SECTION 1. INTRODUCTION

1.1. The Aim And The Scope Of The Research Of Adobe Technology

People can live healthy in specific environmental conditions. Adobe construction has been providing inner space comfort for more than 9,000 years [1].

Structures have been built with industrial structural materials since industrial revolution. However, these materials cannot meet the demand alone. It is necessary that various materials complete one another to avoid effects of heat, moisture balance, fire, water and sound isolations.

Industrial production (conrete, iron etc.) pollutes the environment with solid, liquid and gas wastes and consumes non-recyclable natural resources of the world with the energy it uses in the process. 1.6 million tones carbondioxide is released to the atmosphere in 1976. 6000 people died due to air pollution. It reduced heat energy of the USA by 28% between 1977-1980. It is planned to provide 500.000 barrel oil savings daily by changing type of the lamp in illumination energy. It is estimated that $ 700 billion is spent annually for balancing damage given to the environment and maintaining human life for some more time.

If there is no precondition to live in a multi-storied building and there is chance or need of widespread settlement, “gypsum stabilized adobe” is an irreplaceable construction type. It makes use of the local materials and productive power supplies. As a result of stabilization, its mechanical and physical qualities have been improved. Trustworthy buildings, whose inner space comfort is high and whose restoration expenses are reduced, are being built.

In this study, the workability of gypsum-stabilized adobe has been revised to ensure rational constructions with contemporary construction methods and equipment. The ones who benefit from gypsum stabilized adobe materials and technology may be:

a. The ones who make their own buildings or the ones who build housing estates. In the possibility of housing estates either
b. It may be planned as a labor intensive work or

c. Industrialized construction process for mass production.

The aim of this study, which can reduce the environmental impact of large settlements and which has an important contribution to the preservation of local life and building culture, is to provide;

1) Wealthy and affordable houses for the user,

2) Reliable adobe construction technology for the planner, applicator and investor.

3) Settlings that preserve energy, budget, natural sources and cultural heredity for the authorized.

1.2. The Aims Of The Housing Sector

Together with the housing demands of the growing population a "group settling" because of war, earthquakes, flood, and political migration, is the point of discussion. At the end of 2nd World War, Europe set 'rationalization' as a target for housing sector. Rationalization can be defined as making the best production in the largest amount but in the shortest time with the existing opportunities". In this way, within a short time fabrication and mounting techniques in the construction and production sector have been developed.

The next important target generation can be defined as intelligent buildings. The automation control of services that has been used since 1930 in multistoried office buildings and that provides human comfort mechanically leads to the term 'intelligent buildings'. Automation is later given a chance to be used in houses and the 'intelligent buildings' period has thus started in houses.

In greatly industrialized countries, it has been seen that the damage given to the environment has started to endanger 'human life'. The threat of environmental pollution also continues in the production of construction materials like "cement", "brick", "aluminum", etc., at the same dimensions. Thus, the 3rd target-generation aimed to be reached in the housing sector is determined as "healthy buildings" which reduce environmental impacts at most.

The aims of the healthy buildings can be summarized as:

A) Occupant health

B) Ecology

C) Affordability

A. Occupant Health

If structural exterior materials such as walls surrounding the space, floor, woodwork are insufficient in terms of detail, material, heat insulation values, condensation occurs at (a) exterior surface, (b) cross-section of element and (c) interior of element, namely the part facing the space. Microorganisms such as fungi, mould on the surface deteriorate living conditions of the space. Temperature at interior surface of exterior structural materials may be maximum 3° C less than the temperature at the space. If there is a greater variance, element deteriorates living conditions of inner space with air flow and heat radiation at its surface. On the other hand, relative moisture increase rapidly within a short period with activities such as meal cooked in the kitchen, having a bath, making sport. Heavy moisture, which discomforts people, cannot always be removed by air circulation. This results in energy loss of heated space. In such cases, structural materials, whose vapour diffusion is low such as reinforced curtain wall, deteriorate space conditions. Partial absorption of moisture from wall and its return within time provides comfort (See Section 3.4, Figure 3.9).

Many diseases such as rheumatism, allergy, skin fungus, cancer, tuberculosis and fatigue either start or develop with the effect of space. Factors such as properties of materials, temperature-moisture balance (Sec. 3.4, Table 3.7.B) are significant for human health.

Many industrial structural materials have been introduced to the market recently. Chemicals used for the production or for the protection of these materials have been long discussed in terms of their effect on human health. Asbestos fibres, radon gas, synthetic resins, solvents, radioactive materials etc. are among the research fields of “Structure Biology”.

B. ECOLOGY

- Respect for Environment

Environment is an integral with flora, atmosphere and water resources. People live as a part of both this natural environment and environment created by microwaves coming from the centre of Earth and Airspace. Changes in the environment (such as changes in micro waves- cancer) threaten human health. It is necessary that environment be protected for survival of humans. Change and settlement in nature should be controlled and consumption and misuse of underground and surface water, demolition of flora and living creatures within it and the process in which environment becomes unusable due to solid and liquid wastes should be prevented.

TABLE 1. THE AIM OF HOUSING

(Keywords)

1st GENERATION (1945-)	2nd GENERATION “ (1980-)	3rd GENERATION (1990-)
Rationalization	Intelligent Buildings	Healthy Buildings
Rationalization Industrialization Prefabrication Large Settlement Low Cost	Automation	A- Occupant Health B- Ecology C- Affordability

Economical meaningfulness
Technological applicability
Appropriateness for the user
Using, attention, repair
| Affordability — C

Saving
Recycle
Alternative Energy
| Energy Efficiency — Ecology — B

Material Selection
Resource Efficiency
Using less amount of water
Structural durability
Toxic and harmful
| Minimizing harmful materials

Flora
Little water pollution
Solid, liquid, gas wastes
Disorderly settlements
| Environmental Responsibility

Occupant Health — A

- **Energy**

When each material used in buildings is transformed from raw material into structural material, it uses different amount of energy (for example, gypsum is baked at 120°C and cement is baked at 1200°C). Energy is required for transport of raw material to factory and to site and for constructing the building. Construction is the sector, which uses heat energy for providing comfort conditions during usage. Housing sector uses energy most with its phases such as material production, building production and usage. The least savings to be realized in the system will reduce energy budget of both individual and country and protect non-recyclable resources of the country (such as fossil fuels).

