AN INVESTIGATION ON THE PLASTERING PROPERTIES OF PERLITE

by

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INTRODUCTION

Although lightweight aggregate concrete has become much more familiar in recent years, it is in no sense a new class of building material. Indeed,a form of lightweight concrete was frequently used by the Romans,and it is known that the I43 ft. diameter dome of the Pantheon in Rome,built in the second century A.D. is composed largely of cast in situ concrete employing pumice aggregate. The development of lightweight aggregate industry after the first World War in the United States and in Europe,especially in Great Britain and Germany is surprising (I).

The most obvious characteristic of lightweight aggregate of course,is its density,which is always considerably less than,and often only a fraction of,that of ordinary aggregates. There are many advantages in low density,for example reduction of dead load,faster building rates,and lower haulage and handling costs. The weight of a building on the foundations is an important factor in design,particularly now that the tendency is to the construction of taller buildings.

We basically differentiate between two types of lightweight aggregates:

I- Structural lightweight aggregates like foamed slag,expanded clay,expanded shale,sintered pulverized-fuel ash,pumice etc. produce a lightweight concrete whose use, especially with reinforced concrete units,is not without certain problems,but the difficulties have been largely overcome.

2- Insulation-grade aggregates in very rich mixes can, in some cases, produce strength sufficient for load-bearing purposes, but they have inferior insulation value and are generally uneconomical, since concrete of comparable properties can be produced with less expensive aggregate using leaner mixes. This type of aggregates produce very low density and low thermal conductivity. These are exfoliated vermiculite and expanded perlite.

In this small research plastering properties of expanded perlite aggregates are investigated. Lightweight aggregate production is a completely new industry for Turkey. Practicing engineers will undoubtfully find it very difficult to leave the well established old methods of construction with normal concrete and use lightweight concrete, whose properties are still unknown for them, in their structural elements. However, used as a plastering material, perlite has many obvious advantages that will be mentioned later. Consequently, the purpose of this investigation is to present a technical data and make a comparison of test results among different types of mixes.

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CHAPTER I

I-A PLASTERING IN GENERAL

Plaster provides external as well as internal protection for the walls of buildings. To fulfill this function, it must be a good insulator against heat conduction and moisture transmission and , at the same time , a fireproofing coat. It forms a regular surface by covering the irregularities of brick or stone walls. To do this, it must be very workable and must have adhesive properties. Strength is not an important property for plaster mixes. Workability, elasticity, insulating properties are more important characteristics than strength, and they are obtained with mixes of low strength. Comparatively high strengh mixes form a rigid surface which, failing to adjust themselves to the movements of the wall underneath them, may crack and loose their protective function. In order to prevent this cracking the coefficients of expansion of the wall and the plaster coat should be nearly the same so that the differential movement is annulated. The following coefficients of expansion are taken from reference (I6) .

Brick wall..........0.0050 mm/m
Reinforced concrete..0.0I25 mm/m
Cement mortar ....0.0080 mm/m
Cement ....0.0I40 mm/m
Lime mortar ....0.0080 mm/m

Plaster should possess a certain porosity in order to have the humidity inside buildings diffuse through the pores as water vapor. But, at the same time, plasters exposed to weather should be impermeable to rain water. As will be seen in chapter IV, perlite plasters fulfill this function satisfactorily.

I-B WHAT IS PERLITE ?

Perlite is not a trade name but a petrographic term for a naturally occurring siliceous volcanic rock. The distinguishing feature which sets perlite apart from other volcanic glasses is that when heated to a suitable point in its softening range, it expands four to twenty times its original volume.This expansion is due to the presence of two to six percent combined water in the crude perlite rock. When heated above 1600 degrees F, the crude rock pops in a manner similar to popcorn as the combined water vaporizes and creates countless tiny bubbles in the heat softened glassy particles. It is these tiny glass-sealed bubbles which account for the amazing light weight and other exceptional physical properties of expanded perlite. The expansion process also creates one of perlite's most distinguishing characteristics: its white color. While the crude rock may range from transparent light gray to glossy black, the color of expanded perlite ranges from snowy white to grayish white.

<u>Typical chemical composition of perlite</u>

Silicon dioxide (SiO_2)......	7I.0 to 75.0 %
Aluminum oxide (Al_2O_3)......	II.5 to I8.0 %
Potassium oxide (K_2O).......	4.0 to 5.0 %
Sodium oxide (Na_2O)	2.9 to 4.0 %
Calcium oxide (CaO)	0.5 to 2.0 %
Ferric oxide (Fe_2O_3)	0.5 to I.5 %

Magnesium oxide (MgO)	0.I to 0.5 %
Titanium dioxide (TiO_2)	0.03 to 0.2 %
Manganese dioxide (MnO_2) ...	0.03 to 0.I %
Sulfur trioxide (SO_3)	0 to 0.2 %
Ferrous oxide (FeO)	0 to 0.I %
Chromium (Cr)	0 to 0.I %
Barium (Ba)	0 to 0.05 %
Lead oxide (PbO)	0 to 0.03 %
Nickel oxide (NiO)	Trace
Copper (Cu)	Trace
Boron (B)	Trace
Beryllium (Be)	Trace
Molybdenum (Mo)	Trace
Arsenic (As_2O_3)	Less than 0.I ppm
Free Silica	0 to 2 %
Total Chlorides	Trace to 0.2 %
Total sulphates	None

<u>Typical physical properties of perlite</u>

Color	White
Softening point	1600-2000 ^{o}F
Fusion point	2300-2450 ^{o}F
pH	6.6 to 8.0
Specific heat	0.20
Specific gravity	2.2 to 2.4
Refractive index	I.5

% Free moisture, maximum .. 0.5

Loose weight, pcf .... As desired

Solubility :

-Soluble in hot concentrated alkali and in hydro fluoric acid.

-Slightly soluble in concentrated mineral acids.

-Very slightly soluble in dilute mineral or concentrated weak acids.

I-C ASTM SPECIFICATIONS COVERING PERLITE AGGREGATES ASTM Designation : C 332-54 T (21)

I- These specifications cover lightweight aggregates intended for use in concrete not exposed to the weather, in which the prime consideration is the thermal insulating property of the resulting concrete.

2- The grading of perlite aggregates shall conform to the following requirements:

Perçentages (by weight) passing sieves having square openings.

No.4	No.8	No.I6	No.30	No.50	No.I00
I00	85 to I00	40 to 85	20 to 60	5 to 25	0 to I0

To assure reasonable uniformity in the gradation of successive shipments of lightweight aggregates, fineness modulus determinations shall be made periodically. If the fineness modulus of the aggregate differs by more than 7 percent from that of the sample submitted for acceptance, the aggregate may be rejected, unless it can be demonstrated that it will produce concrete of the required characteristics.

3- The unit weight of perlite aggregates shall conform to the following requirement:

Dry loose weight, pcf $7\frac{1}{2}$ to I2

The unit weight of successive shipments of lightweight aggregates shall not differ by more than IO per cent from that of the sample submitted for acceptance tests.

Laboratory results:

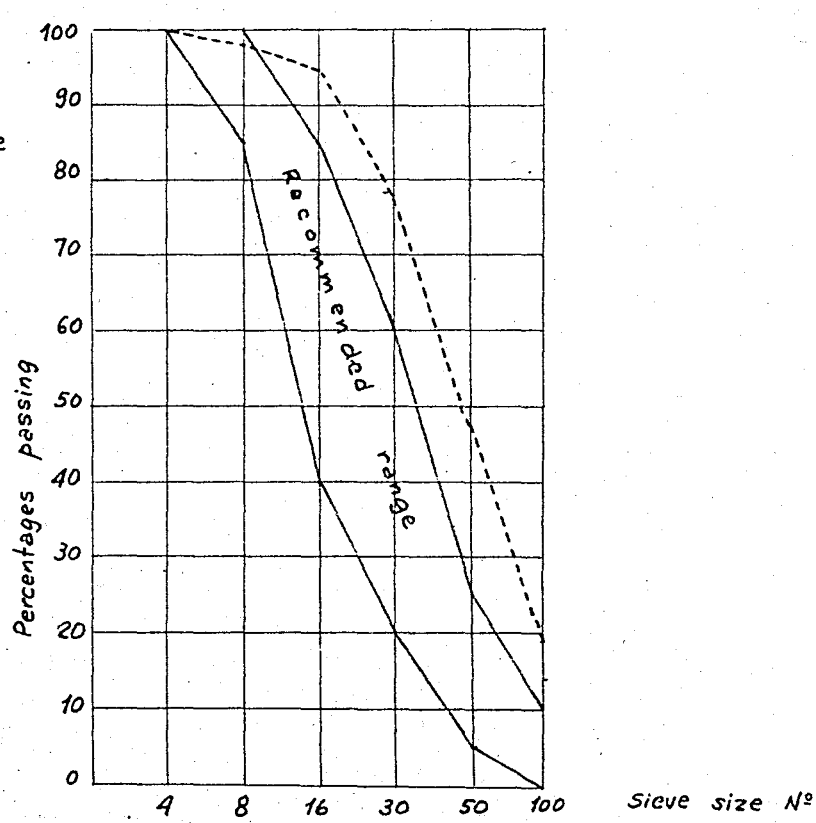
According to tests conducted in the laboratory, dry loose unit weight of perlite aggregates was fouhd to be IO.8 pcf which is an average value conforming to the requirement mentioned above.

Sieve analysis:

As will be seen from the following graph, the material used was finer than the recommendations of the ASTM. But, perlite aggregates being very soft particles, gradation does not play an important role in plastering.Finer particles even increase workability.

Fig. (1)

Granulometric curve of perlite aggregates



Bulk specific gravity:
(oven-dry)

A 300 gr. sample of dry fine material was put in a flask and mixed with enough kerosene (about 20 ml.) to wet all the surfaces of the aggregate. Water was added and the amount required to bring the water level to the 500 ml. calibration mark was noted. The film of kerosene prevented absorption of water into the aggregate during the brief time required for this test.(3)

A Weight in grams of oven-dry sample in air.

B Volume of flask (500 ml.)

W Volume of water added to flask ml.

Bulk specific gravity (oven-dry) : A / B-W

A = 300 gr.

B = I000 ml

W = 595 ml.

Bulk specific gravity 300 / I000 - 595 = 0.743

CHAPTER II

PERLITE-GYPSUM LIGHTWEIGHT BASECOAT PLASTER

2-A DESCRIPTION

Perlite-gypsum plaster consists of a blend of expanded perlite aggregate and neat gypsum cement properly mixed with water for either hand or machine application to wall and ceiling surfaces or for fireproofing structural steel.

Plaster made with perlite aggregate weighs about 60 per cent less than ordinary sand-gypsum plaster and is the only lightweight aggregate plaster closely comparable in strength, workability and drying time to sand plaster. In commercial construction perlite plaster on metal lath can save as much as 2 tons of dead load per 80 square meters of plaster surface, thus permitting reduction in the size and cost of structural members and foundations. In residential buildings, perlite plaster saves about one ton of weight for every 80 square meters of plaster ½ in. thick on gypsum lath. This minimizes building settlement and reduces maintenance cost (8) .

