THE INFLUENCE OF CEMENT TREATED SUBBASES ON THE DESIGN OF AIRPORT P.C. CONCRETE PAVEMENTS

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1) Introduction

There is no doubt that at the present moment the linear multilayered elastic model and the finite element method of analysis are the most advanced means to evaluate stresses and strains in a pavement layer. However, while such a model has been extensively applied to the design of bituminous pavements, its application to portland concrete pavement is less frequent. This is probably due to the fact that Westergaard's theory, up to now, has been considered to give sufficiently satisfactory results, although the papers of McCollough and Boedecker (1) and Wang, Sargious and Cheung(2) have shown that a certain difference exists between the two models, specially with respect to surface deflections. The analysis developed by Eisenmann (3), which is based on a two layer elastic system resting on a Winkler elastic half space, provides an intermediate position between the two.

In this paper the influence of a cement treated subbase course on the performance of the pavement is examined in light of the results obtained by applying the linear elastic layered theory. A comparison is also made with the results obtained by applying Westergaard's and Eisenmann's methods and with the results obtained by Childs (4) in laboratory tests.

2) The Model

The interest of such an approach is that, unlike Westergaard, it makes possible to evaluate, in terms of flexural stiffness, the influence upon the pavement system of a cement treated subbase (CTS). Two different conditions at the interface between the slab and the subbase have been considered, i.e. no friction and no slip. Furthermore the case of the multi-wheel undercarriage can be directly analysed, without resorting to the Equivalent Single Wheel Load (ESWL) concept, which, as will be seen later, causes some perplexities.

The subgrade is considered as a Boussinesq elastic half-space, characterized by a modulus E_0 and a Poisson's ratio μ_0; the subbase and the concrete slab as elastic layers of thickness h_1 and h_2 and elastic constats E_1 and μ_1, and E_2 and μ_2 respectively.

The three layers are considered to be of infinite horizontal extension, i.e. edge effects are ignored, in accordance with the possibilities offered by the programme adopted (5). This corresponds to the internal load application case. Such a condition is not considered to be too limitative. First of all because, in modern pavements, the existence of dowels or other load transfer systems across the joints, and the presence of a rigid cement treated subbase, virtually gives the same results as the above case. Secondly because it is believed that the conclusions which can be drawn, qualitatively if not quantitatively speaking, can be extended to other load positions.

The boundary conditions existing between the slab and the subbase layer are extremely complex, inasmuch as they are complicated by warping effects due to temperature and by the physical condition of the interface.

Only the finite element analysis however can take into account the warping effects (6) while the layered theory can consider either the possibilities of full, partial or no friction at the interface. In practice it is probable that an intermediate situation will exist between full friction and no friction, according to whether the surface of the subbase is rough, or smooth, or if a cring membrane has been adopted.

Therefore, like other authors have done (1), (3), (4), (7), and in order to compare ours and theirs results, the extreme conditions of full friction and no friction have been considered.

3) The Loads

Since the aim of our research mainly pertains to airport pavements, the load considered are those of the landing gear of the B 747 F aircraft, i.e., 825 kN, double tandem, 1,3 MN/m^2 tire pressure. The action of only one gear has been considered, since this shortens calculation time. However a stricter quantitative analysis of results shows that the action of the closer gear should not be neglected as it involves stress differences which can reach 20%.

Furthermore in order to compare other authors results , a 40 kN single wheel load has also been examined, applied to a 20 cm. radius circular plate.

4) The Parameters of the Pavement Layers

The use of rational design methods, while consenting a more through understanding of the structural performance of the pavement, creates some difficulties when choosing the input parameters of the layers.

As a matter of fact, the properties of the materials in situ, especially that of CTS, evolves and undergoes a change which cannot be adequately represented by simple values of the elastic constants E and μ, as measured by laboratory tests.

For the CTS the volume changes due to shrinkage and temperature can cause either a fine cracking process or the building up of localized cracks, according to the cement content, whose extension and shape are unknown and in order to bear this in mind in the design some authors propose a reduction of the value of the uncracked modulus measured in the laboratory.

As a result we noted in many papers currently adopted values of 12.000-9.000 MN/m^2 (3), (4), of 7.000 - 1.400 MN/m^2 (8), (9) and 500 MN/m^2 (10) the latter value is comparable to a good unbound granular base course.

For this reason the following values have been considered for the input parameters:
- For the subgrade a modulus E_0 = 13 MN/m^2 and a Poisson's ratio of μ_0 =0,5 as adopted by Childs (4);
- For CTS, moduli of 500, 4.000, 10.000, 12.000 MN/m^2 and a Poisson's ratio μ_1=0,25;
- For the concrete slab a Young's modulus E_2 = 30.000 MN/m^2 and a Poisson's ratio μ_2=0,15.

