t** = Thickness of pavement
- **W** = Maximum wheel load on a pair of dual wheels
- **M** = Maximum subgrade resistance
- **p** = Calculated equivalent uniform pressure on subgrade
- **K** = \( \frac{M}{p} \)
- **L_1** = \( \frac{1}{3} \) the major axis of ellipse of tire contact area
- **L_2** = \( \frac{1}{3} \) the minor axis of ellipse of the tire contact area
- **S** = Center to center spacing of dual tires
- **A** = Area of equivalent subgrade pressure

Diagrams of the footprint areas of wheels show footprints to be elliptical in shape. The major axis is almost twice as long as the minor axis.

The footprint area of one wheel = 500 in\(^2\). If we call the minor axis \( b \), and the major axis \( 2b \), we have the relation \( 2b^2 = 500 \). From this relation we get the major axis to be 17.82 in. and the minor axis 8.91 in.
\[ L_1 = 8.91 \]
\[ L_2 = 4.46 \]
\[ S = 58 \text{ inches} \]
\[ K = 2 \]
\[ W = 135,000 \text{ lbs.} \]
\[ M = 3.45 \text{ tons/ft}^2 = 48 \text{ p. s. l.} \]

\[
t = \sqrt{\frac{(2)(135,000) - (2)(58)(8.91) - (\pi)(8.91)(4.46)}{48} + \left(\frac{2)(58) + 8.91 + 4.46}{2}\right)^2 - \frac{(2)(58) + 8.91 + 4.46}{2}}
\]

\[ t = 10.51 \text{ inches} \]

It was shown before that by using the chart published by the C.A.A. (Fig. IV) a thickness of 15 inches was found to be necessary. Golbeck's formula shows that a thickness of 10.51 inches is necessary. Because of the fact that Golbeck's formula gives a close approximation only of the required thickness, and in order to comply with the C.A.A. specifications, a thickness of 15 inches will be used.

Investigations and tests conducted by various authorities show that diagonal corner cracks develop at a distance of from 2 to 4 feet from the edges of concrete slabs. In the case of pavements where no reinforcement is used this cracking has to be prevented by a thickening of the edge. The following formulas can be used to compute this thickness:

---

(1) Sharp H. Oakley, Shaw G. Reed, Dunlap A. John, Airport Engineering, 1944, p. 82.
(1) Arthur G. Bruce, John Clarkeson, Highway design and Construction, 1950, p. 472
(2) Sharp H. Oakley, Shaw G. Reed, Dunlap A. John, Airport Engineering, 1944, p. 85.
In cases where there is some way of transferring the load to the adjacent slab.

In cases of unprotected edges where there is no load transfer.

Where:

\[ t = 1.275 \sqrt{\frac{1.92 W}{S}} \]

\[ t^1 = 1.275 \sqrt{\frac{2.4 W}{S}} \]

\( t \) = edge thickness of the pavement

\( W \) = Weight acting on a single wheel

\( S \) = Allowable Flexural stress in the concrete.

\( W \) will be taken as \( 135,000/2 = 67,500 \text{ lbs.} \)

For a concrete whose ultimate compressive strength at the end of 28 days is 3,500 psi, the expected modulus of rupture under a steady load is about 700 psi. Using a factor of safety of 1.6 which was found to be necessary for the 11,000 repetitions that will occur in 30 years (Fig 1), the value of \( S \) can be taken as 438 psi.

The thickness at joints where there is some kind of device to transfer the load to the adjacent slab will be:

\[ t = 1.275 \sqrt{\frac{1.92 \times 67,500}{438}} = 21.9 \text{ inches will be used} \]

The thickness at edges where there is no load transfer will be:

\[ t = 1.275 \sqrt{\frac{2.4 \times 67,500}{438}} = 24.3 \text{ inches will be used} \]

In order to comply with the requirements of the C.A.A. a width of 200 ft. will be used for the runways.

(1) It is required that a 200 ft. width be adopted for paved runways to be used for day and night operations, as well as instrument landings. Airport design Information, Technical development division, C.A.A.
In determining the kind of joint to be used, it is necessary to determine the length, width, and the stresses that act on the slabs.