For fireproofing use, perlite-gypsum plaster offers the lightest, thinnest, most economical means available for achieving 2, 3 and 4 -hour fire ratings. Up to 80 per cent of the dead load of fireproofing can be eliminated by substituting a thin membrane of perlite-gypsum plaster for the heavy masonry encasement of columns, beams and girders. Ceilings of perlite-gypsum plaster provide complete fire protection for the underside of floor and roof assemblies and at the same time provide a durable and nice looking finish.

Packed in convenient 2 cubic foot bags, perlite is easy to handle, measure and mix. Plasterers cover more area per day with less fatigue, better workmanship. The light weight of perlite plaster makes it ideal for machine application with plaster spray equipment. Large quantities of perlite can be stored inside on lightly supported floors. There is no waste, no shoveling off street, no frozen aggregate piles.

Countless tiny dead air cells in perlite aggregate are natural insulators. Perlite plaster thus offers up to 4 times more resistance to heat transmission than ordinary plaster.

Plastering specifications of the American Standards Association and Perlite Institute require that gypsum basecoat plaster have a setting time of less than four hours. Slow setting plaster may result in a weak basecoat, excessive drying shrinkage and needless finish coat fractures. Perlite contains no impurities to hasten the setting time of gypsum. Therefore if a heavily retarded or slow-setting gypsum is used, enough accelerator should be added to assure a set of less than four hours.

2-B SPECIFICATIONS OF THE AMERICAN PERLITE INSTITUTE (8)

Plaster thickness

Grounds shall be of such thickness and so set as to provide the following thicknesses of plaster measured from the face of plaster base to finished plaster surfaces, unless otherwise shown on the drawings:

Metal lath, wire lath .... 5/8" min.

All other types of lath ...... ½" min.

Masonry and concrete walls ... 5/8" min.

Monolithic concrete ceilings . 1/8" min.
3/8" max.

Materials

A- Perlite aggregate: used for basecoat plastering shall weigh not less than 7½ nor more than I5 lbs. per cu. ft. and particle gradation shall conform to ASTM specification C 35. If plaster is to be machine applied, the perlite manufacturer shall be consulted for recommendations.

B- Gypsum plaster: shall be of standard quality fibered or unfibered gypsum conforming to ASTM specification C 28 and preferably specially formulated for use with lightweight aggregates.

C- Water: shall be clean, fresh, suitable for domestic consumption, and free from such amounts of mineral and organic substances as would affect the set of plaster.

Base coat proportions

A- General

All metal and wood lath surfaces and gypsum lath ceilings attached by resilient clips shall be three-coat work, namely a scratch, brown and finish coat. Unit masonry and nailed-on gypsum lath may be either three-coat or two-coat double-up work.

B- Two-coat work

a) Gypsum lath: The mix ratio shall be not more than 2½ cu. ft. of perlite to IOO lbs. of neat gypsum plaster.

b) Masonry unit bases: The mix ratio for double-up work shall be not more than 3 cu. ft. of perlite to Ioo lbs. of neat gypsum plaster, except that on masonry unit bases exhibiting high suction not more than 4 cu. ft. of perlite to IOO lbs. of neat gypsum may be used.

C- Three-coat work

a) scratch coat: On all types of lath, the mix shall be not more than 2 cu. ft. of perlite to IOO lbs. of neat gypsum plaster, and on all masonry other than monolithic concrete shall be not more than 3 cu. ft. of perlite to IOO lbs. of neat gypsum plaster.

b) Brown coat: In all three-coat work the mix shall be not more than 3 cu. ft. of perlite to IOO lbs. of neat gypsum plaster.

2-C WHAT IS GYPSUM PLASTER ?

Chemical composition:

Gypsum plasters are produced by the partial or complete dehydration of gypsum ($CaSO_4 \cdot 2H_2O$). At least four distinct forms exist: (18)

a) Gypsum

b) Hemihydrate or bassanite ($CaSO_4 \cdot \frac{1}{2}H_2O$)

c) Soluble anhydrite or γ- $CaSO_4$

d) Anhydrite (also called insoluble anhydrite or dead burned gypsum , β- $CaSO_4$)

The existence of a further polymorph , α-$CaSO_4$, stable above I200 ^oC, has also been suggested. (I8)

The thorough discussion of chemical behaviour of these forms will be rather unnecessary and beyond the purpose of our subject. However, thinking that their solubility might be a measure of their stability, the following figure showing water solubility of different forms of gypsum is included.

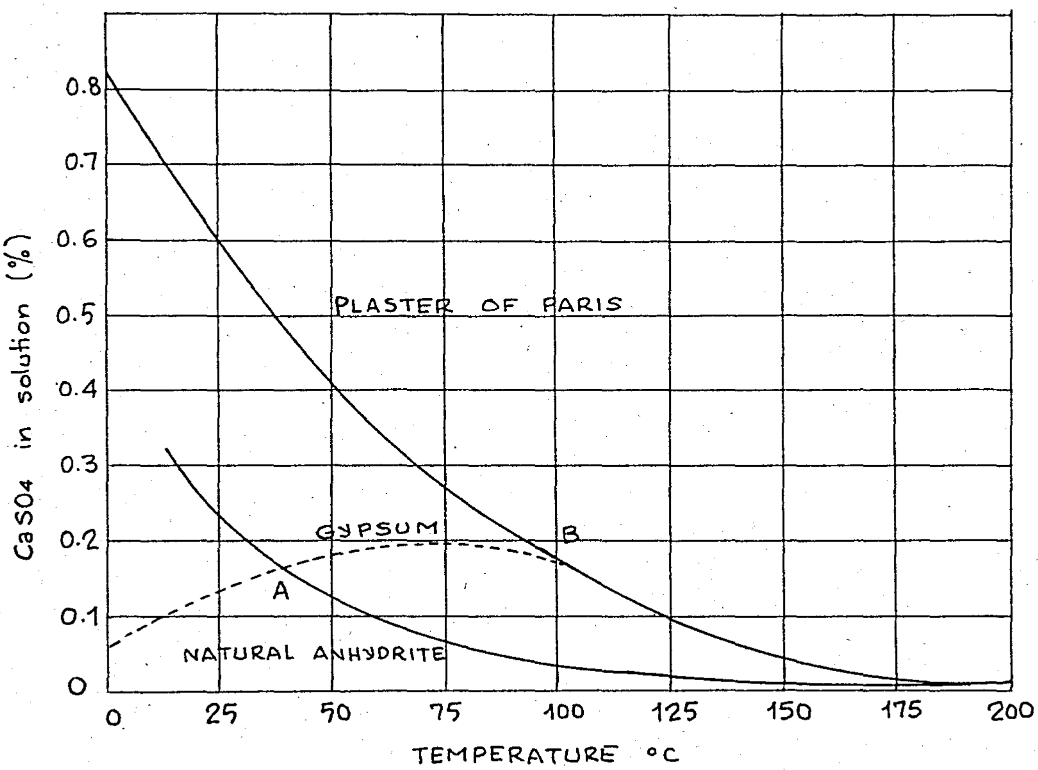


Fig. 2 Water solubility of different forms of $CaSO_4$

The curves show that above about 40 degrees C. (point A) natural anhydrite is the most stable calcium sulphate. However, gypsum in contact with water at temperatures somewhat above 40 degrees C. (point B) gypsum is more stable than hemihydrate. Saturated solutions of hemihydrate are, therefore, supersaturated with respect to gypsum, and gypsum can precipitate rapidly from these solutions.

The following table describes the principal varieties of gypsum plaster, including methods of production and setting behaviour. The temperatures of formation of the various phases are higher than those mentioned above, because relatively short heating periods are used. In all cases, setting takes place on mixing into a paste with water and is due to rehydration of gypsum.

NAME	METHOD OF PREPARATION	PHASES PRESENT	SETTING BEHAVIOUR
Plaster of Paris	Gypsum heated to about 150°c in open vessels	Mainly hemihydrate with some gypsum and some γ- $CaSO_4$	Very rapid
Retarded hemihydrate gypsum plaster	Plaster of Paris + retarder (0.1 % keratin)	As above	Moderate
Anhydrous gypsum plaster.	Gypsum heated to about 190 - 200° c	γ - $CaSO_4$	Moderate
Estrich gips	Gypsum heated to about 1100 - 1200° c	Anhydrite and CaO	Very Slow

Table (1) - Different types of gypsum plasters.

Plaster of Paris, whose setting behaviour is very rapid, is used throughout this first part of the experiments. Its compressive strength, according to ASTM C28-55, was found to be 792 psi which is above the value stated by the above specification.

2-D DESCRIPTION AND PROPERTIES OF THE MIXES MADE WITH GYPSUM PLASTER

According to the recommendations of the Perlite Institute at NewYork and taking into consideration the market conditions in Turkey e.i. commercial weights and volumes of perlite and gypsum plaster, the following mixes are prepared:

Table (2) - Perlite-gypsum plaster mixes

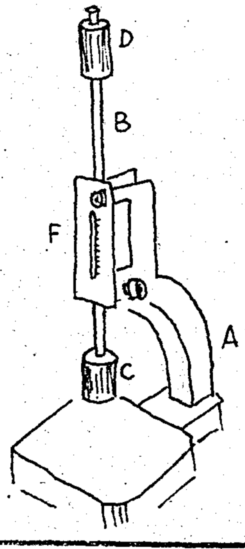
MIX Nº	PERLITE bag = 2 ft^3	GYP. PLAST. bag = 35 kg.	WATER Lit.
1	1	1	23.8
2	1½	1	30.8
3	2	1	39.2

Two types of gypsum plaster are used: The first quality, whose unit weight (loose) is 880 kg/m^3, is white and the second quality is 900 kg/m^3 and its color is grayish white. Both are the products of the Kartal plaster factory in Istanbul.

Letter F is used to designate the first quality and K to designate the second. According to this nomenclature, I-F shows Mix No. I prepared with first quality gypsum plaster.

The amount of water necessary to bring the mixture to the normal consistency is determined by means of the modified Vicat apparatus in accordance with the method described in ASTM C 26-54. The modified Vicat apparatus consists of a bracket A bearing a movable brass rod B, 6.3 mm in diameter and of suitable length to fit the Vicat bracket.

Fig. (3)



MODIFIED VICAT APPARATUS

On the lower end of the rod shall be attached a plunger C, I9.0 mm in diameter and 44.4 mm in length, made of aluminum tubing. The total weight of the rod with the plunger shall be 50 gr. This total weight may be increased by means of a weight D, screwed into the rod. The rod can be held in any desired position by a screw E.

All gypsum mixtures containing aggregates shall be considered of normal testing consistency when a penetration of 20 ± 3 mm is obtained, weight of rod and plunger for these determinations to be I50 gr.

The following penetrations are obtained with the specified amounts of water:

Table (3) - Penetrations by the modified Vicat apparatus

MIX №	PERLITE gr.	GYP. PLAS. gr.	WATER ml.	PENETRATION mm.
1	140	500	340	22
2	210	500	440	20
3	280	500	560	22

About the setting time of gypsum plaster:

In the preparation of perlite-gypsum plaster mixtures the quick setting of gypsum made it difficult to determine the consistencies by the modified Vicat apparatus. It was necessary to make two or three trials in order to determine the correct amount of water which was a time taking job. Therefore the presence of a special retarder for gypsum was indispensable. According to ref. I8 and table (1), 0.I % of keratin is recommended as a retarder for gypsum plasters. But, this compound being difficult to find and to control the quantity, a practical and easy way of delaying the setting time is used. The proportions and the amount of "glue solution" to be used as retarder are determined experimentally in the laboratory. The following recommendations are useful:

I part of glue and IO parts of water (by weight) should be heated very gently until glue is dissolved completely in a warm bath. For Ikg. of gypsum plaster inthe mix, the addition of 50 ml. of this solution delays the setting time about 25-30 minutes.