5) Comparison With Other Models

5 - 1 Westergaard's Theory: Reference is made to Teller's and Sutherland's formula for the interior load case (11).

In comparing the results of the layered theory with those of Westergaard the following considerations have been made:

a) For the subgrade, the relationship given by Peltier (12) between Young's and "k" moduli:

$$k_o = \frac{E_o}{58}$$

which gives somewhat greater results than the one proposed by Wang (2). Therefore, with reference to $E_o = 13$ MN/m^2 (see par.4) this corresponds to $k_o = 22$ MN/m^3 as observed by Childs in his tests.

b) For the "k_1" modulus of reaction on the subbase surface, which depends on the thickness of the layer, the value measured by Childs and later adopted by Packard (13) were used.

c) In the case of airport pavements, it was necessary to calculate the ESWL of the double tandem gear of the B 747 F by means, for instance, of the diagrams proposed in the ICAO Airport Manual (14), (15).

5 - 2 Eisenmann's Theory: This method is based on the assumption that Westergaard's model is not in line with experience, when a CTS is present between the slab and the subgrade. Therefore he applies Odemark's theory of equivalent layers to the slab and CTS thus obtaining a single equivalent slab resting on a Winkler's subgrade to which the Westergaard's formulae can be applied. Furthermore the "k" modulus depends on the relative flexibility of the slab and the CTS with respect to the subgrade. The method also considers the full friction and the frictionless condition between the slab and the CTS.

6) Results

6 - 1 General Considerations

The results can be grouped as follows: A first group obtained by applying the layered system to the B 747 gear, and to the 40 kN single wheel load. A second group obtained by comparing the results of the layered theory with those of other theories.

Comparisons are by no means straightforward, and results may be often contradictory, due to the fact that different methods rely on entirely different design hypothesis, and most refer to the single wheel load thus making necessary to pass to an ESWL when dealing with multiwheel gear.

Furthermore the authors have measured different properties of the pavement which cannot be easily correlated.

6 - 2 Layered Theory - Multiwheel aircraft loads

Airport pavement structures studied are those commonly adopted in modern international european airports. The thickness of the slab ranges from 30 to 40 cm., while that of the CTS ranges from 15 to 30 cm.

The response of the pavements to the loads of the B 747 gear, in terms of flexural stress (σ_2) in the slab, flexural stress (σ_1) in the CTS and deflection (d_v), is given in table 1, 2 and 3.

6 - 2 - 1 Flexural stress in the slab: Fig. 1 shows the relationship between the max flexural tensile stress in the slab and the thickness of the CTS for different h_2 slab thicknesses and different E_1 CTS moduli in the case of full friction at the interface. Fig. 2 shows the same relationship in the case of no friction at the interface.

a) It is immediately evident that stresees σ_2 in the slab, when there in no bond, are greater than those predicted for full friction conditions.

Furthermore, while the influence on σ_2 of an increase of E_1 and h_1 is very marked in the case of full friction, it is much less pronounced in the case of no bond. This influence, as found by Hank and Scrivner (16), increases when the ratio of the stiffness of the slab and CTS decreases, as it occours when bounded subbases are used instead of unbounded ones.

b) It is also evident that only by increasing the thickness and the modulus of the CTS the advantage of this layer can be fully exploited.

c) As mentioned in par. 4, the value to be given to the modulus of the CTS in situ in order to take into account the cracking of the material is a very debated question inasmuch as in situ measurements are very scarse and the opinions of the various authors range from 12.000 to 500 MN/m2. However we can deduce a range of most probable values as follows:

- If we take a value of 500 MN/m^2, from fig. 1 and 2 it can be inferred that a concrete slab of 35 or 40 cm. on a 15 cm. thick CTS would have a stress of over 5,0 MN/m^2, which corresponds approximately to the average 60 days breaking strength. This means that such a structure would not be resistant to traffic for an appreciable time. Now, in modern european airports such as London, Orly, Fiumicino, such a structure has undergone for many years of heavy jet traffic without failing. This means that the modulus should have a much higher value.

- On the other hand, if we take a value of 10.000 MN/m^2, from fig. 3 and 4 of the following paragraph, it can be deduced that in a 15 cm. thick CTS there would be a flexural stress σ_1 of the order of 1,6 - 1,9 MN/m^2. Such values are not consistent with the resistance of the material which ranges from 0,7 MN/m^2, (4), (7), to 1,4 MN/m^2 (8), (17). Consequently a value of the E_1 modulus between 2.500 and 4.000 MN/m^2 seems to be the most acceptable.

6 - 2 - 2 Flexural stress in the CTS layer: Fig. 3 and 4 show the same relationships as fig. 1 and 2, but they refer to the flexural tensile stress σ_1 in the CTS.