In addition to savings, the greatest profit can be obtained through "recycle". Recycle means benefiting from energy in wastes emerging during "production processes" and "building usage".

Other researches on energy encourage alternative energies such as solar energy in housing sector.

- **Minimizing harmful materials**

Housing sector consumes world's resources for buildings at a high level. T ones of natural resources are processed and transformed into structural materials for each building. Each material uses separate amounts of energy during the transformation. It contaminates nature, atmosphere and water resources during the process.

It should be paid attention to that "harmful or toxic" (such as radioactive raw materials) processes or materials, which affect human health, are not involved in the process or usage.

C- AFFORDABILITY

Affordability for housing sector can be defined as economy, technological affordability, socio-cultural requirements as well as usage requirements of user. The importance and stress of these concepts are equal. A production which can be technologically constructed but is expensive loses its meaning for mass housing. On the other hand, maintenance-renovation period of building in usage period, expenses and the required technique should be minimized.

1.3. Evaluation of Conformity of Adobe Construction for Building

Lifecycle of all sorts of building is composed of "procurement of raw material, production of material, production of element, construction, usage, maintenance- restoration, composing wastes, returning to the beginning".

Environmental pollution occurring in the world, the fact that it endangers human future, creation of highly unhealthy inner space conditions as a result of unconscious construction urged "new construction target" in the housing sector to be "healthy buildings", which has been stated above. When healthy buildings are mentioned, concepts such as "protection of occupant health, protection of energy, minimizing harmful materials, affordability" have been defined.

Evaluation methodology is used for determining conformity of any building type to mass housing [5]. The following matrix composed of "building life- process" and "requirements of healthy buildings" is prepared to evaluate conformity of the building to "healthy buildings" principle (Table 1.2).

EVALUATION MATRIX

Targets / Building Life- Process		Occupant Health	Protection of Energy	Protection of Environment	Minimizing Harmful Materials	Affordability
		1	2	3	4	5
Procurement of Raw Material	A					
Material Production	B					
Element Production	C					
Construction	D					
Usage	E					
Maintenance + Renovation	F					
Returning to the beginning or waste formation	G					

Table. 1.2 Evaluation of Adobe Building in relation to Humans and Environmental Load

According to matrix, conformity of building phases with the requirements of healthy buildings will be evaluated as harmful (-) and beneficial (+). If a building composed of reinforced curtain walls is selected as an example for matrix,

- Evaluation of its conformity at the phase of Line A and 2nd column:

A 2- Procurement of raw material/ Protection of Energy

Cement and construction irons have been heavily used in the building. It will get (-) point since cement and iron consume more energy than other material productions during their productions.

- Evaluation of its conformity at the phase of Line A and 3rd column:

A3- Procurement of raw material and environment relation

It will get (-) point since cement and steel consume non-recyclable resources during their production and contaminate environment with solid and gas wastes.

If conformity of adobe building is evaluated in relation to humans and environmental load by using the matrix:

A. Procurement of Raw Material

A1 – Procurement of raw material/ Human health

Procurement of raw material only consists of excavation of appropriate soil from a place near the construction and its transport to construction site. Soil preparation activities as well as factory processes of gypsum and lime do not endanger human health. Wastes from burning are scarce (+).

A2- Procurement of raw material/ Protection of energy

Only excavation energy for soil, a raw material, and lower drying energy for gypsum and lime are sufficient. The greatest voluminous material in the construction is wall material. Since soil is transported from a near neighbourhood to construction site, transportation energy is very low (+).

A3- Procurement of raw material/ Protection of environment

Since its drying energy is low, the value obtained from pollution due to wastes is lower compared to other load-bearing construction materials.

A4- Procurement of raw material/ Minimizing toxic and harmful materials

Materials such as solvents, asbestos fibres etc., which are toxic or harmful for human, may exist in some construction materials. Adobe is natural and appropriate for human health (+).

A5- Procurement of raw material/ Affordability

Material can be obtained from near neighbourhood without spending money. Besides, it does not require stacking workmanship during loading and offloading since it is bulk material. It is discharged through dumper truck (+).

B. Material Production (Preparation of the Mixture)

B1- Material Production/ Human Health

Preparation of gypsum stabilized adobe material used in the construction of load-bearing wall involves only mixing raw materials in site mixer. During this process, works or materials, which may affect human health negatively, are not involved (+).

B2- Material Production/Protection of Energy

Since concrete mixing process is completed within minutes during mortar preparation phase, hardly any energy is used (+).

B3- Material Production/Protection of Environment

Environmentally hazardous materials or workmanship do not exist in mortar preparation phase (+).

B4- Material Production/Minimizing toxic and harmful materials

Any toxic or harmful material does not exist in mixture preparation phase (+).

B5- Material Production/ Affordability

Adobe material is a material whose procurement is based on local resources, workmanship can be easily conveyed and raw material and workmanship costs are low (+).

C. Element Production (Wall Casting)

C1- Element Production/ Human Health

It is composed of casting mortar, which has been prepared in the mixture during element production, into wall mould and ramming. This process can be performed either manually or by machine. Materials or works that are harmful for human health do not exist (+).

C2- Element Production/ Protection of energy

When compression of mortar, which has been placed into the mould, is performed mechanically, it is completed within a short time. Preparation of mixture lasts 2 minutes. Electrical energy requirement is very low (+).

C3- Element Production/ Protection of environment

Materials or works contaminating the environment do not exist during casting and compression of mortar, which is given a shape in the mould (+).

C4- Element Production/ Minimizing Toxic and Harmful Materials

Materials or works that are toxic or harmful do not exist in casting or placing mortar in the mould.