Unit weights:

Table (4) - Unit weights of gypsum plaster mixtures

MIX Nº	WET		AIR-DRY (21 days)		OVEN-DRY {100°c 24 hr.	
	kg/m³	pcf	kg/m³	pcf	kg/m³	pcf
1-F	1397	87	1166	72.6	868	54.2
1-K	1428	89	1200	74.8	897	56.0
2-F	1294	80.6	1100	68.6	762	47.6
2-K	1308	81.5	1110	69.2	780	48.7
3-F	1056	65.8	848	52.9	594	37.0
3-K	1262	78.6	1045	65.2	720	45.0

Air-dry unit weights may change with the relative humidity of the ambient air.

Compared with a normal I:3 mixture of sand and gypsum plaster, the following percentages of reduction in the dead load per cubic meter are obtained.

Table (5) - Percentages of reduction in the dead load per m^3

MIX Nº	WET		OVEN - DRY	
	Unit Weight kg/m^3	Reduction in D.L. %	Unit Weight kg/m^3	Reduction in D.L. %
Mixture with sand	1794	—	1550	—
1-F	1397	22	868	44
2-F	1294	28	762	51
3-F	1056	41	594	62

Volumetric composition and other information about perlite-gypsum plaster mixtures:

Table (6)

Mix Nº	PROPORTIONS BY VOLUME			AMOUNT OF PLASTER in 1 m^3. (kg)	Area in m^2 covered by the specified amounts of material for thicknesses of plaster shown.		
	PERLITE	GYPSUM PLASTER	WATER		1 cm.	2 cm	3 cm
1-F	1.44	1	0.635	290	5.00	2.50	1.66
1-K	1.46	1	0.645	290	4.90	2.45	1.63
2-F	2.16	1	0.800	225	6.28	3.14	2.09
2-K	2.19	1	0.810	225	6.20	3.10	2.06
3-F	2.88	1	1.015	182	9.00	4.50	3.00
3-K	2.93	1	1.030	182	7.50	3.75	2.50

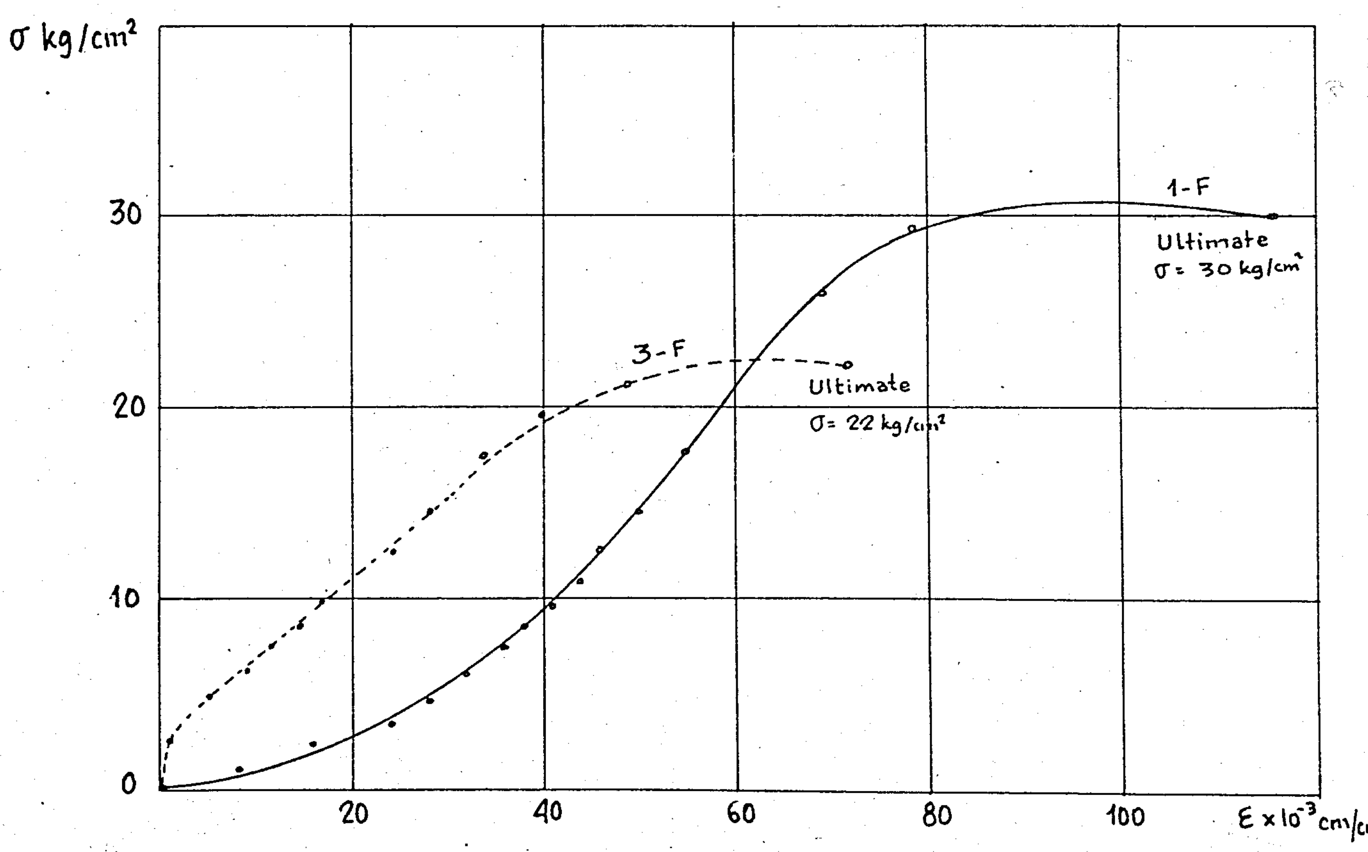
Compressive strengths:

Compressive strength tests are conducted at the Materials Laboratory of the Istanbul Technical University. The results, which are the average values of 3 specimens, are tabulated on the next page. In these tests small size (4" height, 2" diameter) cylindrical specimens are used. Considering the size effect on the compressive strength, the results are higher than they are in reality.

Table (7) - Average 28-day compressive strengths

Mix No.	Comp. Strength	
	kg/cm^2	psi
1-F	30	427
2-F	44	626
3-F	22	313
1-K	79	1110
2-K	59	840
3-K	30	427

To give an idea about the stress-strain characteristics of these mixes, two $\sigma - \varepsilon$ curves are drawn for I-F and 3-F: Fig. (4)



CHAPTER III

PERLITE-LIME-CEMENT PLASTER

DESCRIPTION AND PROPERTIES

This category includes four types of mixes:

Table (8)

Mix Nº	PERLITE bags = 2ft³	HYD. LIME m³	CEMENT bags = 50 kg	WATER lit.
L-1	8	0,200	1	99
L-2	8	0,200	2	93
L-3	8	0,300	3	111
L-4	4	0,625	1	87

* The indicated amounts of water may show slight variations due to water content of the hydrated lime.

Table (9)- Unit weights of perlite-lime-cement mixtures

Mix Nº	WET		AIR-DRY (21 days)		OVEN-DRY { 100°c 24 hours	
	kg/m³	pcf	kg/m³	pcf	kg/m³	pcf
L-1	1223	76.3	765	47.7	730	45.6
L-2	1345	83.8	926	57.7	840	52.4
L-3	1338	83.4	965	60.2	844	52.7
L-4	1276	79.5	782	48.7	673	42.0

* air-dry unit weights may change with the relative humidity of the ambient air.

Compared with a normal sand-lime-cement mixture, whose proportions are given below, the following percentages of reduction in the dead load per m^3 are obtained.

Sand m^3	Lime m^3	Cement 50 kg	Water lit.
I	0.200	3	I68

Table (10)- Percentages of reduction in the dead load per m^3

Mixture	WET		OVEN-DRY	
	Unit Wt. kg/m^3	Reduction %	Unit Wt. kg/m^3	Reduction %
SAND	1937	—	1678	—
L-1	1223	37	732	56
L-2	1345	31	840	50
L-3	1338	31	844	50
L-4	1276	34	673	60

Table (11)- Volumetric composition and other information about perlite-lime-cement mixtures.

Mix №	PROPORTIONS BY VOLUME				AMOUNT OF CEMENT in 1m^3 kg.	Area in m^2 covered by the specified amounts of material for thicknesses of plaster shown		
	PERLITE	LIME	CEMENT	WATER		1 cm	2 cm	3 cm
L-1	2.26	1	0.16	0.5	125	40	20	13.3
L-2	2.26	1	0.32	0.465	250	40	20	13.3
L-3	1.57	1	0.33	0.370	273	55	27	18
L-4	0.364	1	0.053	0.139	64	78	39	26

Compressive strengths:

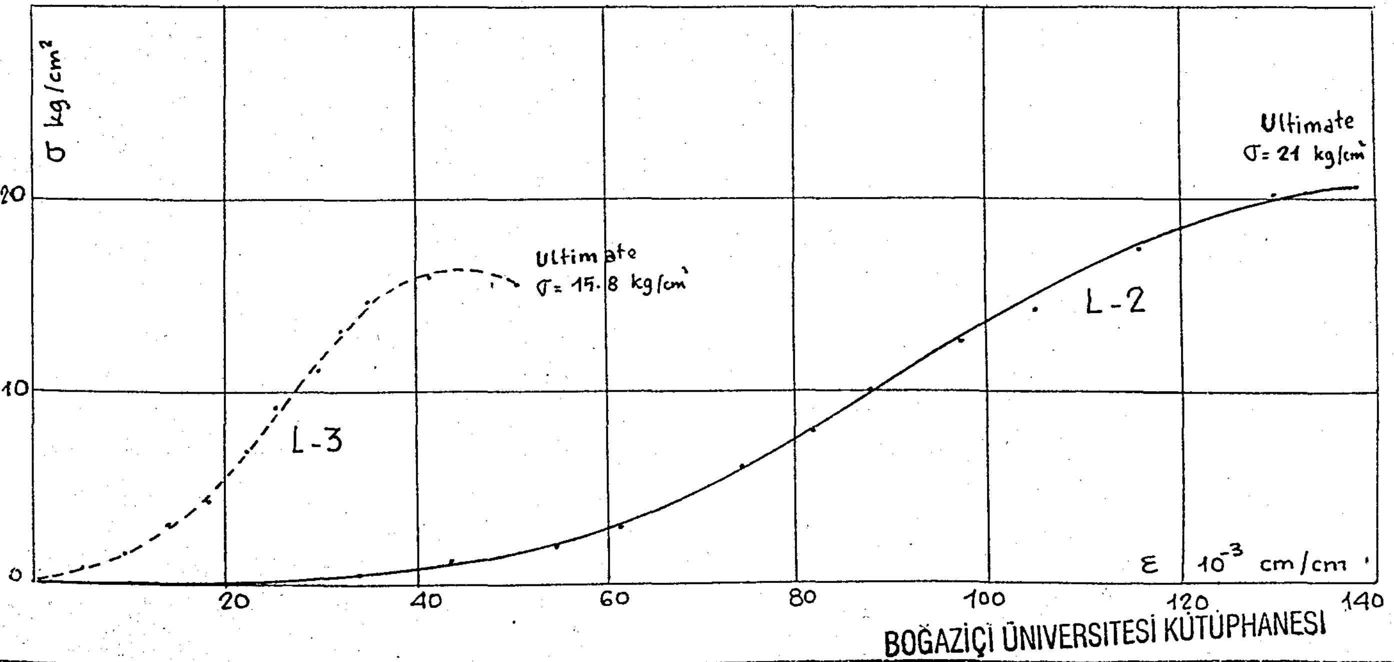
The rate of gaining strength for lime mixtures is slower than any other type of mixture because carbon dioxide is the required agent for the chemical transformation of the hydrated lime. Since test specimens are of cylindrical shape, a very long time is necessary for the inner parts to gain full strength, which is due to the lack of contact with air. Therefore the 28-day strengths for lime mixtures will be lower than they will be in reality.