As already mentioned, traffic induced stresses, for a given CTS thickness, increase as CTS stiffness increases. So, while a high modulus material will be very effective in reducing stresses in the concrete, it will be affected by high tensile stresses and this must be fully taken into account in pavement design.

Furthermore, the data presented in fig. 5 suggest that, if full friction exists at the interface of the slab and the bounded subbase, the values of σ_1 in the CTS increase; on the other hand, when it does exist, an increase in CTS thickness produces a reduction of σ_1, specially when E_1 has high values. Such a conclusion emphasizes the advisability of giving the CTS layer a thickness greater than 15 cm., when full friction is acheived.

6 - 2 - 3 The conclusions which an engineer who is called to design a pavement can draw are the following:

a) The need to ensure the max bond between the slab and the CTS in order to obtain the maximum benefit from the use of the later layer. This is in keeping with the findings of Eisenmann and others and the modern construction trends.

b) The need to find a reasonably compromise between the reduction of the slab thickness, the increase in the CTS thickness and the increase in the flexural rigidity of this layer.

An increase in the CTS thickness offers the possibility of reducing σ_2, that is to say the slab thickness.

An increase in the E_1 modulus of the CTS, which can be obtained by increasing the cement content, makes it possible to substantially reduce the slab thickness but causes the building up of high tensile stress in the base course layer (fig. 5). Such stresses must be limited to avoid an excessive cracking of the layer, which reduces the fatigue resistance of the material (17).

High E_1 modulus values are acceptable in lean concrete subbase courses but this may entail the need to include joints in the subbase.

6 - 3 Layered Theory - Single Wheel Load

With respect to highway pavements, in order to dispose of Childs's experimental results, the same pavement structures examined by him have been taken into consideration, i.e. slab thicknesses ranging from 8 to 18 cm. and CTS thicknesses ranging from 8 to 23 cm.

The results of the single wheel highway load, in terms of σ_2, σ_1 and d_v, are illustrated in tables 4 and 5.

It is not possible to directly compare the latter results with those of the multiwheel case, inasmuch as the tyre pressure, the load geometry and the pavement structures are entirely different: however, as a general rule, the results of the multiwheel load are confirmed as shown in fig. 6 and 7 (for bonded conditions) with the following differences:

a) The slab, in the bonded case, in general less overstressed.

b) The differences between the stresses in the slab for the bonded and unbonded conditions are more marked (the stresses in the unbonded case are much greater).

c) An increase in the CTS thickness causes, even in unbonded conditions, a more consistent reduction of the flexural tensile stress in the slab.

6 - 4 Comparision with Eisenmann's and Westergaard's Theories

6 - 4 - 1 B747 Aircraft: The results of calculations made for Eisenmann's theory are indicated in tables 6, 7 and 8; table 9 shows those for Westergaard. We will limit comparision to the E_1= 4.000 MN/m^2 case, for the previously mentioned reasons.

With reference to the tensile stress σ_2 in the slab, layered and Eisenmann's models offer very similar results and his values are slightly lower than those of the former. On an average, the differences

are limited to 10 - 15%, both in bonded and unbonded cases.

Westergaard's theory offers different results, like McCullough (1) and Wang (2), as can be seen from fig. 8, where, for clarity sake, only the values for h_2=35 cm. have been plotted.

The differences may be justified by the fact that the change from the multiwheel to Estergaard's ESWL seems incorrect when stiff subbase layers are present in the pavement. This is not the case for Eisenmann's approach, whose ESWL depends not only on the "k_0" value but also on the E_2/E_0 and E_1/E_0 ratio. Treybig and others (18), who have examined Westergaard's half-space model by means of the finite element analysis without recurring to the ESWL, reach similar conclusions.

With respect to flexural tensile stress σ_1 in the CTS, there is a close connection between the layered model and Eisenmann's theory, whose results differ on the average from 5 to 20%.

A comparision between the layered theory and Westergaard's model can also be made in terms of surface deflections of the slab under load, for which the layered theory gives results much greater than the latter (fig. 9). The experimental deflections, measured by Childs for the single wheel load, are, however, very similar to Westergaard's, and this means that with respect to surface deflections, the layered theory gives unrealistic results.

Such conclusions were also stated by McCulluogh (1), who gave an explanation of the fact. He states that in actual practice the uniformity of the subgrade with depth is an unrealistic assumption and in order to bring closer together his experimental results with those given by layered theory, he introduces a very stiff layer at a depth of 1,8 - 3,0 m. below the soil's surface.

It is our opinion that a more rational approach to this problem would be to consider a constant increment in the modulus as depth increases to account for the increment of the confining pressure in a homogenous soil. Such a solution can be obtained by recurring to Frölich's theory (19), and adopting a stress concentration factor higher than 3(").