C5- Element Production/ Affordability

Element production, industrial mould, compression processes either manually or by machine are suitable in terms of technology and costs (+).

D. Construction Phase

D1- Construction Phase/ Occupant Health (Human Factor)

Adobe construction site can be completely carried out by manpower. However, if there are requirements such as reduction in workmanship, overwork within a short period and acceleration of work, instruments such as mixer, belt conveyor and mechanical compressor can be used in site. While such instruments are proprietary tools, which can process soil (namely, are adapted to structure of soil), universal construction machines could be used in this research since properties of mortar have been developed. Adobe construction site together with machines have protected human health and human energy (+).

D2- Construction phase/ Protection of energy

Since process periods are short in adobe construction sites, which are performed with mechanization, energy consumption is very low (+).

D3- Construction phase/ Protection of energy

There are no environmentally hazardous or contaminating wastes in construction phase (+).

D4- Construction phase/ Minimizing toxic and harmful materials

Materials or works that are harmful or toxic for workers and environment do not exist in construction (+).

D5- Construction phase/ Affordability

Technology and costs are lower than other construction materials in adobe site (+).

E. Usage Phase

E1- Usage Phase/ Occupant Health

Adobe construction is the most suitable building for human health with its temperature-moisture balance, sound level, fire-resistance and non-existence of toxic and harmful materials (+). (Some modern materials are found to be harmful for human health and are removed from the market).

E2- Usage Phase/ Protection of energy

Since thermal conductivity of adobe material is low, thermal loss in walls is also low. This provides energy conservation during usage phase of the building (+).

E3- Usage Phase/ Protection of environment

Naturally, lower amounts of fuel will be consumed in a building, which loses lower energy during usage. Thus, on the one hand, solid and gas wastes will be reduced depending on fuel in adobe buildings and on the other hand, illegal tree cuttings in forestry settlements will be prevented. Use of non-recyclable resources of the world will reduce (+).

E4- Usage Phase/ Minimizing toxic and harmful materials

Toxic and harmful materials, which may affect human health negatively, are not used during usage (+).

E5- Usage Phase/ Affordability

It is appropriate for occupant and easy and economic in terms of maintenance and renovation during usage (+).

F. Maintenance + Renovation

Damages, which may occur in adobe wall paintings and coverings or wall itself, "have been observed in 1st case-research building since 1983. Exterior wall plaster has survived for 8 years and wall has absorbed moisture from plumbing in the bathroom but has not fallen off. Interior plasters are not damaged.

F1- Maintenance + Renovation/ Occupant Health

According to these determinations, it does not have a negative effect on occupant health (+).

F2- Maintenance + Renovation/ Protection of energy

There is not any factor changing energy protection in wall texture or plasters (+).

F3- Maintenance + Renovation/ Protection of environment

Maintenance and renovation to be performed in wall and its coverings will not generate environmental load (+).

F4- Maintenance + Renovation/ Minimizing toxic and harmful materials

Toxic and harmful materials or applications are not carried out in wall and its coverings.

F5- Maintenance + Renovation/ Affordability

It is reduced after stabilization due to maintenance and renovation in wall and its coverings. It is minimum in terms of technology and costs (+).

G. Returning to the Beginning or Waste Formation

Buildings are demolished when their functions change and their service life is over or to provide profit or due to natural disasters. Large amounts of nonperishable solid wastes emerge with the demolition of buildings. Some construction materials can be regenerated; in other words, can be transformed into usable materials. Adobe material returns to nature more than other wall materials and can be used as wall material once again.

G1- Returning to the Beginning/ Occupant Health

Adobe wall does not give damage to person performing demolition transaction. It is not necessary that health measures be taken during disassembly as in asbestos construction (+).

G2- Returning to the Beginning/Protection of energy

Demolition of adobe wall requires hardly any energy when current construction machines are used (+).

G3- Returning to the Beginning/Protection of environment

Adobe material returns completely to nature after demolition or can be transformed into construction material, if preferred (+).

G4- Returning to the Beginning/ Minimizing toxic and harmful materials

There are no toxic or harmful materials during the demolition of adobe wall (+).

G5- Returning to the Beginning/ Affordability

Returning adobe wall to the beginning does not require complex technologies and its cost is low (+).

It can be seen in the matrix examination that adobe building is an appropriate construction material and system for current and future housing expectations. If this evaluation is to be conducted for buildings whose load bearing material is reinforced concrete, brick, timber or steel, such positive results cannot be obtained.

Current housing targets attach importance to human and environment. Considering benefits of adobe building for human health and environment, the research number 622 has improved workability of adobe and it is offered to the utilization of mass housing.

1.4. The Improvement Fields Of Adobe Buildings

In order to make adobe building technology applicable for the mass housing, it must be determined why this most used construction material was replaced by industrial construction materials in the world and in our country.

It is assumed that people live more comfortably in buildings constructed by industrial materials. But we know that, even construction elements produced by appropriate technology cannot fulfill all duties that elements should undertake. Layers, which are composed of many materials, must be detailed. For instance, in a space formed by reinforced concrete wall, in order to maintain thermal value of the space and to keep temperature of interior surface of the wall at an adequate and required level, wall isolation must be added. This brings together an extra cost of material and labor. After these additions, relative humidity balance in the space is spoiled. Since heat isolation must be maintained in the direction of the space, together with a vapor barrier layer so as not to lose its isolation value. In this case, although “load bearing reinforced concrete wall + heat isolation material and workmanship + vapor impermeable layer and workmanship” will be used altogether, it is seen that the relative humidity in the space will rise over the comfort level.

However, adobe wall with “load-bearing + heat insulation + heat conservation + vapor diffusion value”, provides the load-bearing and protection tasks and even comfort conditions of the building alone.

Still, inadequate aspects of traditional adobe have resulted in disfavor of this material. “Limiting characteristics” and “improved characteristics” of adobe, which have been obtained as a result of researches (MAG505 and TEZ’84), are compared in Table 1.