Table (12)- 28-day compressive strengths of lime mixtures.

Mix Nº	kg/cm²	psi
L-1	9	128
L-2	18	256
L-3	20	284
L-4	7	100

From this table we also see that compressive strengths are proportional to the relative amounts of cement in the mix.

To give an idea about stress-strain characteristicsof these mixes two σ-ε curves are drawn for L-I and L-3. fig. (5)



CHAPTER IV

VAPOR PERMEABILITY TESTS

4-A GENERAL CHARACTERISTICS OF THE MECHANISM OF MOISTURE MOVEMENT

The moisture in a wall of hygroscopic material can move in two different ways, by diffusion of water vapor through the air-filled pores and spaces of the material and by capillarity in the pores filled completely or partially with water. A difference in the partial pressures of the water vapor on either side of the wall is a prerequisite for the diffusion. As a rule, the partial pressure of the water vapor in the cold external air is substancially lower than indoors. For this reason the diffusion generally takes place from the inside out. The capillarity, on the other hand, is closely related to a difference in the moisture content of the material. The moisture content of a hygroscopic material which is in equilibrium with the ambient air depends on the relative humidity of the atmosphere and increases with it. Therefore, in a simple wall the capillary movement takes place either from the outside - in or from the inside - out depending on whether the relative humidity of the atmosphere is higher or lower at the outside of the wall than it is at the inside.

If, at any point in the wall, the vapor pressure attains the saturation value, the water vapor condenses, and moisture accumulates in the wall. This may occur at the outside of cavities and air spaces and the possibility is greatest at low external temperatures. If the temperature of the interior wall is below the dew point of the air in the room, water precipitates on the wall and is absorbed by the latter. A corresponding phenomenon may be observed on external walls during rain. (I3)

4-B THE PROBLEM OF VAPOR PERMEABILITY

The vapor permeability of building materials is one of the recent problems in civil engineering. For the massive constructions of the older days with their heavy walls and dense solid materials there was no question of vapor flow. Whereas our present systems with lightweight, porous materials and with walls thinner than ever, brought along problems to be solved in connection with heat insulation, prevention of moisture penetration etc. Recent investigations in this field have mostly been done and published in countries with colder climates like Sweden and North America. Other publications in connection with moisture flow but in the field of drying of wood or of the vapor permeability of insulating materials for cooler systems are available in German.

Our present day knowledge on the problem of moisture transfer through porous materials is unfortunately very limited. It is probable that the flow takes place as vapor diffusion through the larger pores and as " condensation + capillary flow + evaporation " through the smaller capillaries. The most complete theory for this phenomena has been established by O. Krischer, and with his theory amd with a series of complicated experiments Krischer was able to determine separately the factors for the two types of partial flow in a sample of wood. At present because this method is not applicable to other materials except wood, the generally accepted method consists of using similar equations like in heat flow and of determining an over-all coefficient of moisture transmission from easily ascertainable steady-state conditions: (15)

$$q \cdot dx = K \cdot dp$$

with q Rate of moisture flow per unit area , gr/cm^2.sec

x Distance from surface , cm

K Coefficient of vapor permeability cm/sec

p Vapor pressure at point x , gr/cm^2

Here, difficulty arises from the fact that K is not a constant like in hydrostatic flow, but varies with the vapor pressure. Therefore the above equation cannot be integrated fully.

$$\int_0^x q \cdot dx = \int_{p_0}^{p} K \cdot dp$$

For a steady-state flow, with q constant we have :

$$q \int_0^x dx = \int_{p_0}^{p} K \, dp$$

$$q \, x = \int_{p_0}^{p} K \, dp$$

To go further it is customary to work with mean values of the coefficient :

$$q \, x = \int_{p_0}^{p} K \, dp = K_0 \, (p - p_0)$$

$$K_0 = \frac{\int_{p_0}^{p} K \, dp}{p - p_0}$$

But, the mean value K_0 is still dependent of the interval $p - p_0$. Its value varies with the position and the size of the interval. Comparison of results of independent experiments is therefore difficult.

The usual procedure for measuring vapor permeability is the dry-cup test. By this test the samples are mounted on aluminum dishes, which are filled with a dessicant $CaCl_2$ and the sides are sealed with wax. These dry-cups are stored at constant temperature and constant humidity. Due to the difference of vapor pressures outside and inside ($p_o = 0$) of the cup, vapor diffuses through the pores of the mounted sample and will be taken up by the dessicant.

As pointed above, K_o is a practical approach, but not satisfactory from theoretical point of view. A different approach appeared to be more helpful. As it was possible to obtain the values of q experimentally for given values of p by the dry-cup test, the products of q and the thickness x, plotted against p, would give a curve. Graphical differentiation of this curve would reveal the K values.

$$\frac{\partial}{\partial p}(qx) = \frac{\partial}{\partial p}\left(\int_{p_o}^{p} K\,dp\right) = K$$

4-C HOW PERMEABILITY COEFFICIENT IS CALCULATED ?

I) Relative humidity ψ is defined as the ratio of the prevailing water pressure to the saturated wapor pressure at a certain temperature. $\psi = \frac{P_d}{P_s}$

The values of saturated vapor pressures corresponding to different temperatures are given in the appendix.

2) The slope of the straight line obtained when weight gains are

plotted against time shows the rate of moisture flow per unit time. Dividing this value by the surface area of the sample through which moisture diffuses and multiplying by its thickness will give the qx values corresponding to different vapor pressures and thus relative humidities.

3) A curve is plotted having qx as abscissa and vapor pressure as ordinate. The graphical differentiation of this curve is the variation of the coefficient of permeability (K) with respect to relative humidity.

SPECIMEN № 1-F

Time days	WEIGHTS gr. A	B	C
0	131.8	139.5	137.6
4	134.4	141.1	139.0
5	134.9	141.5	139.1
6	135.6	142.0	139.4
7	136.1	142.5	139.7
8	136.9	142.9	140.3
9	137.3	142.9	140.5
11	138.5	144.2	141.0
12	139.2	144.5	141.2
13	141.1	144.9	141.7
15	141.5	145.8	142.1
16	142.1	146.1	142.3
17	142.7	146.4	142.6
18	143.3	147.0	143.0
19	143.8	147.4	143.2
20	144.3	147.8	143.4

SPECIFIC DATA	A	B	C
SLOPE 10^{-6} gr/sec	6.6	4.69	3.24
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.68	1.85	1.75
q x 10^{-7} gr/sec.cm	5.49	4.30	2.80
RELATIVE HUM. %	96	85	53
TEMPERATURE	78°F	26°C	70°F
P_s mm. Hg	24.63	25.21	18.77
VAPOR PRESSURE $\frac{gr}{cm^2}$	32.0	29.0	13.5

SPECIMEN Nº 2-F

Time days	WEIGHTS gr.		
	A	B	C
0	139.4	133.0	134.1
4	142.7	135.6	135.4
5	143.2	136.4	135.8
6	144.0	137.1	136.1
7	144.6	137.8	136.5
8	145.5	138.5	136.9
9	146.1	139.2	137.2
11	147.7	140.4	137.9
12	148.4	140.9	138.2
13	149.3	141.6	138.6
15	151.1	142.7	139.1
16	151.7	143.4	139.3
17	152.5	144.0	139.6
18	153.3	144.8	139.9
19	153.9	145.4	140.1
20	154.6	145.9	140.4

SPECIFIC DATA			
	A	B	C
SLOPE 10^{-6} gr/sec	8.68	7.06	3.07
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.86	1.74	1.62
q x 10^{-7} gr/sec.cm	8.00	6.08	2.46
RELATIVE HUM. %	96	85	53
TEMPERATURE	78°F	26°C	70°F
P_s mm. Hg.	24.63	25.21	18.77
VAPOR PRESSURE $\frac{gr}{cm^2}$	32.0	29.0	13.5