The width of the slabs is generally determined by the method used in pouring the slabs. In this case a width of slab of 12 ½ feet is recommended, and it also recommended that two lanes at a time be poured. The outer edges as well as the edges at the joints are to be thickened. Transverse expansion joints will be constructed every 100 ft. Four transverse contraction joints will be used at twenty feet intervals between these contraction joints.

As the expansion and contraction joints can also act to relieve the warping stresses, special warping joints will be used. A warping joint essentially is a joint that will relieve the stresses that tend to curl the pavement. Any joint that can act as a hinge can function as a warping joint.

---

(1) "It has been common practice to space transverse expansion joints at intervals of 90 to 120 feet. It is believed that a minimum of 120 feet and a maximum of 400 feet is a satisfactory range to meet normal requirements." "Airport Paving". U. S. Department of Commerce, C.A.A. 1948, p. 30.
Data on the amount of linear elongation and contraction of concrete agree very closely on the figures given below. The factors that cause expansion or contraction are listed in their degree of importance:

Linear Elongation due to temperature changes \[0.000005\% / \text{degree F. (°F)}\]

Linear Elongation due to seasonal change in moisture content of the pavement (max.) \[0.000118\% \text{ (° or -)}\]

Linear shrinkage due to hardening \[0.000115\% \text{ (-)}\]

Unit plastic flow strain (Average) \[0.0001\% \text{ (-)}\]

In a slab 100 ft long there will be a contraction or expansion equal to 100 \(\times\) \(0.000005\) \(\times\) 50 \(\times\) 12 = .33 inches due to temperature changes. A contraction or expansion due to seasonal changes in moisture content of the pavement equal to \(0.000118\times 100 \times 12 = .143\) inches. A contraction due to hardening equal to \(0.000115\times 100 \times 12 = .138\) inches; and a contraction equal to \(0.0001\times 100 \times 12 = .120\) inches due to the plastic flow strains.

Most of the time stresses will act all at one time, so that the total possible elongation or contraction must be investigated. The total possible contraction or elongation must be investigated. The total possible expansion will be equal to \(.143+.33 = .473\) inches. The total possible contraction will be equal to \(.330+.143+.138+.120 = .731\) inches.

(1) Introduction to Reinforced Concrete Design, H. Sutherland, R. C. Reece, 1947, p. 28.
It was stated under the heading of meteorological data that the temperature varies between 5°F and 101°F degrees F. In the above computations however a difference in temperature of 50 degrees was used because no concrete will be poured at temperatures below 50°F.

It is not necessary to provide any space in the contraction joints. A slot, which will eventually be filled with some kind of plastic material, is provided at the joint to prevent the space left when the slabs contract from being filled with incompressible material, and to keep water out of the joint.

It is not necessary to use any longitudinal expansion joints in the runways as the runways are only 200 ft wide and the pavement is free to expand sideways. Runways up to 250 ft width have been found to give satisfactory service without any longitudinal expansion joints.

It was stated before that pavements develop diagonal corner cracks at a distance of 2 to 4 feet from the edges. The pavement is therefore designed with a thickened edge at the end of the slab and at the joints. There is a straight slope up to a distance of 5 ft from the edge of the slab.

It is proposed to pour two 12½ ft wide slabs at a time, with a dummy groove longitudinal joint at the center, and a keyed longitudinal construction joint at the ends where there is an adjoining slab. (See Fig. VI) The slabs will be 15 inches thick. The ends of the slabs where there is no load transfer are to be 25 inches thick, the thickened part to
have a straight slope up to a point 5 feet from the end of the slab. The slabs are to be thickened at the joints as well. The thickness at the joints is 22 inches. The tongue at the joint will have a thickness of eight inches.

In checking the shear developed at a longitudinal construction joint, use will be made of Fig. V. It can be seen from this figure that when one tire of the dual wheel is over the joint, 67,500 lbs will act on an area whose greatest dimension in the direction of the joint will be \(2(L_1 t)\). Actually much less weight will act on the joint, because the 67,500 lbs do not act on a straight line over the joint, but are distributed over an area equal to \(\frac{1}{3} A\). (See Fig. V)

As \(L_1 = 8.91\) inches, \(t = 15\) inches, and the thickness of the tongue in the joint (Fig. VI a) is equal to 8 inches, the shear developed in the concrete at the joint will be equal to

\[
\frac{67,500}{2(8.91+15) \times 8} = 177 \text{ psi}
\]

This much shear is allowable in concrete such as the one that is to be used in this project. (3500 psi compressive strength)

(1)"Test results reported by professors Talbot and Spofford indicate that the shear strength of concrete is a least 50 percent of the compressive strength." Introduction to Reinforced Concrete Design, H. Sutherland, R. C. Reece 1947, p. 28
Actually much less stress will be developed in the concrete because in computing the shear it was assumed that the sub-grade does not give any support.