In order to introduce the variation of the soil's modulus in the layered system, we have divided the upmost portion of the subgrade, more directly affected by stress induced by traffic loads, in 8 layers each 20 cm. thick. The ratio of the moduli of subsequent layers is given by the following relationship proposed by Veverca (20):

$$\frac{E_i}{E_{i+1}} = \left(\frac{i}{i+1} \right)^{n-3}$$

where n is Frölich's stress concentration factor.

In the calculations we took a value of n=4 and n=5. The first of which corresponds to a linear variation of the moduli as depth increases.

The results are plotted in fig. 9. It can be seen that they are much closer to Westergaard's deflections. On the other hand, we noted that the stresses in the pavement are far less sensitive to such a subgrade schematization, since they are reduced only by 10 - 14 %.

6 - 4 - 2 Single wheel load: This case has been examined mainly to assess whether the considerations concerning the values of the deflections proposed by the Westergaard's and the layered theory in the case of the multiwheel load, could be confirmed by the experimental results

(") The value of 3 corresponds to the Boussinesque half-space.

obtained by Childs (4). Therefore it was necessary to extend the analysis of par. 6-4-1 to the single wheel load.

The results are shown in table 10 and plotted in fig. 10, together with Childs's results. In this case too Westergaard's theory provides deflections which are lower than those provided by the layered theory and this difference is substantially reduced by applying Frŏhlich's subgrade model.

6 - 5 Conclusions

The principal conclusions which can be drawn on the basis of this study are the following:

1 - The layered theory analysis, applied to the design of rigid airport pavements provided with stiff portland cement treated subbases, has shown the great importance that the choice of the thickness and the value of the modulus of the subbase course has on the results, in terms of stresses and surface deflections of the concrete slab.

2 - In order to obtain the maximum benefit from the use of such subbases it is necessary to assure full friction conditions at the interface with the slab. Furthermore the thickness of the layer should not be less than 20 cm.

3 - With respect to the moduli, the values which seem to reach the best compromise between allowable stresses in the slab and in the subbase layer, are included between 2.500 and 4.000 MN/m^2. However, it is surprising how little knowledge it is available on the properties of the materials in situ, and how they may influence the values of the parameters measured in the laboratory.

4 - The layered theory analysis leads to more conservative structures in comparison with Westergaard's approach, which is in line with other authors findings. It is closely connected with Eisenmann's theory. In terms of deflections, in order to bring closer together experimental and theoretical results, the schematization of the subgrade as a Boussinesque model, i.e. an infinite half space with a constant value of the modulus, should be replaced by an infinite half space whose modulus value increases as depth increases in keeping with Frŏhlich's model.

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TAB. 1 LAYERED THEORY

B 747 E_r=10.000 MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)		d_v (mm)	
h_2 (cm)	h_1 (cm)	No Bond	Bond	No Bond	Bond	No Bond	Bond
30	15	5,93	2,85	1,25	2,27	8.53	7.16
	20	5,65	2,15	1,50	2,06	8.37	6.62
	30	4,87	1,24	1,78	1,66	7.87	5.71
35	15	4.88	2,59	0,92	1,88	7.53	6.47
	20	4,72	2,04	1,11	1,74	7.43	6.04
	30	4,23	1,27	1,37	1,45	7.10	5.29
40	15	4,08	2,34	0,70	1,59	6.73	5.89
	20	3,98	1,89	0.85	1,49	6.66	5.55
	30	3.66	1,24	1.07	1,27	6.43	4.92

TAB. 2 LAYERED THEORY

B 747 E_1=4.000 MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)		d_v (mm)	
h_2 (cm)	h_1 (cm)	No Bond	Bond	No Bond	Bond	No Bond	Bond
30	15	6,07	4,31	0,55	1,22	8.60	/
	20	5,94	3,68	0.66	1,20	8.15	7.48
	30	5,53	2,72	0.83	1,07	8.24	/
35	15	4,96	3,71	0,40	0,99	7.58	7.04
	20	4,88	3,26	0,49	0,98	7.52	6.75
	30	4,64	2,48	0,62	0,91	7.34	6.13
40	15	4,13	3,21	0,31	0,81	6.76	6.36
	20	4,08	2,87	0.37	0,81	6.72	6.13
	30	3,93	2,27	0,48	0,77	6.60	5.65