LIMITING CHARACTERISTICS (Traditional adobe buildings)	**IMPROVED CHARACTERISTICS (MAG 505; TEZ'84 and INTAG 622 '95)**
1. Swelling and dispersing when meets water	It hasn't dispersed within the service life even from the installation leakage
2. Low Resistance	2,8-4,5 N/mm2 (Standards 2N/mm2)
3. Surface dusting, spoiling	No dusting; enduring surface.
4. Short duration, needs maintenance	8 years of plaster duration
5. Shrinkage problem	Reduced to 1,5%
6. Adobe production: not in rainy seasons	Not limited by the seasons
7. Adobe drying: No rain - only in summer	No drying process.
8. Construction period: No rain-summer	Not limited by the seasons
9. Adobe production: long term workmanship	Tamping or forming processes
10. Adobe drying: long term workmanship	No drying process
11. Masonry: long term workmanship	No work
12. Mud preparing: broad area	No mud preparing process
13. Adobe production: broad area	Casting on the wall
14. For drying process: broad area	No drying process
15. Special clayey earth	No clayey earth required
16. Geometric instability in block production	Geometric stability
17. Exterior wall must be protected from rain	May be left open
18. Cannot be done in rainy regions	Can be done

Characteristics of adobe construction have been examined in further detail in the section regarding building performance (see 3.4). The reasons why adobe construction is used limitedly and improvement methods can be compiled under the following headings:

1.4.1. Technological

Construction technology covers information about material, workmanship, tools and instruments as well as and other aspects that provide construction of a building. The building has two main functions: carrying and protection. These two functions also divide into two groups. The first is to carry reliably itself and things resulting from human requirements and the second is to create spaces for building health and human factor. Technology's contribution to the building is to ensure that the building fulfils these functions successfully with current opportunities. The aim of researches conducted in Faculty of Architecture is to contribute to adobe building to overcome carrying and protection functions at a level where current requirements are met.

1.4.2 Sociological

Despite adobe construction's advantages and its technological developments, it does not hold a place in housing sector that it deserves. This can be associated with socio-economic developments in society.

- **Forgetting construction rules**

Those coming from rural areas to urban areas in order to earn money usually work in constructions. When they return to their hometown, they build houses by using information they have obtained from construction; in other words, they build houses with reinforced concrete framework and walls made of thin brick. Thus, construction rules of healthy buildings pertaining to their own culture cannot be conveyed to new generations.

- **Construction fashion**

Rural people think that they can live more comfortably in buildings made of industrial materials in cities. They build their houses in pillar-joist system so as to keep pace with urban fashion and to provide superiority over their neighbours. However, carrying and protection functions of buildings are not in compliance with rules and are inadequate.

- **Since adobe is not an industrial material**

Adobe construction material is not in brisk "demand" since it cannot satisfy market conditions. As known, industrial material can "be in demand in the market" when it is introduced to those who need it. Introduction can be realized with advertising campaigns whose budget is provided. This budget should have an investor who will get profit from this advertising campaign. All of this mechanism cannot be materialized since adobe construction material is not an industrial material and does not have an investor. The duty of introducing adobe construction is assumed by researchers who consider the contribution of adobe to individuals of society, national economy and world ecology. This behavior is basically is a part of "technological developments" process. The research has been represented and published in many countries. Introductory meeting and education seminars will be held for applicators in our country.

1.4.3. Administrative

Adobe construction has not benefited from "technique of regional building culture" and "assurance of contemporary researches" for a long time. Thus, buildings constructed randomly have lost their reliability due to damage of years as well as destruction caused by earthquake (92% of the total area of our country is under the risk of earthquake).

- Regulation

When individual and mass housings are to be built with gypsum stabilized adobe material, it is necessary that regulations regarding its control and approval be prepared.

- Standard

Proper standards must be established for INTAG TOKI 622, which has changed raw material procurement, material and element productions, building construction and tools and instruments. In the 4^{th} section of this research, the contribution to standardization will be mentioned.

- Setting an example for the society

It is necessary to prove to society that adobe construction fulfils carrying and protection functions so as to bring adobe construction material back to housing sector, which has lost its reliability due to the abovementioned reasons [6]. To this end, the research group materialized 1st Case-Research Building together with TEZ'84 and 2nd Case-Research Building with INTAG TOKI 622'95. 1st Case-Research Building was used as Kindergarten of Ayazaga Campus of ITU Rectorate (Istanbul Technical University) for 9 years.

Picture 1.1

Figure. 1.1. Adobe Houses in Osmaneli District (Cultural Heritage)

Picture 1.2

Figure 1.2. Houses in Aegean Region

1.4.4. Cultural Heritage

- Regional building culture

Milestones of the history are "architectural" and "anonymous architectural" works. These works convey the developments in their era (such as open library) to society and keep region's identity alive thanks to their regional characteristics. Protecting structural characteristics of regions means protecting cultural heritage and regional identity.

While people assume that they will resemble each other more within the framework of "Globalization" and "European Community", the greatest war is actually "identity war". Identity war involves superiority of cultural parameters. For example, it arranges that language or music or currency unit of a country becomes superior to others.

Each country requires cultural identity. Americans acknowledged adobe buildings, which are inherited from Indians, as initial culture of the country and established research centres to protect them [7]. Contemporary adobe construction regulations exist for new adobe buildings (1982). It is a responsibility to protect "our rich adobe construction entities" which is our cultural identity and cultural heritage (Figure 1.1, Figure1.2).

- Regional living culture

Different living cultures exist in our country according to regions, urban and rural areas. Living culture is affected especially from the activity from which people earn their incomes. The expectations of a person who does desk work are different from the expectations of a farmer who performs irrigated agricultural labour in rural areas. When a house is to be designed, survey and analysis of occupant requirements should certainly be considered.

Primary requirements of people in rural area are houses with plain foundations and which also include a storage room for tools and instruments that they use, a cellar for dry food for winter and a barn for animals. Adding all of these functions to 4-storey reinforced mass housings, which we encounter in every corner of our country, will not be rational (Figure 1.5).