There will be one transverse expansion joint every 100 ft. Load transfer at these joints will be accomplished through a device similar to the one shown in Fig. VII b.

There will be four transverse groove joints situated between two consecutive transverse joints. (Fig. VII)
Transverse Section
Of The Runway (1st Alternative)

Fig VI
Plan of Transverse Joints

Keyed Longitudinal Construction

Expansion Joint

This half painted & greased

Fig. VII
SECOND ALTERNATIVE: REINFORCED CONCRETE RUNWAYS

Steel reinforcing is usually placed with the aim of preventing crack formation in the pavement and control of the cracks once they are formed. A crack can be caused either by the expansion or contraction of the concrete, or as most often is the case, because there is poor subgrade support at one spot in the pavement. Reinforcement in the slab will reduce progressive deterioration due to traffic, as well as infiltration of dirt into the cracks. Welded wire fabric will be used in this design, because it is much more efficient than bar reinforcement in reducing the rate of cracking in the concrete slab. The great number of small closely spaced members in welded wire fabric serve to distribute and equalize the stresses that occur at cracks. The advantages of using welded wire will be discussed in a later part of this study. As failure in airport pavement is caused by the shearing forces due to the load of the planes that use the runways, reinforcement will be designed to resist shear. In doing this the worst possible case will be investigated. It will be supposed that the subgrade under the whole of area A (Fig. VO has failed completely to give any support to the pavement. In that case the area over the subgrade will act as a flat slab. The allowable unit shear stress for this slab is 106 psi.

(1) Reinforced Concrete Structures, Dean Peabody, 1946, p. 466.
The reinforced concrete pavement will therefore be designed so that the shear will not exceed 106 psi. As the steel reinforcement in this case will take some stress, the thickness of the pavement will be reduced to 10 inches.

The area \( A \) (Fig. V) which is the area of uniform pressure on the subgrade will be assumed to constitute a two way slab with dimensions \((2L_2+2t+3)\) by \((2L_1+2t)\). Substituting the values from page 17, the slab is seen to have a length of \(7'-0.91''\) by \(2'-11.82''\).

\( W \), the total load per square foot is:

\[
W = \frac{9}{12} \left( \frac{135,000}{(7.08)(2.99)} \right) = 6500
\]

\( m \), the ratio of the long span to the short span is equal to

\[
m = \frac{2.99}{7.08} = .423
\]

\( f_c' \) which is the ultimate compressive strength of the concrete at the end of 28 days is equal to 3500 psi. \(( j = 7/8 \) )

\( d \), the depth of the slab is 9 inches

\( F_s \), the allowable unit tensile stress in the welded wire fabric is 28,000 psi

The Moment coefficients \( C \) for the above value of \( m \) are:

<table>
<thead>
<tr>
<th>Positive Moment at Midspan</th>
<th>Negative Moment at continuous edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Span ((.062))</td>
<td>((.083))</td>
</tr>
<tr>
<td>Long Span ((.025))</td>
<td>((.033))</td>
</tr>
</tbody>
</table>

(1) Reinforced Concrete Structures: by Dean Peabody, "Design of a Joint Committee Two Way Slab", 1946, p. 226
By the use of the formula:

\[ A_s = \frac{C W (l^2)}{F_s (d-2)} \]

it is found that the following reinforcement is necessary in the slab:

- Longitudinal positive reinforcement \( (0.251 \text{ in}^2) \)
- Longitudinal negative reinforcement \( (0.337 \text{ in}^2) \)
- Transverse positive reinforcement \( (0.513 \text{ in}^2) \)
- Transverse negative reinforcement \( (0.725 \text{ in}^2) \)

For the positive reinforcement in the pavement a welded wire fabric having gauge No. 1 wires spaced at 3 inches center to center longitudinally and gauge No. 00 transverse wires spaced at 2 inches center to center will be used. This gives an area of \(.252 \text{ square inches per foot of longitudinal section. It was determined that .251 square inches were required. The area per foot of transverse section is .516 inches. It was found that .513 inches were required.}\)