TAB. 3 LAYERED THEORY

B 747 $E_1 = 500$ MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)		d_v (mm)	
h_2 (cm)	h_1 (cm)	No Bond	Bond	No Bond	Bond	No Bond	Bond
30	15	6.19	5.92	0,09	0.20	8.68	/
	20	6.15	5.75	0,10	0,21	8.65	8.48
	30	6.06	5.37	0,13	0,23	8.56	8.25
35	15	5.04	4.86	0,07	0,15	7.64	/
	20	5.02	4.74	0.08	0,16	7.62	7.51
	30	4.95	4.50	0,10	0,18	7.56	7.34
40	15	4.18	4.05	0,05	0,12	6.82	6,77
	20	4,17	3,98	0,06	0,13	6,80	6.73
	30	4,13	3,81	0,08	0,14	6,76	6.60

TAB. 4 LAYERED THEORY

single wheel load $E_1 = 12.000$ MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)		d_v (mm)	
h_2 (cm)	h_1 (cm)	No Bond	Bond	No Bond	Bond	No Bond	Bond
8,0	8,0	4,83	0,64	1,89	1,70	/	1.00
	15,0	2,15	0,02	1,57	0,94	1,06	0.69
	23,0	1,03	0,18	0,98	0,59	0,76	0.53
13,0	8,0	2,74	1,03	0,67	0,99	0,98	0.76
	15,0	1,97	0,34	0,88	0,65	0.85	0.57
	23,0	1,24	0,12	0,73	0,44	0.69	0.45
18,0	8,0	/	0,84	/	0,64	/	0.59
	15,0	1,45	0,40	0,48	0,47	0.67	0.48
	23,0	1,10	0,22	0,49	0,34	0.59	0.39

TAB. 5 . LAYERED THEORY

single wheel load $E_1 = 4000$ MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)		d_v (mm)	
h_2 (cm)	h_1 (cm).	No Bond	Bond	No Bond	Bond	No Bond	Bond
8,0	8,0	5,65	2,6	0,74	1,04	1,58	1.25
	15,0	3,73	0,96	0,89	0,67	1.32	0.89
	23,0	2.24	0.45	0,69	0,44	1.03	0.68
13,0	8,0	2.87	1,85	0,24	0,52	0.99	0.88
	15,0	2.51	1,08	0,38	0,41	0.94	0.71
	23,0	1.98	0.69	0,39	0,30	0.84	0.58
18,0	8,0	1,73	1,30	0,11	0,30	0.72	0.66
	15,0	1.63	0.90	0,18	0,27	0.70	0.58
	23,0	1.45	0.65	0,22	0,22	0,66	0.49

TAB. 6 EISENMANN

B 747 $E_1 = 10.000$ MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)	
h_2 (cm)	h_1 (cm)	No Bond	Bond	No Bond	Bond
30	15	5,79	2,58	0.96	1,95
	20	5,68	1,79	1.26	1,74
	30	4,92	0,79	1,64	1,32
35	15	4,73	2,30	0.68	1,56
	20	4,63	1,69	0,88	1,42
	30	4,08	0,86	1,16	1,13
40	15	3,75	2,00	0,47	1,26
	20	3,69	1,55	0,61	1,17
	30	3,40	0.88	0,85	0,97

TAB. 7 EISENMANN

B 747 $E_1 = 4.000$ MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)	
h_2 (cm)	h_1 (cm)	No Bond	Bond	No Bond	Bond
30	15	5,84	4,10	/	1,15
	20	5,84	3,30	0.52	1,12
	30	5,57	2,04	0,74	0,98
35	15	4,74	3,38	0,27	0,87
	20	4,70	2,87	0,36	0,87
	30	4,49	1,91	0.51	0,79
40	15	3,77	2,84	0,19	0,68
	20	3,75	2,45	0,25	0,69
	30	3,64	1,77	0,36	0,66

TAB.8 EISENMANN

B 747 E_1 = 500 MN/m²

Layer's thickness		σ_2 (MN/m²)		σ_1 (MN/m²)	
h_2 (cm)	h_1 (cm)	No Bond	Bond	No Bond	Bond
30	15	5.83	5.72	0.05	0.19
	20	5.84	5.65	0.06	0.22
	30	5.82	5.08	0.10	0.26
35	15	4.78	4.52	0.03	0.14
	20	4.79	4.46	0.05	0.16
	30	4.74	4.14	0.07	0.19
40	15	3.79	3.65	0.02	0.11
	20	3.78	3.56	0.03	0.12
	30	3.77	3.39	0.05	0.14

TAB.9 WESTERGAARD

B 747

h_2 (cm)	h_1 (cm)	k_1 (MN/m³)	E.S.W.L.(N)	σ_2 (MN/m²)	d_v (mm)
30	15	84	257.8	2.77	0.42
	20	110	246.3	2.58	0.35
	30	166	242.6	2.40	0.28
35	15	84	281.6	2.29	0.37
	20	110	266.1	2.13	0.30
	30	166	248.5	1.91	0.23
40	15	84	300.0	1.95	0.32
	20	110	289.5	1.83	0.27
	30	166	261.9	1.60	0.20