Picture

Figure 1.3. Housing Requirement of Society (Ankara Region)

Figure 1.4. Housing Presented to the Society

Figure 1.5. Mass Housing Example

Figure 1.6. Frank Llyod Wright, Santa Fe, 1959, "Pottery House" Pueblo Revival Architecture Era

Figure 1.7. Pueblo Adobe Building based on Red Indian Construction Culture in the USA

1.5. Methodology

Technology means attaching importance to the application of principles instead of theoretical development [9]. Technology researches should follow these stages [10]:

1. Basic research
2. Research through experiments
3. Research by application
4. Development through experiments
5. Creation of demo, pilot, reference or models
6. Determination of production conditions
7. Researching the market, costs, quality and standardization
8. Researching conditions of purchaser and applicator

Adobe technology research has continued uninterruptedly in Faculty of Architecture, ITU since 1978 [Annex-1]. At basic research stage, properties of gypsum stabilized construction material are defined in 1980 through TUBITAK MAG 505 [11]. At the stage of "reference researches", 1st Case-Research Building was constructed in 1983 as the subject of postgraduate thesis [12] (Figure 1.8-1.9). The place of INTAG TOKI 622 within "technological researches" is "determination of production conditions" stage. In brief, methodology of the research is as follows:

1) Examination and presentation of previous studies,
2) Modification of workability of materials through laboratory experiments,
3) Conducting experiments appropriate for mechanization in site and construction of case-research building.

Picture 1.8. & 1.9.

Figure 1.8. 1st Case-Study Building (Exterior)

Figure 1.9. 1st Case-Study Building (Interior)

1.6. Conclusion

Today, housing sector aims at construction of "healthy buildings". Healthy buildings should not only consider human health and environment but also do not give up rationalization. Since adobe building creates healthy conditions, it is suitable for housing. At stages of construction material production and building occupancy, it is the construction type that protects ecology balance of world and makes contributions to national energy budget.

Sociological, administrative, technological improvements are required for reuse of adobe in housing construction. INTAG TOKI 622 research has researched mechanization conditions suitable for gypsum stabilized adobe construction for

a) Those building their own houses,
b) Mass housing sector,
c) Those designing adobe construction,
d) Those approving adobe construction,
e) Managers who are responsible for protecting national budget, cultural heritage, national ecology.

Picture

Figure 1.10 Emlak Bankası İstanbul 1. Levent House

Figure 1.11 INTAG TOKI 622 Adobe Building

SECTION 2. MECHANICAL AND PHYSICAL PROPERTIES OF GYPSUM STABILIZED ADOBE

2.1. Introduction

In this section, workability of gypsum stabilized adobe construction material in relation to mechanization is examined. “Mixture type” of gypsum stabilized adobe construction material (Alker) has been obtained from previous studies of ITU Faculty of Architecture [Annex-1] [11, 12].

Mechanical and physical properties have been comprehensively examined by changing gypsum rate in previous studies and it has been observed that 10% gypsum admixture gives the best result. In this research, analysis of gypsum rate of new soil is performed through limited sampling by considering that gypsum and lime are used and similarity between the results is observed. Thus, gypsum added stabilization, which is 10% of the dry weight of soil used in laboratory and field researches, is taken as the basis.

At the first stage, properties of soil, gypsum and lime, which compose gypsum stabilized adobe construction material to be used in the research are summarized in a way to provide assignations both in previous studies and in this research.

At the second stage, assignations regarding properties of the mixture composed of soil; gypsum and lime are presented together with the results of previous studies and this research. Besides, determinations to learn with what kind of technology the best results will be obtained are made.

In conclusion section, results regarding both material and construction technology as a result of experimental researches are evaluated together and some determinations towards application are made.

2.2. Raw Material Experiments

Determination of properties of materials used in gypsum stabilized adobe production are important for increasing performance expected from building. Thus, properties of soil, gypsum and lime used in the research are examined in order to obtain positive results from material. The results obtained from previous studies in this field and this research are explained below.

2.2.1. Determination of the situation (Previous studies and Results)

Gypsum is generally defined as a water sensitive material having low compressive strength due to drying shaped clayed soil in the air. It has been seen in the researches conducted that strength of adobe results not only from dehydration of lime but also from physical and chemical structure of soil.

Grains in various sizes within soil, which is composed of mineral and organic materials as well as water and air, form solid part of soil. This part is composed of gravels, sand, clay and silt, which are called "Structural Particles" [11]. These particles are classified by Swedish soil expert Atterberg in 1912 according to their particle sizes as in Table 2.1:

Material	Diameter Limits (mm)
Gravel	20.00 – 2.00
Coarse Sand	2.00 – 0.20
Fine Sand	0.20 – 0.02
Silt	0.02 – 0.002
Clay	0.002 - below

Table.2.1 Classification of Structural Particles [11]

Adobe quality can be improved by the adjustment of particle sizes of gravel, sand, silt and lime, which compose soil. To this end, curves and ideal size distribution (granulometry) curve determining upper and lower limit of soil types, which can be used in adobe brick, are put forward with the research "effect of ground fabric on physical properties of adobe" by H.C. Schwalen from Arizona University (Figure.2.1).

Whether any soil type is appropriate for adobe block construction in terms of its granulometric structure can be evaluated according to its proximity to ideal curve in

Figure.2.1. Proximity of granulometric curve of soil to ideal curve indicates that that soil type is suitable for adobe production. However, it is not a condition in rammed earth production that granulometric structure of soil is adapted to ideal state. E. Kömürcüoğlu (1962) [14], who has examined adobe construction culture of the country, has stated that earth construction material can be used without being processed; namely, as it comes out of oven by ramming technique. However, he points out that this method requires due diligence or unexpected damages may occur.