For the negative reinforcement in the pavement, a welded wire fabric having gauge No. 00 longitudinal wires spaced at 3 inches center to center, and gauge No. 0000 transverse wire spaced at 2 inches center to center be used. This gives an area of \(.344 \text{ square inches per foot of longitudinal section where it was determined that .337 square inches were necessary. The area per foot of transverse section is .731 square inches. It was found that .725 square inches per foot of section were required.}\)
Positive reinforcement will be placed at a distance of two inches from the bottom of the pavement. Negative reinforcement will be placed at a depth of two inches from the surface of the pavement. The spacing of the joints will be the same as in the case of the plain reinforced runways. (Fig. VIII) and Fig. IX) Each 100 feet of longitudinal length of the runway will contain three transverse expansion joints. The third transverse expansion joint will divide the 100 ft. long slab into lengths of 60 and 40 feet respectively. (Fig. IX) These lengths will be divided into 20 ft lengths by the use of transverse Dummy Joints. (Fig. IX b) C.A.A. Specifications allow the use of three consecutive slabs with dummy transverse joints with reinforcing continuous across the joint. The use of slabs so connected however is restricted to three slabs, and the length of each slab is not to exceed 25 feet.

Doweled longitudinal contraction joints will divide the pavement into 25 ft. slabs. (Fig VIII) Each 25 ft. slab will have a longitudinal Dummy joint with reinforcement continuous through the joint. This joint will be situated at the center of the slab as shown in Fig. VIII. It was calculated that a space of .473 inches must be provided for the expansion of a length of 100 ft. of the pavement. However, as C.A.A. specifications require each expansion joint to have a 3/4 inch width, it is obvious that the pavement is safe.

Although much smaller dowels are needed to transfer the load from one slab to the next one, in order to conform to the C.A.A. specifications, dowels 1 1\(\frac{1}{2}\) inches in diameter and 20 inches long will be used. The maximum spacing is 15 inches.

(1) "Airport Paving" U.S. Department of Commerce, C.A.A. May 1948, p. 27.
Fig. VIII

Transverse Section of Runway (2nd Alternative)

Same as joint (b.) in Fig. VII
The welded wire fabric extends up to a distance of 3" from the edge.
Longitudinal Section
Of The Runway (2nd Alternative)

Fig. IX
As this is a study to determine the most economical design only and is not a complete cost analysis, items that are identical in both alternatives will be left out. The airport whose runways are being discussed will be built in Turkey. It is therefore evident that this comparison must be based on the cost of materials in Turkey. The lira is the basic unit in Turkish money. It is divided into hundredths. The value of one lira in American money is 0.353 dollars.

It is easier to construct the joints in reinforced pavement however the placing of the reinforcement takes time. It will therefore be assumed that although the plain concrete is much thicker than the reinforced concrete pavement, the pouring of both pavements will require the same workmanship.

Items required for 100 ft of the reinforced pavement in excess of those required for the plain concrete pavement:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>2 x 86.5 x 650.02</td>
<td>$86.5</td>
<td>$112,400</td>
</tr>
<tr>
<td>Steel Dowels</td>
<td>80 x 8 x 4.172 x 20</td>
<td>$20</td>
<td>4,450</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>116,850</strong></td>
</tr>
</tbody>
</table>

Items required for 100 ft of the plain concrete pavement in excess of those required for reinforced concrete pavement:
Plain Concrete:

\[
\left( \frac{200 \times 6 + 7(5 \times 7) + 5 \times 10}{12} \right) \frac{100}{27} = 461 \text{ cu yds @ 38} \quad 17,550 \text{ Liras}
\]

Additional excavation of 461 cu yds, and compacting and sloping the ground to form the thickened edges, to be done mostly by manual work: 461 cu yds @ 4 1,844 Liras

Total: 19,394 Liras

It is seen from the preceding figures that the reinforced concrete pavement will cost about 1,606 Liras more per 100 feet of length. It was also shown that the items required for 100 feet of the reinforced pavement in excess of those required for the plain concrete pavement were worth about 21,000 Liras. As this amount is only half of the total cost of the pavement, items identical to both alternatives having been left out of the cost comparison, it can be seen that by adopting a reinforced pavement the initial cost is augmented by only about 3.8%. The low maintenance cost and the better service afforded by the reinforced concrete pavement make it more economical in the long run to adopt a reinforced concrete pavement for the runways.
SUMMARY

This study is for the purpose of determining the most economical design for the runways of a Class 4 Airport to be constructed in Yesilkoy, Turkey.