TAB.10 WESTERGAARD

single wheel load

h_2 (cm)	h_1 (cm)	k_1 (MN/m³)	σ_2 (MN/m²)	d_v (mm)
8.0	8.0	55	3.99	0.60
	15.0	108	3.33	0.43
	23.0	145	3.05	0.37
13.0	8.0	55	1.98	0.28
	15.0	108	1.75	0.20
	23.0	145	1.48	0.17
18.0	8.0	55	1.22	0.17
	15.0	108	1.10	0.12
	23.0	145	1.05	0.10

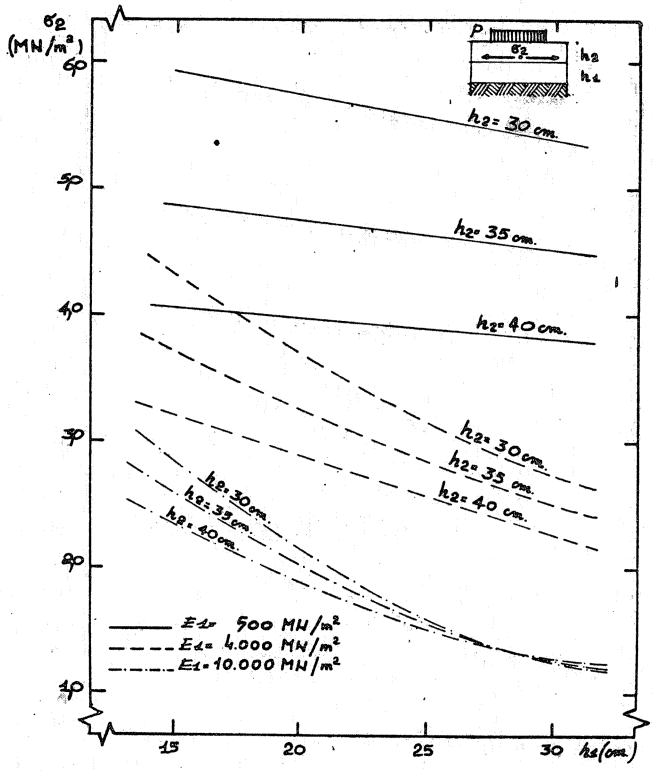


Fig.1: B 747 - Stress in the slab - Full friction at interface.

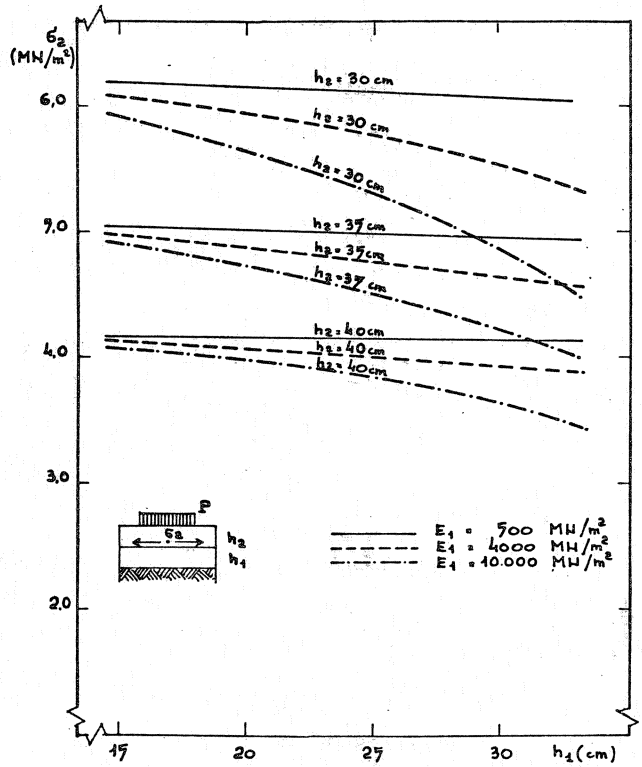


Fig.2: B 747 - Stress in the slab - No friction at interface.