Figure 2.1. Limits Of Soil Types Useable According To Grain Size, Arizona University, 1935 [13]

Fine grains such as clay and silt, which are among structural particles, can provide rigidity by attaching coarse grains of sand size to each other; in other words, they compose clay concrete (geoconcrete [15]). Besides, materials being stabilized by undergoing a reaction with chemicals are clay and silt. Thus, type of clay material and its rate within soil cause properties of construction material to change considerably.

In addition, since inorganic materials within clay (such as quartz, feldspar, mica etc.) affect certain physical properties such as tingeing and reducing shrinkage and since organic materials affect chemical properties by holding as organic molecules among clay particles, these materials within soil should be determined. Especially, high amounts of organic materials within soil are disadvantageous in terms of their effect on chemical properties. Solvable salts (such as calcium carbonate), whose rate is above 2%, shorten building life [16].

Properties of gypsum and lime used in soil stabilization in the research should also be known. Gypsum stone, raw material of gypsum, is a sedimentary stone composed of gypsum minerals. “Gypsum is obtained when water is removed from gypsum, whose chemical compound is CaSo4 2H2O, by heating until approximately half-molecule crystal water remains and later is grinded. This construction material attains binding characteristics during hydration when it is mixed with water” [17].

Since gypsum hardens in a short time (5-8 min) when mixed with water, working period of gypsum stabilized construction material decreases. Thus, it is necessary that this hardening period, which is called as setting time, be taken under control. This period, which is also related to water/ gypsum content of gypsum paste, is calculated through vicat needle. Figure.2.2 demonstrate setting time curve for 80% water/ gypsum rate [11].

Effect of lime admixture added to the mixture in various amounts to delay setting time of gypsum is demonstrated on the same graphic. For example, in cases where 10% lime is added, gypsum setting time delays for 4 minutes. Thus, setting starts 12-13 minutes later.

Figure 2.2. Effect Of Lime Addition To Gypsum On Setting Time [11]

2.2.2. Experimental Contribution of the Research

Characteristic of finished building is limited to construction material used in the construction and its application method. Materials and application method used in this research are explicated based on previous studies. Since lime and gypsum are industrial materials, experiments determining physical and mechanical properties of soil are focused on in experiments section of the research.

2.2.2.1. Analyses regarding Soil

The case-study building constructed in order to examine workability and mechanization is located at ITU Ayazaga Campus. Soil used in the construction is provided from the same campus area. Examinations such as sieve analysis, consistency limit, unit weight, pH value, mineralogical analysis, organic material analyses are performed upon samples obtained from several parts of the area.

2.2.2.1.1. Sieve and Hydrometer Analyses

Sieve analysis from these two analyses, where rates of structural particles in soil are determined, is used for determining coarse grained material distribution and hydrometer analysis determines distribution of grains whose diameter is smaller than 0.074mm; in other words, rates of silt and clay.

Values for Ayazaga soil used in the research are determined to be as 49% gravel, 32% sand, 20% silt and 8% clay as result of analyses conducted in ITU Faculty of Architecture Soil Mechanics Laboratory.

Figure 2.3. Granulometric Curve Of Ayazaga Soil Used In The Research

The granulometry curve mentioned before and the curve determining granulometry structure of Ayazaga soil can be seen together in Figure 2.3.

Adobe construction material, whose granulometric structure can be used as it comes out of oven, provides the following advantages:

a- Coarse grained mortar requires less mixing water,
b- Shrinkage is less where less water is used in mortar,
c- Strength increases in materials where less water is used,
d- Savings in sieving process and period during construction.

Binding in gypsum stabilized adobe research is strengthened through

a) Placing by ramming,
b) Gypsum stabilization
c) Workability with lime

And the building becomes to a point where it will not cause damage.

2.2.2.1.2. Consistency Limits

Determination of the relation between change in water content of soil and its consistency is important for workability of material. Thus, consistency limits defined as plasticity limit, liquid limit and shrinkage limit are determined for Ayazaga soil.

As a result of experiments conducted in ITU Faculty of Architecture Soil Mechanics Laboratory, plasticity limit, defined as minimum water amount required for the workability of material, is determined as 20%. Liquid limit, defined as minimum water amount where material exhibit liquid characteristic, is 29%. Shrinkage limit, which can be defined as water level, which will not result in further decrease in volume, is 7%.

Determination of consistency limits provides information about for which placing method the mixture will be suitable. State of rammed earth [19, 20] and adobe blocks [21] is demonstrated in the graph by Atterberg [18] where the relation between plastic index and liquid limit is presented in Figure 2.4.

In which intervals consistency limits of Ayazaga soil used in the research are located is also demonstrated in the same graph. In line with this, soil used in the research is suitable for rammed earth production.

Figure 2.4. Plasticity Diagram [19]

2.2.2.1.3. Unit Weight

Determination of soil's unit weight is important for determining in which way unit weight in gypsum stabilized adobe material changes. Thus, change in heat conductance coefficient values and sound speed depending on unit weight can be examined for gypsum stabilized adobe material.

During Proctor experiment conducted in ITU Faculty of Construction Soil Mechanics Laboratory, unit weight value is determined as 1850 kg/m3 according to 15% water content for Ayazaga soil.

In Figure 2.5, proctor curves by Swiss Highway Association (VSS), where changes in dry unit weight volume values according to water content are determined for different types of soil, can be seen [21]. According to these curves, Ayazaga soil shows resemblance to the soil of "gravel, sand, clayey, silt" type, which is defined with number 2.

Figure 2.5. Proctor Curves [21]

2.2.2.1.4 pH Test

Setting time of gypsum added to the mortar for stabilization slows down in acid. In case such effect, environmental characteristics of the soil to be used are examined.