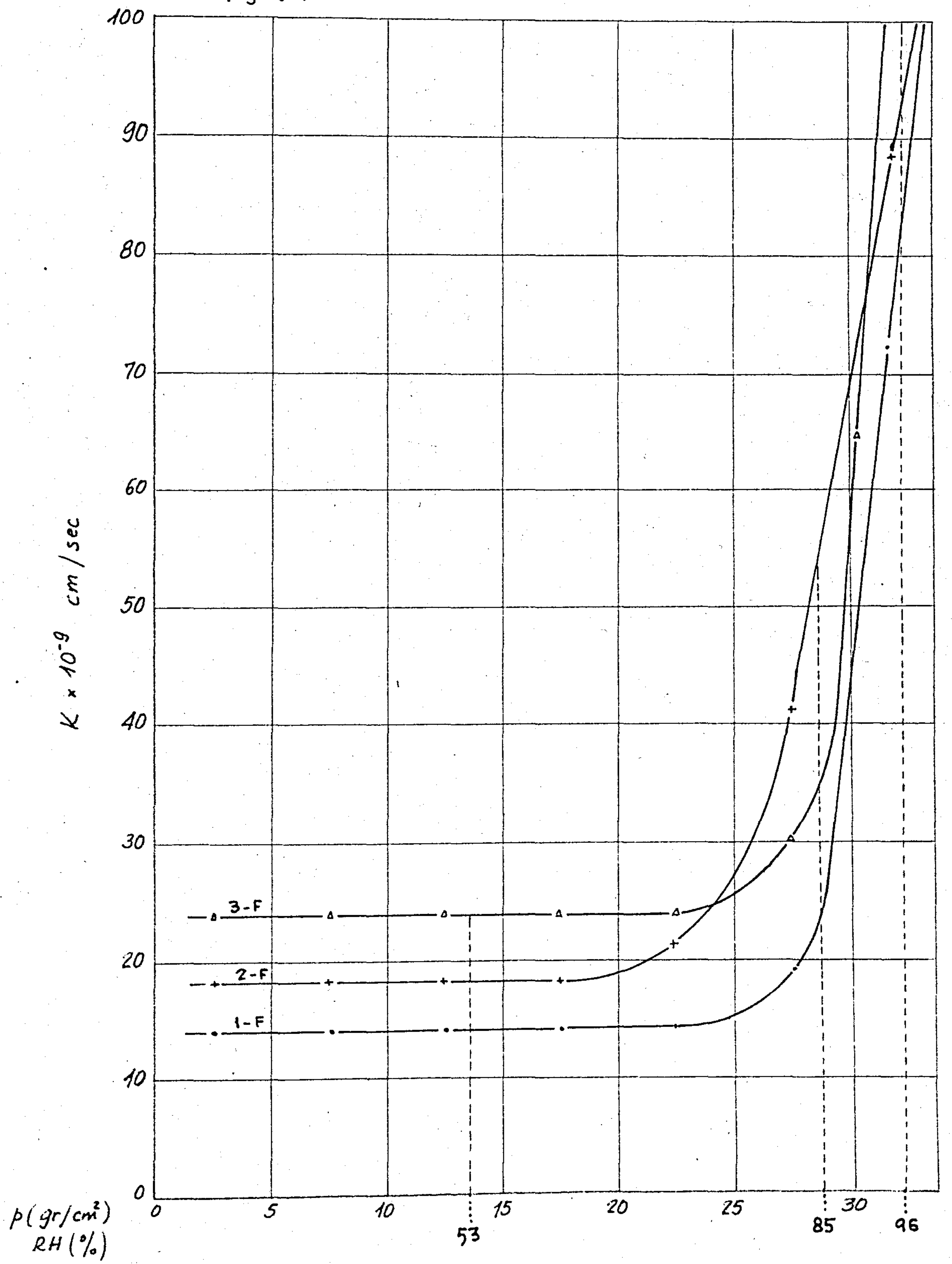
SPECIMEN Nº 3-F

Time days	WEIGHTS gr.		
	A	B	C
0	126.1	126.8	129.4
4	130.1	129.9	131.5
5	130.9	130.7	132.0
6	132.1	131.5	132.5
7	133.0	132.2	133.0
8	134.0	133.0	133.7
9	134.8	133.8	134.2
11	136.6	135.2	135.0
12	137.6	135.8	135.5
13	138.5	136.6	136.0
15	140.2	138.0	136.8
16	141.0	138.6	137.2
17	141.9	139.5	137.6
18	142.8	140.1	138.0
19	143.5	140.8	138.5
20	144.4	141.5	138.8

SPECIFIC DATA			
	A	B	C
SLOPE 10^{-6} gr/sec	9.73	8.05	4.69
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.88	1.72	1.70
$q \times 10^{-7}$ gr/sec.cm	9.05	6.85	3.95
RELATIVE HUM. %	96	85	53
TEMPERATURE	78°F	26°C	70°F
P_s mm. Hg	24.63	25.21	18.77
VAPOR PRESSURE gr/cm^2	32.0	29.0	13.5

VAPOR PERMEABILITY CURVES FOR PERLITE - PLASTER MIXTURES
(F - SERIES)

fig. (6)



SPECIMEN Nº 1-K

Time days	WEIGHTS gr. A	B	C
0	142.0	142.7	134.5
4	144.8	144.7	135.6
5	145.3	145.1	135.8
6	145.9	145.8	136.2
7	146.5	146.4	136.5
8	147.1	146.9	137.1
9	147.6	147.4	137.4
11	148.9	148.3	137.9
12	149.4	148.7	138.1
13	150.1	149.3	138.5
15	151.4	150.4	139.1
16	152.0	150.8	139.3
17	152.5	151.3	139.6
18	153.3	151.8	139.9
19	153.8	152.3	140.2
20	154.3	152.8	140.4

SPECIFIC DATA	A	B	C
SLOPE 10^{-6} gr/sec	6.83	5.62	3.18
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.70	1.92	1.60
q x 10^{-7} gr/sec.cm	5.75	5.34	2.52
RELATIVE HUM. %	96	85	53
TEMPERATURE	78°F	26°C	70°F
P_s mm. Hg	24,63	25.21	18.77
VAPOR PRESSURE gr/cm^2	32.0	29.0	13.5

SPECIMEN No 2-K

Time days	WEIGHTS gr.		
	A	B	C
0	133.0	133.7	133.6
4	135.9	136.3	135.0
5	136.6	137.1	135.3
6	137.4	137.9	135.7
7	138.2	138.7	136.1
8	138.8	139.5	136.6
9	139.4	140.0	136.8
11	140.7	141.3	137.6
12	141.4	142.0	137.9
13	142.1	142.6	138.3
15	143.4	143.9	138.9
16	143.9	144.4	139.1
17	144.6	145.1	139.5
18	145.3	145.8	139.7
19	145.8	146.2	140.1
20	146.4	147.1	140.3

SPECIFIC DATA			
	A	B	C
SLOPE 10^{-6} gr/sec	7.23	7.35	3.47
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.84	1.74	1.74
q x 10^{-7} gr/sec.cm	6.59	6.33	2.99
RELATIVE HUM. %	96	85	53
TEMPERATURE	78° F	26°c	70°F
P_s mm. Hg	24.63	25.21	18.77
VAPOR PRESSURE gr_2/cm^2	32.0	29.0	13.5

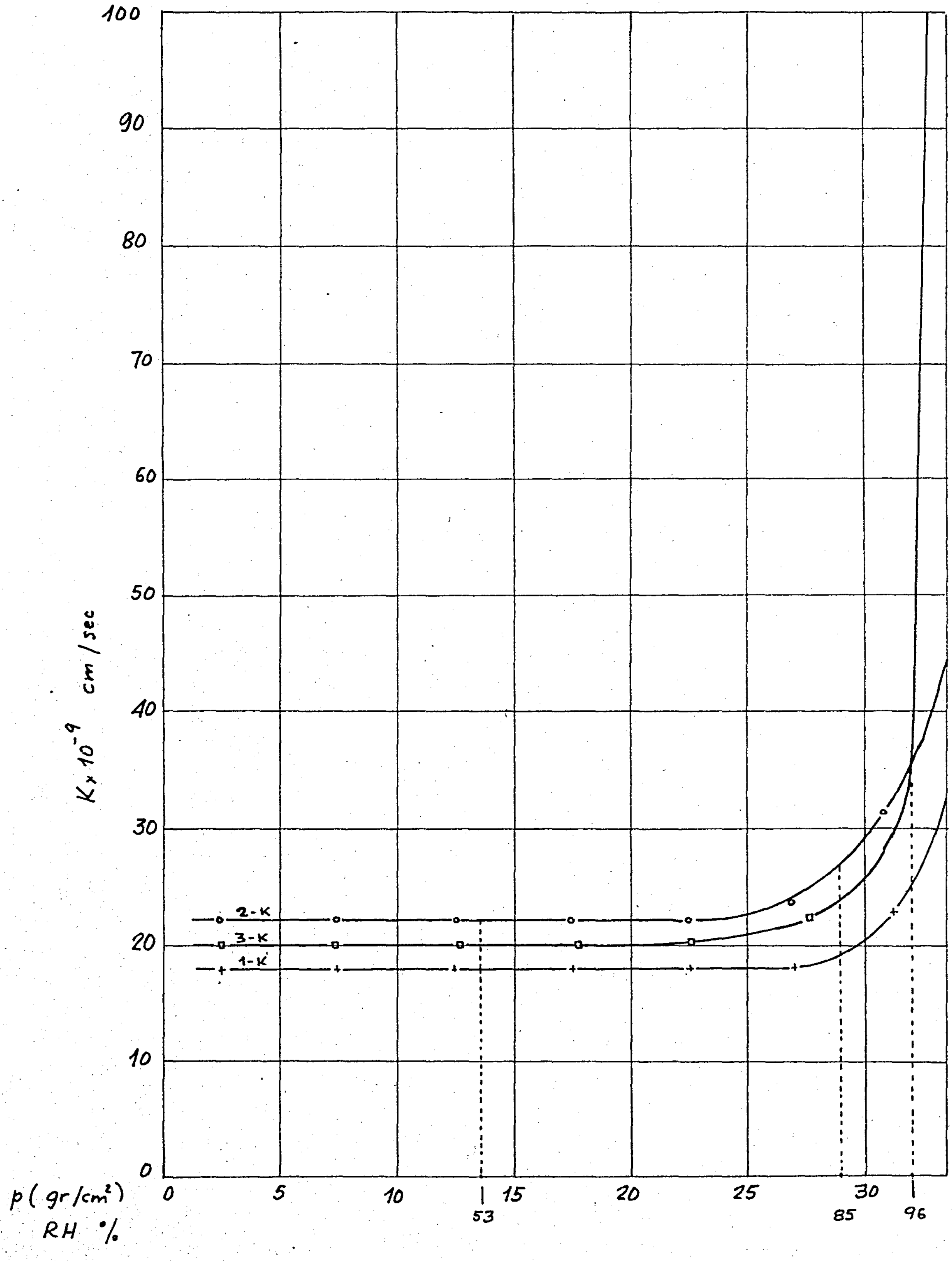
SPECIMEN N° 3-K

Time days	WEIGHTS gr.		
	A	B	C
0	126.3	128.5	136.0
4	129.4	131.2	137.5
5	130.1	132.0	137.8
6	130.9	132.6	138.3
7	131.7	133.3	138.7
8	132.5	134.0	139.2
9	133.1	134.7	139.4
11	134.6	135.9	140.0
12	135.4	136.5	140.6
13	136.1	137.2	141.0
15	137.5	138.3	141.5
16	138.3	138.9	141.8
17	138.9	139.6	142.2
18	139.8	140.3	142.6
19	140.4	140.8	142.7
20	141.1	141.6	142.9

SPECIFIC DATA			
	A	B	C
SLOPE 10^{-6} gr/sec	8.23	7.23	3.59
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.84	1.67	1.60
$q \times 10^{-7}$ gr/cm.sec	7.50	5.98	2.82
RELATIVE HUM. %	96	85	53
TEMPERATURE	78°F	26°C	70°F
P_s mm. Hg.	24.63	25.21	18.77
VAPOR PRESSURE gr/cm^2	32.0	29.0	13.5

fig.(7)

VAPOR PERMEABILITY CURVES FOR PERLITE - PLASTER MIXTURES
(K - SERIES)



SPECIMEN N° L-1

Time days	WEIGHTS gr. A	B	C
0	135.9	133.1	131.4
2	138.1	134.2	132.0
3	138.8	135.0	132.2
5	140.6	136.2	133.0
7	142.8	137.7	133.8
8	145.1	138.1	134.0
9	145.5	138.4	134.5
11	147.3	139.8	135.1
12	147.9	140.3	135.4
13	148.6	141.0	135.7
14	149.4	141.5	136.1
15	150.1	142.0	136.5
16	150.6	142.5	136.7
17	151.1	143.0	136.9
19	152.3	144.0	137.5

SPECIFIC DATA	A	B	C
SLOPE 10^{-6} gr/sec	6.95	5.80	3.47
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.94	1.65	1.77
$q \times 10^{-7}$ gr/cm. sec	6.57	4.74	3.04
RELATIVE HUM. %	96	74	52
TEMPERATURE °C	23.3	24	23.3
P_s mm. Hg.	21.72	21.72	21.72
VAPOR PRESSURE gr/cm^2	28.2	21.8	15.3