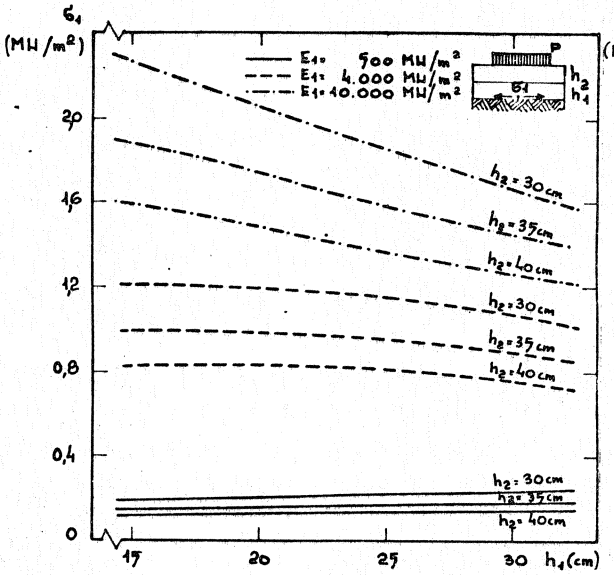


Fig.3: B 747 - Stress in the CTS - Full friction at interface.

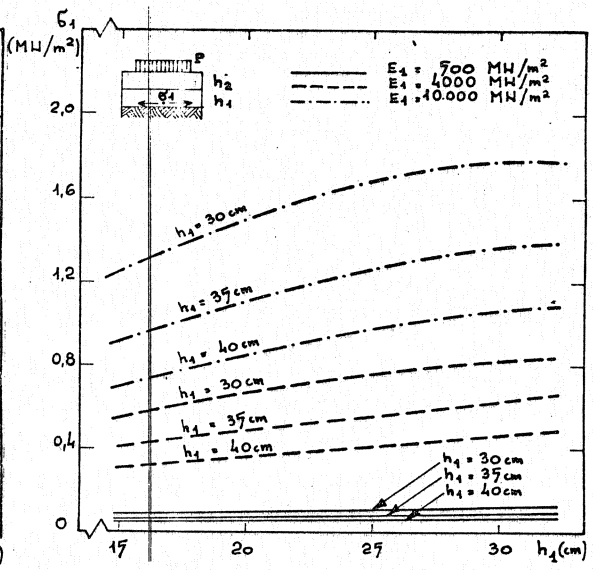


Fig.4: B 747 - Stress in the CTS - No friction at interface.

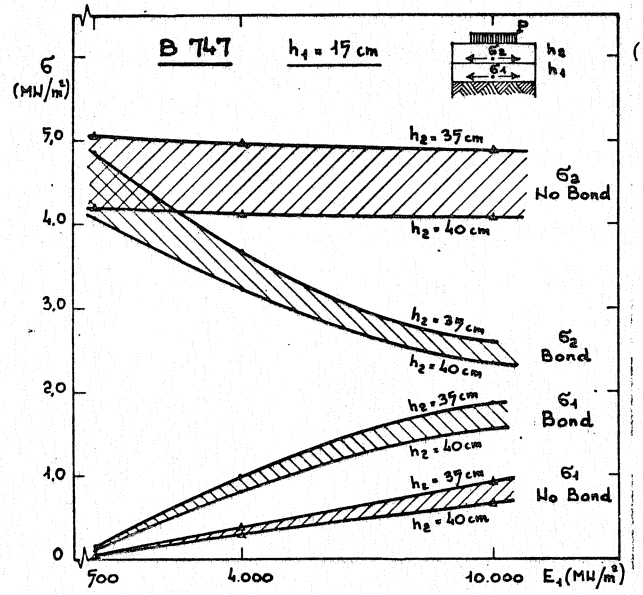


Fig.5: B 747 - Influence of the CTS modulus and of the interface condition on the stresses in the slab and in the CTS.

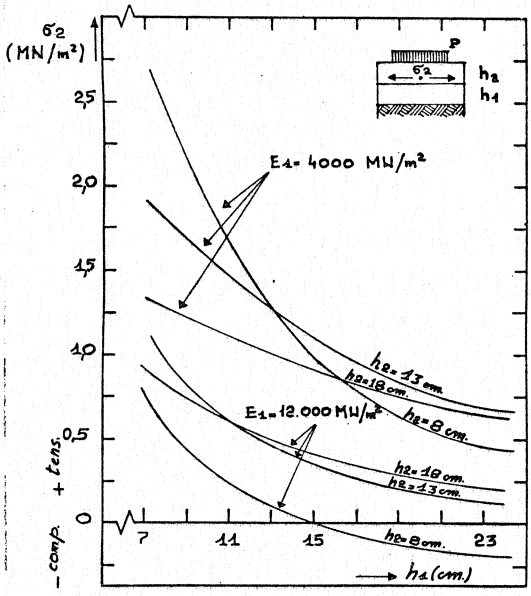


Fig.6: Single Wheel Load - Stress in the slab Full friction at interface.