Two alternatives were considered in this study; a design for plain concrete runways and a design for runways reinforced with welded wire fabric. In order to conform to the specifications of the Civil Aeronautics Administration, the pavements were designed with a view of accommodating a plane with a gross weight of 300,000 lbs in the very near future.

In designing the runways for the 300,000 lbs plane the weight was assumed to be transferred to the runway through the landing system of a Boeing Stratocruiser 377. This type of loading was used because it assures the greatest possible loading on the runways. Had a landing system that has main wheels with four tires each been used, a much lighter loading would result. The weight of the imaginary 300,000 lb plane for which this design was made was assumed to be divided among the two main wheels and the nose wheel in the same proportion that the weight is distributed in the Boeing Stratocruiser 377.

The Civil Aeronautics Administration specifications were used in the design of the plain concrete runways. They were also used in determining the thickness of the subgrade and the spacing and type of contraction, expansion and warping joints.

In most conventional designs, the thickness of the pavement is determined as if no reinforcement would be used,
and the steel is put in only to assure crack control. Because of the fact that this is a pavement designed for a very heavy load, and in order to economize on the concrete, a different approach was used. It was assumed that the subgrade under the whole of the assumed area of uniform pressure on the subgrade has failed to give any support to the pavement. The part of the pavement above this area was then assumed to act as a two way slab, and was designed as a two way slab.

While in a regular two way slab some of the positive steel can be bent up, this was not possible in this case; because the exact place the subgrade will fail and the pavement will be called upon to act as a two way slab was not known. It was therefore necessary to furnish both positive and negative steel all through the pavement. It is evident that the subgrade, even under the worst conditions, will give some support to the pavement, and that the pavement will always be subjected to stresses lower than the ones it was designed for.
CONCLUSIONS

Although the initial cost of the reinforced concrete pavement is slightly higher than the cost of a plain concrete pavement it is advisable to use a reinforced concrete pavement, because lower maintenance cost and better service make it cheaper in the long run. It is recommended that welded wire fabric be used because this kind of reinforcement will reduce the rate of cracking of the concrete. The small and closely spaced members of the fabric distribute and equalize the stresses and by so doing keep the edges of cracks that may form close together, thus preventing any incompressible material from getting into the cracks.

It is advisable to pour the concrete in 25 ft lanes. A longitudinal Dummy joint with reinforcement continuous through the joint must divide this 25 ft slab into two. Doweled construction joints are to be provided to connect the slabs together. It is necessary to have one transverse expansion joint every 100 feet and transverse dummy joints every twenty feet. Doweled construction joints are to act as expansion joints as well as warping joints.

Should the pavement be designed as a plain concrete pavement, even though the proper number and spacing of joints be provided, cracks would occur. The cracks thus formed always tend to open and make the surface of the pavement uneven. How soon this happens depends on the traffic and the kind of aggregate that was used in making the concrete. The
use of a welded wire fabric reinforced concrete pavement designed to withstand the worst possible conditions, as shown in the second alternative in this study, will assure long life, low maintenance and satisfactory service of the pavement.
BIBLIOGRAPHY


Fressch, C., Prekesch, W., Airport Planning, 1946.

Oakley, Sharp H., Reed, Shaw G., John, Dunlap A, Airport Engineering, 1944.

Peabody, Dean, Reinforced Concrete Structures, 1946.


Public Roads Administration, Principles of Highway Construction as Applied to Airports, Flight Strips and other Landing areas for Aircraft, 1943.

Sutherland, H., Reese, R. C., Introduction to Reinforced Concrete, 1947.


Wire Reinforcement Institute, In., Design Manual for Airport Pavements.
VITA

Yani Triandafilidis was born on December 29, 1927 at Istanbul, Turkey, the son of Christe and Eleni Triandafilidis.

He attended a Greek primary school in Arnavutkey, Turkey, from where he graduated in June 1939.