200gr soil is dried in drying oven and placed into desolator in accordance with TS 3263 [22] in order to determine pH value of soil. After waited approximately for 24 hours, it is placed into 75mm water and this mixture is mixed for about 1min with 0.1mg sensitive METTLER tool. Finally pH value is determined to be 6.6. This value indicates that soil is almost neuter (Table 2.2) [6]. The mixture is placed into SPIN-MASTER after 24 hours to measure its pH value once again. At the end of this time, it is observed that pH value is 7.6 when soil. This value demonstrates that after soil reaches a certain degree of saturation, it gains alkaline characteristic.

pH Value	Environment Characteristic
5.5	High acid
5.5 - 6.5	Low acid
6.5 - 7.0	Neuter
7.0 - 8.0	Low Base
8.0	High Base

Table 2.2. pH Environment Characteristic of Ayazaga Soil

2.2.2.1.5. Mineral Composition

Since clay and silt, which take place in gravel, sand, clay and silt mixture composing solid part of the soil, have binding characteristic for grains and undergo a reaction with chemicals, it has been mentioned that amount and types of these materials should be determined (see Sec. 2.2.1).

To this end, mineral composition of soil used in this research is determined in ITU Faculty of Mines Optic Mineralogy Laboratory. Initially, by taking cross section, its mineral composition is determined and its mineral transformation is determined through grain size. Besides, clay mineral composition is determined through “x-ray dust scattering” in Main Department x-ray laboratory to determine clay minerals. Solid natural rock determination, its mineral composition, model rates as well as grain sizes are determined in examinations carried out with polarization microscope (Table.2.3). While rates of detritic-grained minerals in sample rocks vary between 30-35%, clay sized minerals, such as mica, are ferrous (iron oxide, hematite-limonite) caoline- illite type. On the other hand, solvable salts such as carbonate (CACO3), calcite are not found.

MINERAL TYPES	MINERAL COMPOUND (%)	GRAIN SIZE (mm)	FABRIC PROPERTY
Quartz	22	0.06- 0.09	Coarse-fine grains, round and broken
Feldspar	14	0.3	Its edges are surrounded by opaque material
Plagioclase	7	0.3- 0.6	Euhedral, broken, polysynthetic double
Biotite (Black mica)	7	0.3	Locally opaque, thin prick shaped
Muscovite (White mica)	3	0.3	Fine grained, fibrous, prick shaped
Foreign rock	1	0.35	Semi-edged
Matrix	46	Very small	Fine grained

Table 2.3 Mineral Types and Components of Ayazaga Soil

2.2.2.1.6. Organic Material Analysis

Organic materials within clay (quartz, feldspar, mica) affect only physical properties (such as colouring, reducing shrinkage). However, organic materials affect chemical properties by hanging on among clay particles as organic molecules. Thus, it is disadvantageous that soil to be used as construction material includes organic materials abundantly since they affect strength and durability negatively.

According to TS 3673 [23], soil is placed into NaOH to determine whether soil used includes organic materials and it is observed that the mixture becomes yellow and sediment does not occur upon the soil. This finding indicates that there is not a disadvantage in relation to organic material in soil.

2.2.2.2. Gypsum

Setting times of gypsum with admixture (monohydrate citric acid as retarder) and without admixture, which are supplied by ABS Alçı Sanayi and ENTEGRE Harç Sanayi ve A.Ş., are calculated through vicat needle.

Start of setting for mortar with 60% water/ gypsum content in gypsum with admixture is determined as 5min and the end of setting as 12min. These values in gypsum without admixture are 2,5 min and 8 min, respectively.

As can be seen, start and end of setting in gypsum with admixture are longer than gypsum without admixture. However, both gypsum types set so rapid if mixed with soil that workability is not possible. When it is considered to add retarder to extend the period, gypsum without admixture (i.e. raw or base) has been preferred. Production and transportation costs are low. Gypsum stone is easily available in every part of Turkey.

2.2.2.3. Lime

Hydra lime from chalk supplied by ENTEGRE Harç Sanayi ve A.Ş. for the research is used to retard setting time of gypsum (Figure.2.2).

2.3. Gypsum Stabilized Earth Experiments

The mixture obtained by adding certain amount of gypsum and/ or lime to soil with proper granulometry and by kneading with water is called gypsum stabilized earth mud and material obtained form this mud through various casting methods is called gypsum earth (Alker) [12].

Since certain standards are aimed to be established in this research for gypsum stabilized earth construction through in-situ tamping method, it is provided for that mechanical and physical properties of the material to be used are determined. Initially, previous studies conducted on gypsum stabilized earth will be dwelled upon.

2.3.1. Determination of the situation (Previous Studies and Findings)

It is known that cost of gypsum stabilized earth is lower than other admixtures (since gypsum production can be made in rural areas through traditional methods). However, there has not been much research on improving properties of earth by adding gypsum. One of the most important researches conducted in this field, TUBITAK MAG 505 project, has determined properties of gypsum stabilized earth material to be produced in blocks.

According to the results of the project, gypsum added to the soil forms a framework within material before even starts to dry. This framework reduces movement of clay particles, which try to get closer to each other during drying. In conclusion, shrinkage reduces since an inner tension occurs within the material. What kind of change shrinkage displays as gypsum admixture increases can be seen in Figure 2.6 for different soil types.

As can be seen when the curves are examined, gypsum admixture up to 10% result in high decrease in shrinkage. When admixture rate is increased to 20%, admixture affects shrinkage less.

Figure 2.6. Shrinkage Changes of Different Soil Types According to Gypsum-Lime Rates [11]

It has been determined in a research conducted by Eyre in New Mexico that in case of 10% gypsum admixture, shrinkage reduction increases again compared to normal earth [24].

Since gypsum added to the soil prevents shrinkage, air gaps occur in the mixture due to evaporation during drying. Thus, a material whose unit weight is lighter than porous and unadulterated earth but which do not disperse in water and whose surfaces are very smooth and does not result in dust can be obtained. In Figure 2.7, the change in unit weight according to the increase in gypsum rate can be seen. Accordingly, as admixture rate increases, unit weight decreases.

Figure 2.7. Unit Weight Change Of Adobes Produced From Garden Soil According To Gypsum And Lime Additions [11].

Decrease in material’s unit weight leads to the decrease in thermal conductance value (λ) (Table 24 [25]) and enables energy savings in cold and hot seasons.