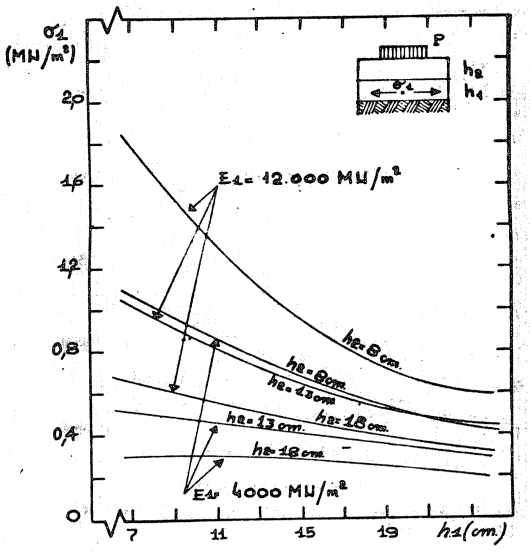


Fig.7: Single Wheel Load - Stress in the CTS Full friction at interface.

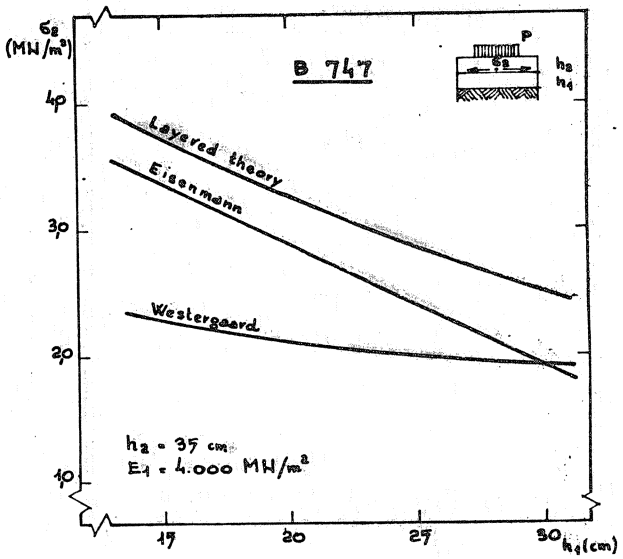


Fig.8: B 747 - Stress in the slab: comparision between Westergaard's, Eisenmann's and Layered Theory - Full friction at interface.

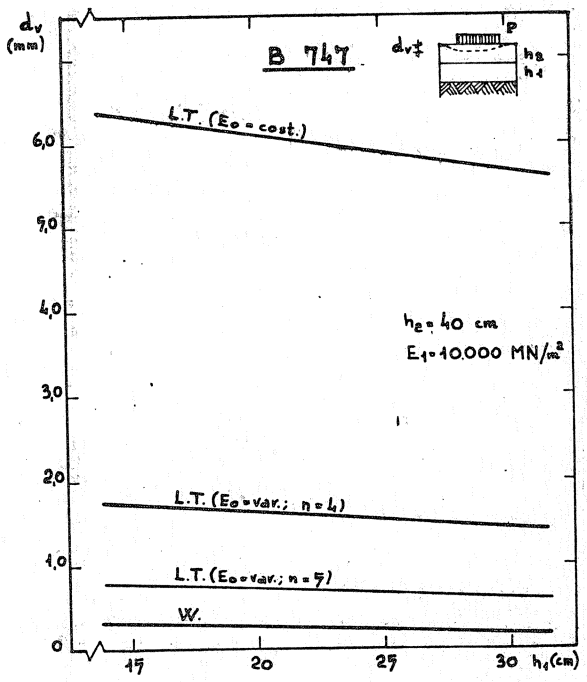


Fig.9: B 747 - Surface deflection: comparision between Westergaard's and Layered Theory and influence of the subgrade schematization - Full friction at interface.

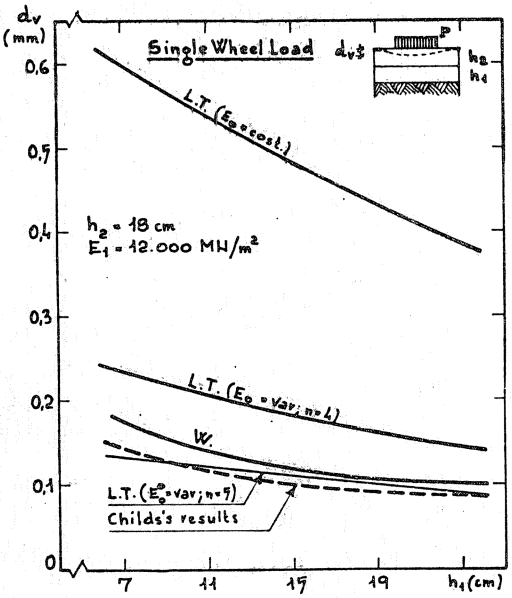


Fig.10: Single Wheel Load - Surface deflection: comparision between Westergaard's and Layered Theory and influence of the subgrade schematization - Full friction at interface.