SPECIMEN N: L-2

Time days	WEIGHTS (gr.)		
	A	B	C
0	139.9	134.8	138.7
2	141.7	135.7	139.2
3	142.5	136.2	139.5
5	143.9	137.3	140.2
7	146.3	138.4	141.0
8	148.1	138.8	141.2
9	148.9	139.2	141.3
11	150.4	140.3	142.0
12	151.1	140.7	142.5
13	151.7	141.4	142.7
14	152.4	141.8	143.0
15	152.9	142.2	143.3
16	153.6	142.6	143.4
17	154.2	143.1	143.7
19	155.4	144.1	144.1

SPECIFIC DATA			
	A	B	C
SLOPE 10^{-6} gr/sec	7.17	5.38	2.84
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.60	1.70	1.70
q x 10^{-7} gr/cm. sec	5.68	3.92	2.06
RELATIVE HUM. %	96	74	52
TEMPERATURE °C	23.3	24	23.3
P_s mm. Hg.	21.72	21.72	21.72
VAPOR PRESSURE gr/cm^2	28.2	21.8	15.3

SPECIMEN Nº L-3

Time days	WEIGHTS gr. A	B	C
0	140.5	139.8	142.8
2	142.4	140.9	143.5
3	143.5	141.4	143.8
5	144.8	142.5	144.4
7	147.0	143.8	145.2
8	148.9	144.0	145.3
9	149.6	144.3	145.5
11	151.1	145.7	146.0
12	151.9	146.0	146.6
13	152.5	146.5	146.6
14	153.2	147.1	147.0
15	153.9	147.3	147.3
16	154.5	147.8	147.6
17	155.2	148.2	147.9
19	156.6	149.0	148.4

SPECIFIC DATA	A	B	C
SLOPE 10^{-6} gr/sec	8.00	4.68	3.53
SURFACE AREA	20.2	20.2	20.2
THICKNESS cm	1.59	1.59	1.78
q x 10^{-7} gr/cm.sec	5.44	3.69	3.11
RELATIVE HUM. %	96	74	52
TEMPERATURE °C	23.3	24	23.3
P_s mm. Hg.	21.72	21,72	21,72
VAPOR PRESSURE gr/cm²	28.2	21.8	15.3

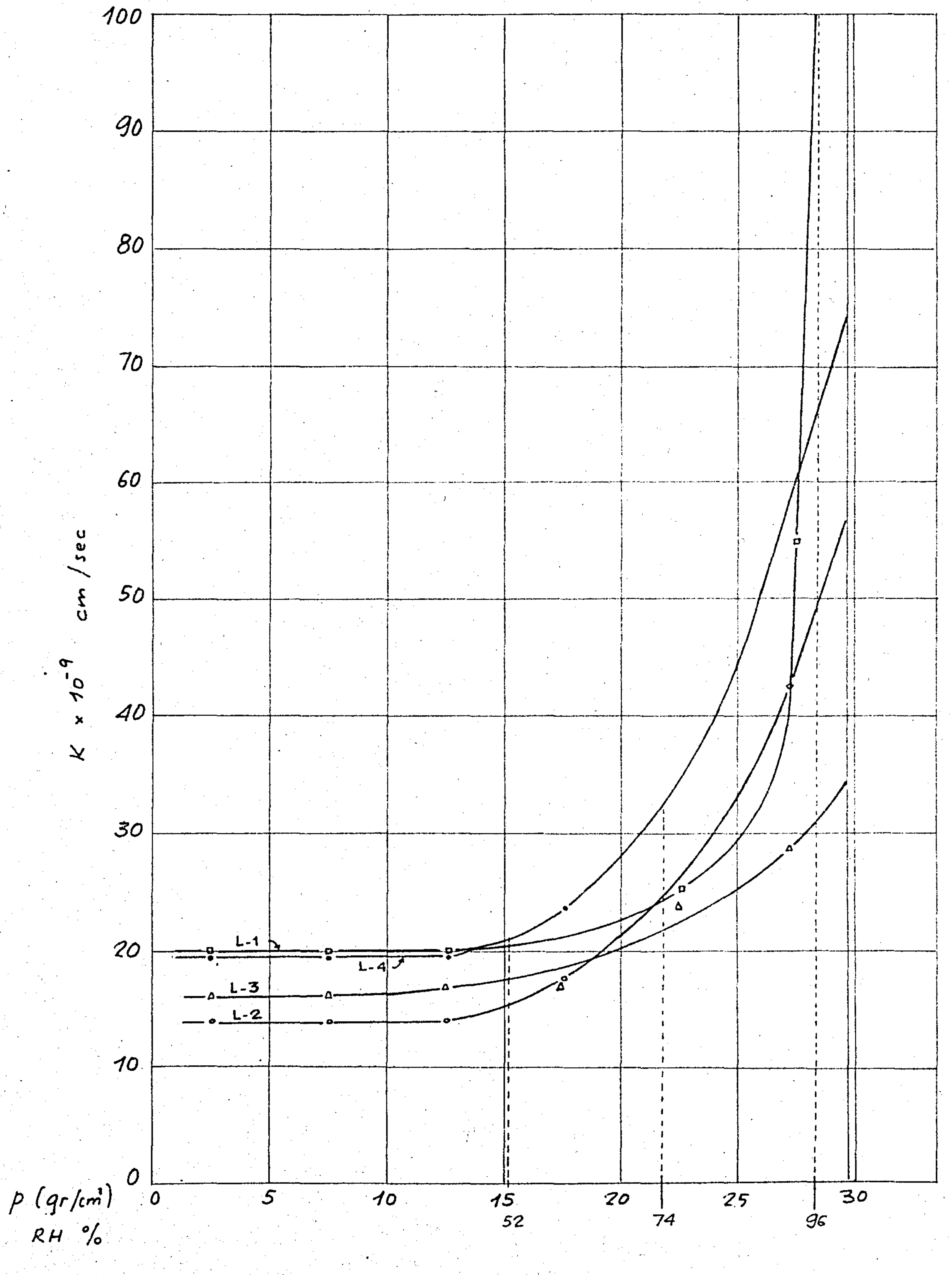
SPECIMEN N: L-4

Time days	WEIGHTS gr. A	B	C
0	128.0	125.5	128.4
2	130.1	127.0	129.4
3	131.3	127.9	129.8
5	133.0	128.9	130.5
7	136.0	130.9	131.4
8	138.4	131.2	131.7
9	139.4	132.1	132.0
11	141.1	133.5	133.0
12	141.8	134.2	133.2
13	142.6	134.8	133.6
14	143.5	135.3	133.9
15	144.3	136.0	134.4
16	145.0	136.5	134.5
17	145.7	137.2	135.1
19	147.3	138.5	135.7

SPECIFIC DATA	A	B	C
SLOPE 10^{-6} gr/sec	9.03	6.89	4.05
SURFACE AREA cm^2	20.2	20.2	20.2
THICKNESS cm	1.60	1.48	1.52
q_x 10^{-7} gr/cm.sec	7.15	5.05	3.05
RELATIVE HUM. %	96	74	52
TEMPERATURE °C	23.3	24	23.3
P_s mm. Hg.	21.72	21.72	21.72
VAPOR PRESSURE $\frac{gr}{cm^2}$	28.2	21.8	15.3

VAPOR PERMEABILITY CURVES FOR PERLITE-LIME-CEMENT MIXTURES

fig. (8)



4-D THE SIGNIFICANCE OF PERMEABILITY CURVES

The relative humidity of the atmosphere, under normal conditions, varies between 45% and 75% and rarely exceeds these limits. Therefore, in these curves the region which interests us the most is the region included between the limits stated above. A study of the permeability curves for all mixture types will reveal us the following facts:

I- For perlite-gypsum plaster mixtures: The permeability curves fig.(6) and (7) are constant in the normal humidity zone and F-series show an increase at the end of this zone.

In this constant region vapor diffuses through the pores without condensation and without capillary flow (15). When the curve starts to rise up, condensation starts to take place in the smaller pores, resulting in capillary flow and therefore the sudden increase in the coefficcient K.

2- As it was expected, for mixtures made with gypsum plaster, the constant part of the curves depends to the amount of perlite in the mix.

Table (13)- The dependence of K to the amount of perlite in the mix

Mix №	Proportions by volume	K* 10^{-9} cm/sec
1-F	1:1.44	14
2-F	1: 2.16	18
3-F	1: 2.88	24

* These values belong to the constant part of the curves

3- For perlite-lime-cement mixes: Here, the situation is slightly different. In the normal humidity zone the curves start to increase at low relative humidities. L-2 and L-3 are less permeable than the others, a fact which can be explained by the cement contents of the mixes. The following table can be a better illustration:

Table (14)- The dependence of K to the cement content of the mix

Mix Nº	Cement Content bags	Lime-Perlite proportions by volume	K values 10^{-9} cm/sec.		
			52% RH	74% RH	AVERAGE
L-1	1	1 : 2.26	22	25	23.5
L-2	2	1:2.26	15	25	20
L-3	3	1:1.57	17	22	19.5
L-4	1	1: 0.36	21	33	27

To be able to make a comparison, the vapor permeability of a mortar made with sand and normal Portland cement is given: (From Prof. Kocataşkın's research results)

Mix proportions			Permeability coefficient K $1/10^9$ cm/sec			
Sand kg/m^3	Cement kg/m^3	Water kg/m^3	50%	60%	80%	90%
1855	250	195	5	5.5	7	15

Consequently, plaster mortars made with perlite aggregates possess a greater porosity and they are more permeable to water vapor. This way they prevent condensation and accumulation of moisture in the wall.

<u>Example</u>:

Suppose that a 2-F mixture having a thickness of 2.5 cm. is subjected to conditions of 53% and 85% relative humidities. The rate of vapor flow from I m^2 surface area of the plaster is wanted.

Solution:

From the corresponding curve on page (34) it is possible to obtain mean value K_o for the range 53-85% R.H.

$K_o = 32 \times 10^{-9}$ cm/sec

$p = 29$ gr/cm^2

$p_o = 13.5$ gr/cm^2

From the formula $q.x = K_o\ (p-p_o)$ see page (28)

$$q = \frac{32 \times 10^{-9} \times 15.5}{2.5} = 198.5 \times 10^{-9} \text{ gr/cm}^2\text{.sec}$$

$q = 7.14$ gr/m^2.hr

CHAPTER V

THERMAL CONDUCTIVITY TESTS

5-A WHY THERMAL INSULATION IS IMPORTANT ?

A difference of temperature between the inside and the outside of a building must result in a transfer of heat from the warmer to the colder zone, so that there is a progressive difference of temperature across the thickness of the wall; the steepness of the temperature drop is termed the temperature gradient. Any wall separating these zones will offer some resistance to, but will not completely prevent, the flow of heat. Thermal insulation may be regarded as the coefficient of resistance to heat transfer. (11)

One of the striking features of lightweight concrete is the relatively high thermal insulation values which they exhibit, the insulation being more or less inversely proportional to the density of the material.