In September 1939 he entered the Academy department of Robert College at Istanbul, Turkey. He graduated from the Academy in June, 1943. He graduated from the Freshman College class of the same institution in June 1944. In September, 1944 he entered the Robert Engineering School at Istanbul, Turkey and graduated from there with the degree of Bachelor of Science in Civil Engineering in June 1949.
### Table I

<table>
<thead>
<tr>
<th>Type of Plane</th>
<th>Company</th>
<th>Wing Span</th>
<th>Max Static Load</th>
<th>Static Load on Main Wheel</th>
<th>Wing Loading/Inch</th>
<th>Tail Number</th>
<th>Gross Weight</th>
<th>Landing Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constitution</td>
<td>Lockheed</td>
<td>36'6&quot;</td>
<td>84,500</td>
<td>21,100</td>
<td>300</td>
<td>184,000</td>
<td>114,600</td>
<td></td>
</tr>
<tr>
<td>DC-7</td>
<td>Boeing</td>
<td>34'2&quot;</td>
<td>76,800</td>
<td>19,250</td>
<td>352</td>
<td>162,000</td>
<td>127,500</td>
<td></td>
</tr>
<tr>
<td>Stratocruiser</td>
<td>Boeing</td>
<td>28'6&quot;</td>
<td>61,000</td>
<td>13,500</td>
<td>326</td>
<td>135,000</td>
<td>121,700</td>
<td></td>
</tr>
<tr>
<td>Constellation</td>
<td>Boeing</td>
<td>28'6&quot;</td>
<td>43,000</td>
<td>11,600</td>
<td>300</td>
<td>92,000</td>
<td>77,000</td>
<td></td>
</tr>
<tr>
<td>DC-4</td>
<td>Boeing</td>
<td>24'8&quot;</td>
<td>39,500</td>
<td>11,700</td>
<td>330</td>
<td>73,000</td>
<td>63,800</td>
<td></td>
</tr>
<tr>
<td>DC-20E</td>
<td>Curtiss-Wright</td>
<td>25'11&quot;</td>
<td>28,000</td>
<td>3,800</td>
<td>336</td>
<td>50,200</td>
<td>46,400</td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>Boeing</td>
<td>25'0&quot;</td>
<td>19,650</td>
<td>3,900</td>
<td>340</td>
<td>36,000</td>
<td>34,300</td>
<td></td>
</tr>
<tr>
<td>DC-3</td>
<td>Boeing</td>
<td>18'6&quot;</td>
<td>11,575</td>
<td>2,190</td>
<td>237</td>
<td>25,300</td>
<td>24,400</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Group</th>
<th>Retained on No. 400</th>
<th>Material at That Size</th>
<th>Combined Sand &amp; Clay Pass %60</th>
<th>Liquid Limit</th>
<th>Plasticity Index</th>
<th>Subgrade Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-1</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>30 -</td>
<td>6</td>
<td>Fa</td>
</tr>
<tr>
<td>E-2</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>25 -</td>
<td>6</td>
<td>Fa</td>
</tr>
<tr>
<td>E-3</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>25 -</td>
<td>6</td>
<td>Fa</td>
</tr>
<tr>
<td>E-4</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>35 -</td>
<td>10</td>
<td>Fa</td>
</tr>
<tr>
<td>E-5</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>40 -</td>
<td>15</td>
<td>Fa</td>
</tr>
<tr>
<td>E-6</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>40 -</td>
<td>10</td>
<td>Fa</td>
</tr>
<tr>
<td>E-7</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>30 -</td>
<td>10-30</td>
<td>Fa</td>
</tr>
<tr>
<td>E-8</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>60 -</td>
<td>15-40</td>
<td>F4</td>
</tr>
<tr>
<td>E-9</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>40 +</td>
<td>30</td>
<td>F5</td>
</tr>
<tr>
<td>E-10</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>70 -</td>
<td>20-50</td>
<td>F5</td>
</tr>
<tr>
<td>E-11</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>60 -</td>
<td>30</td>
<td>F9</td>
</tr>
<tr>
<td>E-12</td>
<td>0-45</td>
<td>Coarse</td>
<td>Fine</td>
<td>60 +</td>
<td>-</td>
<td>F8</td>
</tr>
</tbody>
</table>

**MUD AND FLAT = FIELD EXAMINATION**

**NOT SUITABLE FOR AIRPORT**
For Concrete Pavement Runways

Published by the C.A.A. 1948