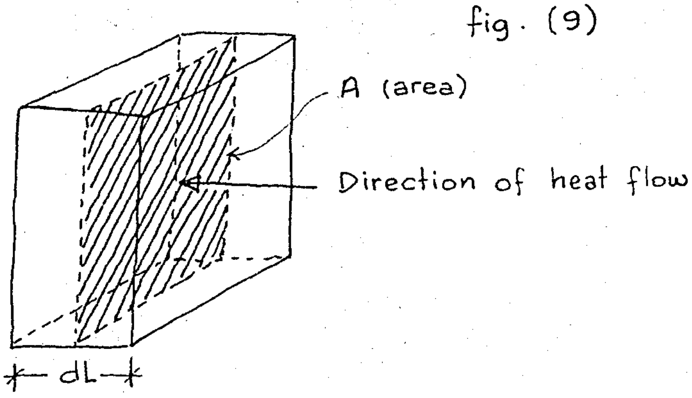
In the construction of roof, floor and wall systems for today's buildings, the importance of properly designed insulation cannot be underestimated. The growing use of air conditioning and rising costs of fuel and power make it ever more obvious that a small investment in proper insulation at the time of design and construction can save a lot in heating and cooling costs during the life of the building.

All of the heat that is put into a building in the winter and all of the power used for summer cooling is eventually lost. Correct use of insulation materials reduces the rate of this loss and saves money for the building owner. Buildings in the southern and western geographical areas of Turkey should be mainly insulated against the loss of summer cooling; in the notth and eastern areas insulation should be primarily against winter heat loss; while in many intermediate areas, a balance of insulation is desirable to develop efficient summer and winter control.

5-B THE PROBLEM OF THERMAL CONDUCTIVITY

The calculation of the rate at which heat flows through any material by conduction involves a property of the material called the thermal conductivity. This property is the rate at which heat flows through the material by conduction per unit of cross-sectional area taken normal to the direction of heat flow and per unit of temperature gradient measured in the direction of flow. Consider for example a small element of the material having a cross-sectional area A and thickness dL, as shown in the figure.

fig. (9)



If the two end faces of the element are maintained at the uniform temperatures t and (t - dt), and if the sides of the element are surrounded by other material at the same temperature so that no heat is lost laterally, heat will flow at some rate q from the face at the higher temperature to the face at the lower temperature. Since the end faces are both at uniform temperatures the direction of heat flow will always be normal to these faces. By definition, the thermal conductivity k of the material is equal to the rate of heat flow q divided by A, the cross-sectional area and divided by the temperature gradient $-\frac{dt}{dL}$ in the direction of heat flow. (12)

$$k = \frac{q}{A\,(-dt/dL)}$$

Effect of temperature and pressure on thermal conductivity :

The thermal conductivities of practically all materials depend upon the temperature of the material. For some materials the thermal conductivity increases as the temperature of the material rises; for others it decreases. This variation is approximately linear over a considerable range of temperature for most materials.

For practical purposes the thermal conductivities of all materials are unaffected by changes in pressure.

If the conduction of heat is steady, the rate of heat transfer through homogeneous flat bodies can be calculated by integrating the fundamental equation:

$$k = \frac{q}{A(-dt/dL)}$$

$$kA\left(-\frac{dt}{dL}\right) = q$$

$$kA\int_{t_1}^{t_2} -\,dt = q\int_{0}^{L} dL$$

$$q = \frac{kA(t_1 - t_2)}{L}$$

from where

$$k = \frac{qL}{A(t_1 - t_2)}$$

q Rate of heat transfer by conduction B.T.U. per hr.

k Thermal conductivity B.T.U./ ft. hr. °F

A Cross-sectional area ft^2

t_I and t_2 Temperatures at the two faces of the body °F

L Thickness of the body ft.

5-C ABOUT THE TESTS

Thermal conductivity tests are conducted at the laboratory of the İmar ve İskân Bakanlığı Yapı Malzemesi Genel Müdürlüğü at Ankara. Due to the fact that one test takes about six hours and because of the limited time, the coefficient of heat conductivity could not be determined for all the mixture types. Only those mixtures which are typical and of major importance could be tested.

The apparatus used was a German made, FEUTRON Fabrik Elektro-physikal Gerate-Greiz. The governing principles are the same as for the Guarded Hot Plate of the ASTM standards. The specimen which has the dimensions of 240/240/40/ mm. is held between two plates, one heated by electric current at around 3I °C the other cooled by a continuous stream of water and kept at 2I °C. The temperature difference between two plates is kept constant by means of thermostats. The coefficient of thermal conductivity of the specimen depends upon the very precise thermometer and electric counter readings and some constants of the machine which are already given by the manufacturer.

Since air is a perfectly good insulator against heat, the dependence of the coefficient of heat conductivity to the porosity and consequently to the unit weight of the material must be accepted as a natural result. To illustrate this fact and to give a general idea about the coefficients of heat conductivity of some building materials, the following table, which is published in the " Annales de l'institut technique du batiment et des travaux publics" (22) is given.

TABLE (15) - COEFFICIENTS OF THERMAL CONDUCTIVITY kcal/m.h.°c

MATERIAL	Average temperature °c					Unit Weight kg/m³
	-10	0	20	30	40	
STONES						
Gravel			1,25			2400
Granite			2,50			2700
Marble	2,30	2,22	2,02	1.93	1,84	2630
CONCRETE						
Ordinary Conc.				1,20		2200
			1,15			2130
Perlite Concrete			0,10			600
			0,11			628
			0,12			733
			0,19			800

TABLE (15) - Continued

MATERIAL	Average temperature °C					Unit weight kg/m³
	-10	0	20	30	40	
Vermiculite conc.				0.066		210
					0.062	280
			0,123			470
Sawdust concrete			0.12			600
		0.066	0.5			1300
MORTARS						
			0.20			1000
				0.21		1030
			0,38			1430
PLASTER						
Ordinary plaster				0.23		1060
				0,25		1220
Molding plaster					0.32	1080
					0.26	950
			0.23			1070
HYDROCARBONATED PRODUCTS						
			0,22			1300
			0,27			1630
			0,34			1800
			0,32			1820

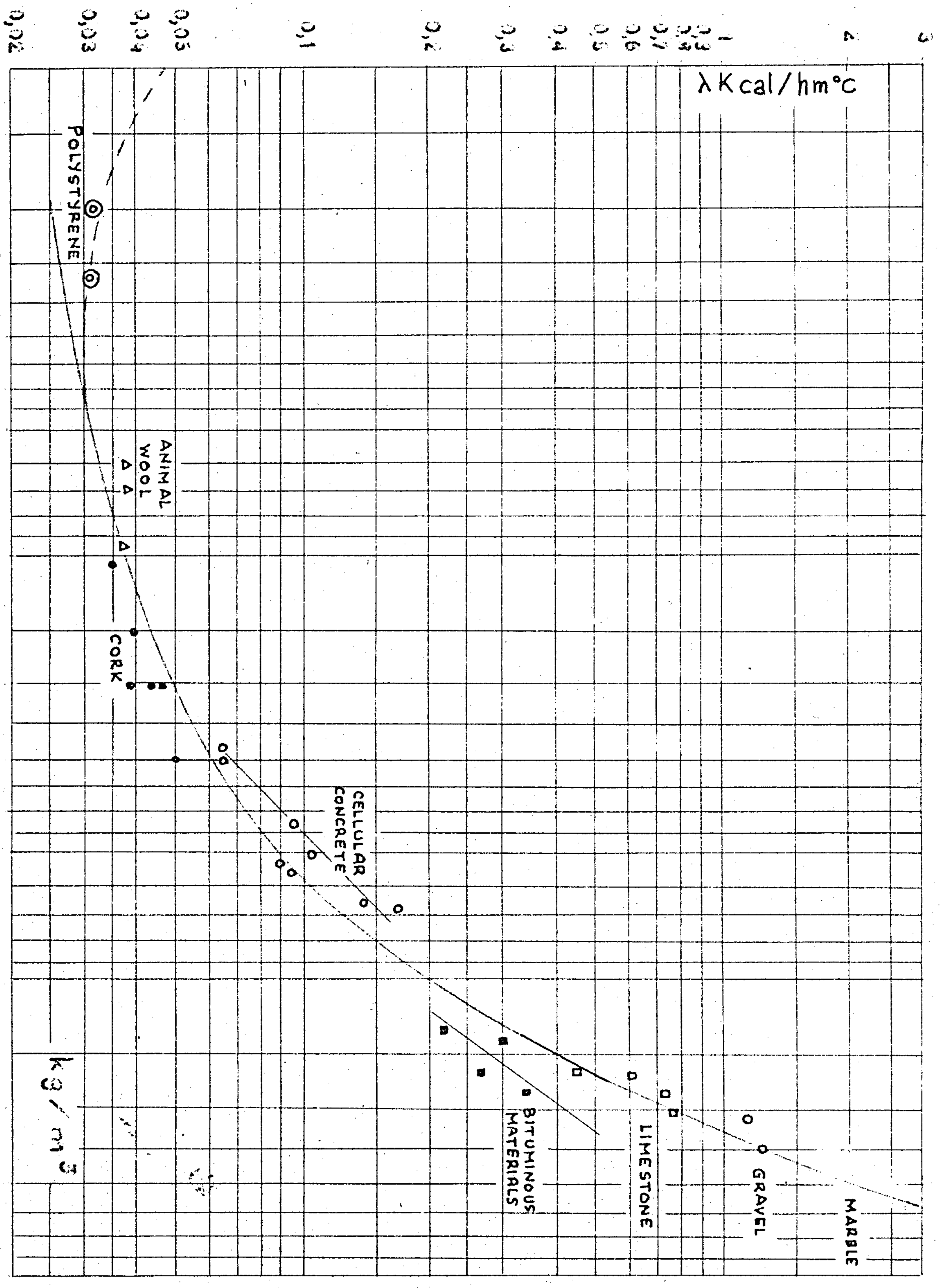


Fig. (10) - VARIATION OF λ WITH UNIT WEIGHT

TEST DATA

SAMPLE Nº 1-F									
Time Z	10^{30}	11^{00}	11^{30}	12^{00}	12^{30}	13^{00}	13^{30}	14^{00}	14^{30}
Cold water temperature	14.00	14.85	14.70	14.10	14.20	14.80	15.00	15.20	14,65
Electric counter readings E	22,038	22,104	22.163	22.219	22,275	22,322	22.386	22.432	22.486
Hot plate inlet temp. t_{w_1}	31,30	31,30	31,30	31,30	31,30	31,30	31,25	31,30	31,30
Hot plate outlet temp. t_{w_2}	31,25	31,25	31,25	31,25	31,30	31,25	31,20	31,25	31,20
Cold plate inlet temp. t_{k_1}	20,95	20,95	20,95	20,95	20,95	20.95	20,95	20.95	20.95
Cold plate outlet temp. t_{k_2}	20,95	20,90	20,95	20,95	20,95	20,95	20,90	20,95	20,95

ΔE	0,066	0,059	0,056	0,056	0,047	0,064	0,046	0.054
ΔZ	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0.5

SAMPLE Nº 3-F									
Time Z	14^{30}	15^{00}	15^{30}	16^{00}	16^{30}	17^{00}	17^{30}	18^{00}	18^{30}
Cold water temperature	15.70	15,60	15.05	14.80	14,70	14.70	14.70	14,75	14,65
Electric counter readings E	21,392	21,458	21,521	21,582	21,642	21,703	21,764	21,825	21,883
Hot plate inlet temp. t_{w_1}	31,40	31,45	31,45	31,45	31,50	31,50	31,50	31,45	31,45
Hot plate outlet temp. t_{w_2}	31,35	31,40	31,40	31,40	31,45	31,45	31,45	31,45	31,45
Cold plate inlet temp. t_{k_1}	20,95	21,00	21,00	20,95	20,95	20,95	20,95	20,95	20,95
Cold plate outlet temp. t_{k_2}	20,95	21,00	20,95	20,95	20,95	20,95	20,95	20,95	20,95

ΔE	0,066	0,063	0,061	0,060	0,061	0,061	0,061	0,058
ΔZ	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5

SAMPLE N: L-1

Time Z	11^{00}	11^{30}	12^{00}	12^{30}	13^{00}	13^{30}	14^{00}	14^{30}	15^{00}
Cold water temperature	14,10	14,20	14,10	14,60	14,70	14,00	14,80	13,90	14,20
Electric counter readings E	22,596	22,669	22,731	22,793	22,853	22,912	22,970	23,031	23,092
Hot plate inlet temp. t_{w_1}	31,35	31,35	31,25	31,30	31,30	31,30	31,30	31,35	31,35
Hot plate outlet temp. t_{w_2}	31,30	31,25	31,25	31,30	31,25	31,25	31,20	31,25	31,30
Cold plate inlet temp. t_{k_1}	20,95	20,95	21,00	20,95	21,00	20,95	20,95	20,95	20,95
Cold plate outlet temp. t_{k_2}	20,95	20,95	20,95	20,95	20,95	20,95	20,95	20,95	21,00

ΔE	0,073	0,062	0,062	0,060	0,059	0,058	0,061	0,061
ΔZ	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5

SAMPLE N: L-3

Time Z	11^{00}	11^{30}	12^{00}	12^{30}	13^{00}	13^{30}	14^{00}	14^{30}	15^{00}
Cold water temperature	14,60	14,55	15,05	14,25	16,00	16,00	15,15	14,85	15,05
Electric counter readings E	23,223	23,297	23,373	23,449	23,524	23,602	23,680	23,757	23,834
Hot plate inlet temp. t_{w_1}	31,35	31,35	31,35	31,30	31,35	31,40	31,30	31,35	31,35
Hot plate outlet temp. t_{w_2}	31,25	31,30	31,30	31,25	31,30	31,30	31,25	31,30	31,30
Cold plate inlet temp. t_{k_1}	21,00	21,05	21,00	21,00	21,00	21,00	21,00	21,05	21,05
Cold plate outlet temp. t_{k_2}	21,00	21,00	21,00	21,00	21,05	21,05	21,05	21,00	21,05

ΔE	0,074	0,076	0,076	0,075	0,078	0,078	0,077	0,077
ΔZ	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5

TABLE (16) DETERMINATION OF THE COEFFICIENT OF THERMAL CONDUCTIVITY FROM TEST DATA

	1-F	3-F	L-1	L-3
$\sum \frac{t_{w_1}}{9}$ (a)	31,18	31,35	31,21	31,34
$\sum \frac{t_{w_2}}{9}$ (b)	31,20	31,38	31,22	31,24
$\sum \frac{t_{k_1}}{9}$ (c)	20,93	20,94	20,94	21,00
$\sum \frac{t_{k_2}}{9}$ (e)	20,93	20.94	20,94	21,01
$\Delta t = \frac{(a+b)-(c+e)}{2}$	10,26	10,42	10,28	10,23
$\sum \Delta E$	0,448	0,491	0,496	0,611
$\sum \Delta Z$	4	4	4	4
* K_i ($Kcal/m^2$)	307,2	307.2	307,2	307,2
$q = \frac{\sum \Delta E}{\sum \Delta Z} \cdot K_i$	34,4064	37,7856	38,0928	46,9248
d (m)	0,0416	0,0409	0,04115	0,03997
* ω ($m^2 h\,°c/Kcal$)	0,0022	0,0022	0,0022	0,0022
** $\lambda = \frac{q\,d}{\Delta t - q \cdot \omega}$	0,140	0,149	0,154	0,185

* Machine constants
** Coefficient of thermal conductivity in Kcal/m.h.°c

The resulting coefficients of heat conductivity conform to the requirements of the ASTM C 332-54T.

GENERAL DISCUSSION

Before starting this dicussion, a price analysis on the basis of prevailing market prices is given. The following are the market prices of materials and labor.

Perlite I m^3		I25.- TL.
Gypsum plaster	I. Quality	0.45 TL.
	2. "	0.38 TL.
Normal Portland cement I kg.		0.20 TL.
Water I ton		I.20 TL
Sand I m^3		25.- TL.
Hydrated lime in-situ I m^3		59.- TL.

In these prices approximate cost of transportation is also included.

Worker salaries:

Unskilled worker	2.- TL. per hour
Skilled plasterer	4.50 TL. per hour

The preparation of I m^3 mortar requires 5 hours of an unskilled worker.

The application of I m^2 of plaster requires:

0.60 hours of an unskilled worker

0.80 hours of a skilled plasterer.

The application of I m^2 plaster surface of I cm thickness:

I- Gypsum plaster mixtures

Normal I:3 sand-gypsum plaster mixture		6.65 TL.
Perlite-gypsum plaster mixtures	I-F	8.90 TL.
	2-F	9.00 TL.
	3-F	8.I5 TL.

	I-K	9.05 TL.
	2-K	8.75 TL.
	3-K	8.58 TL.

2- Lime mixtures

Normal sand-lime mixture		5.42 TL.
Perlite-lime mixtures	L-I	6.36 TL.
	L-2	7.I2 TL.
	L-3	6.80 TL.
	L-4	5.85 TL.

The following table will be a summary of test results:

	Perlite-gypsum plster mixtures	Perlite-lime mixtures
Oven-dry unit weight kg/m^3	594 - 897	673 - 844
Compressive strengths kg/cm^2	22 - 79	7 - 20
Vapor permeability	see figures	
Heat conductivity	0.I50 - o.I85 Kcal/m.hr.°C	
Approximate costs (Im^2)	8.I5-9.05 TL.	5.85-7.I2 TL.

As it is seen from this table, gypsum plaster mixtures are stronger than lime-cement mixtures, they can very well be used for decorative purposes but, they are more expensive. On the other hand, lime-cement mixtures are easier to work with, provide very good bond on any type of surface and they are cheaper. The heat conductivities of both mixes, depending on their unit weights, stay approximately in the same range and is very low. Comparing perlite with other lightweight material produced in Turkey, we will have the following table:

Material	Unit weight kg/m^3	Thermal cond. Kcal/m.h.^{o}C	Comp. strengt kg/cm^2
Perlite plasters	594-844	0.I50-0.I85	7-79
Perliton	300-650	0.080-0.I6o	5-35
Betocel	300-800	0.063-0.I40	6-20
Ytong	400-650	0.070	20-30
Izokam	I90	0.038	-
Durisol	580	0.095	I2-35
Heraklit	360-570	0.080	-

These values are taken from the records of the Imar ve Iskan Bakanlığı at Ankara.

Although perlite plasters have an economic disadvantage over the normal sand plasters which is not very significant, their advantages like light weight, workability, natural white color which provides an excellent base for any other color, fireproofing properties, good insulation properties against heat and sound and permeability to water vapor make them an excellent plastering material.

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A P P E N D I X

Conversion tables

Saturated water vapor pressures
at different temperatures

CONVERSION TABLES

LINEAR MEASURE

in.	ft.	cm.	m.
1	0.0833	2.54	0.025
12	1	30.48	0.305
0.394	0.0328	1	0.01
39.37	3.281	100	1

SQUARE MEASURE

in^2	ft^2	yd^2	cm^2	m^2
1	0.00694	0.000772	6.452	0.000645
144	1	0.111	929.03	0.0929
1296	9	1	8361.3	0.836
0.155	0.001076	0.00012	1	0.0001
1550	10.764	1.196	10.000	1

THERMAL CONDUCTIVITY

Btu.in/ft.h.°F	Kcal/m.h.°C
1	0.1240
8.0636	1

THERMAL CONDUCTANCE

Btu / ft^2.h.°F	Kcal/m^2 h °C
1	4.8824
0.2048	1

WEIGHTS

lb.	Ton	Short ton	kg	Metric tonne
1	0.000446	0.0005	0.4536	0.000454
2240	1	1.12	1016.05	1.016
2000	0.893	1	907.18	0.907
2.2046	0.000984	0.00102	1	0.001
2204.62	0.9842	1.1023	1000	1

CUBIC MEASURE

ft^3	yd^3	imper. Gal.	US Gal.	dm^3	m^3
1	0.0371	6.229	7.480	28.317	0.0283
27	1	168.18	201.98	764.55	0.765
0.1605	0.00595	1	1.201	4.546	0.00455
0.134	0.00495	0.833	1	3.785	0.00379
0.0353	0.00131	0.22	0.264	1	0.001
35.315	1.308	219.97	264	1000	1

STRESSES

lb/in^2	kg/cm^2
1	0.07031
14.223	1

PRESSURES

lb/ft^2	kg/m^2
1	4.8824
0.2048	1

DENSITY

lb/ft^3	kg/m^3
1	16.018
0.06243	1

SATURATED WATER VAPOR PRESSURES AT DIFFERENT TEMP.

Temp. °C	Pressure mm. Hg	Temp. °C	Pressure mm. Hg	Temp. °C	Pressure mm. Hg	Temp. °C	Pressure mm. Hg
- 20	0.77	0	4.58	+ 20	17.53	+ 40	55.32
- 19	0.85	+ 1	4.93	+ 21	18.65	+ 41	58.34
- 18	0.93	+ 2	5.29	+ 22	19.83	+ 42	61.50
- 17	1.03	+ 3	5.69	+ 23	21.07	+ 43	64.80
- 16	1.13	+ 4	6.10	+ 24	22.38	+ 44	68.26
- 15	1.24	+ 5	6.54	+ 25	23.76	+ 45	71.88
- 14	1.36	+ 6	7.01	+ 26	25.21	+ 46	75.65
- 13	1.49	+ 7	7.51	+ 27	26.74	+ 47	79.60
- 12	1.63	+ 8	8.05	+ 28	28.35	+ 48	83.71
- 11	1.78	+ 9	8.61	+ 29	30.04	+ 49	88.02
- 10	1.95	+ 10	9.21	+ 30	31.82		
- 9	2.12	+ 11	9.84	+ 31	33.70		
- 8	2.32	+ 12	10.52	+ 32	35.66		
- 7	2.53	+ 13	11.23	+ 33	37.73		
- 6	2.76	+ 14	11.99	+ 34	39.90		
- 5	3.01	+ 15	12.79	+ 35	42.18		
- 4	3.28	+ 16	13.63	+ 36	44.56		
- 3	3.57	+ 17	14.53	+ 37	47.07		
- 2	3.88	+ 18	15.48	+ 38	49.69		
- 1	4.22	+ 19	16.48	+ 39	52.44		