Material	ρ (kg/lit)	Λ (kcal/mhc)
Adobe (Cement, straw addition)	> 1.70	0.80
Brick	1.80	0.70
Pumice concrete	1.80	0.75
Gas concrete	0.80	0.23
Lime sandstone	1.80	0.85
Normal concrete (Reinforced)	2.40	1.80

Table 2.4. Thermal Conductance Coefficients According to Unit Weight [25]

Compressive strength of gypsum stabilized earth produced by adding 10% gypsum to soil with proper granulometry is 4-5. On the other hand, compressive strength of 0.8-1 N/mm² [26] is sufficient in traditional earth.

In a research where "effects of cement, lime, gypsum and bitumen on physical and mechanical properties of adobe bricks" are examined by E.Özkan and M.S.Al-Herbish, compressive strength of 2.95 N/mm² is obtained in adobe brick with 10% gypsum admixture and compressive strength of 3.57 N/mm² is obtained in adobe brick with 20% gypsum admixture [27].

It is seen in the graph in Figure 2.8, where change in compressive strength according to gypsum admixture amount is presented, that compressive strength increases as admixture amount increases. However, in cases where gypsum is added more than 10%, compressive strength does not increase as much as gypsum amount increases. Thus, since strength obtained with gypsum above 10% satisfies the value expected from material (see Sec. 2.3.2.2.3.2), increasing gypsum rate will only result in higher costs. However, in case gypsum below 10% is added to soil, gypsum cannot form a sufficient framework within earth. Thus, shrinkage increases and strength decreases.

Figure 2.8. Compressive Strength Change of Samples Produced From Garden Soil According to Gypsum Addition Rate [11]

Gypsum admixture plays a role in load (static and dynamic) resistance of material by increasing tensile strength during bending.

Figure 2.9. (A) Bending Tensile Strength Change of Samples Produced From Garden Soil, (B) Compressive Strength Change of These Samples According to Lime Added to 10% Gypsum Added Garden Soil [12]

Lime admixture to gypsum stabilized earth retards setting time of gypsum (Figure.2), decreases shrinkage (Figure.2.6.), results in unit weight decrease and increase resistance against moisture and rain. In addition to these positive characteristics, the amount of admixture within the mixture should be low due to its effect on reducing compressive strength (Figure.2.8). If it is added as much as 2.5-3% of dry soil weight, strength is above bearing level [12].

According to the study by Balasubramaniam and Buensuceso, where "effect of lime admixture to soft clays" is examined, lime admixture increases friction characteristic among grains and thus, long-term stability and bearing capacity increase [28].

2.3.2. The Contribution of the Research

In this research conducted in order to determine mechanized construction technology suitable for and to establish standards for gypsum stabilized adobe construction material, it is necessary that the mixture to be used in production is made suitable for mechanization. To this end, initially, consistency and method for mixing, transporting, placing mortar into mould are determined and then samples are prepared and experiments are performed in accordance with the most suitable results.

2.3.2.1. Workability

Workability explains properties of fresh mortar and why importance is attached to these properties [29]. It covers methods and material changes affecting transportation, fluidity and placement behaviors of mortar. Mortar behaviors can be summarized as follow:

a) Transportation: Suitability for equipments and systems such as bucket, spade, hand chart, band conveyor, transport hose,

b) Fluidity: Suitability for movements in equipment such as movement within mixer, movement within mould,

c) Placement: Suitability for vibration, tamping to improve strength, water absorption characteristics,

d) Finishing Quality: Prevention of homogeneity corruption, segregation, surface view, and dimension change due to shrinkage.

After hardens, mortar performance is defined with characteristics such as form, strength, porosity, permeability, life, geometric accuracy, surface quality. To achieve this performance, studies on a) mortar consistency, b) placement methods and c) standards indicating these should be conducted.

Considering transportation, fluidity and placement and finishing quality characteristics of mortar, consistency, setting time and placement methods are developed in this research and mortar is made suitable for mechanization.

2.3.2.1.1. Mixture Consistency and Process Water

Water amount added to the mortar determines workability of material in adobe production. Since soil is stabilized with 10% gypsum and 2% lime according to soil weight in this research, small grain rate increases. As known, increase in small grains also increases water requirement of mortar. Based on these assumption, 16-25% water admixture changes according to total solid material are tested.

In conclusion, it is observed that mortars with 16% water are too dry to be processed with methods of this research, mortars with 18-20% water have plastic consistency and can be tamped, mortars with 20-22% can be placed through vibration and that in mortars with 25% and above water, coarse grains do not hang on in the mixture and subside due to gravity (segregation). These obtained values display resemblance to the values determined as a result of consistency limit analyses (see Sec. 2.2.2.1.2).

Water added to the mixture for workability is also affected from water existing in soil. It should be assumed that soil is at the level of oven moisture. New water rates should be determined for soils obtained in drier (in summer heat) and wetter (after rain) areas by performing consistency experiment.

2.3.2.1.2. Setting Time

As explained before, since setting time of gypsum is short, workability of the mixture gets harder. However, this process can be taken under control through lime admixture. In the graph in Figure 2.2, effect of lime admixture on retarding setting time of gypsum has been examined. Start of setting time prior to the mixture, which is 3-8min, retards this period 4-5min if 10% lime in proportion to gypsum is added. Thus, new setting time starts 12-13min later. Workability period can be accepted as 25min. However, since lime reduces compressive strength of the material, amount to be added to the mixture should be low. In this way, a suitable material in terms of both compressive strength and workability is obtained.

2.3.2.1.3. Adjustment Method

The aim of application of placement process to construction materials produced by moulding during fresh mortar period is to improve properties of material compromising the element after the element is removed from the mould; in other words, to increase its strength against element deformation, minimize air gaps, to contribute to homogeneity. These developments also provide smooth surfaces and good view.

One of the following devices and methods is used to achieve the performance expected from the material.

1) Skewering
2) Tamping, compacting
3) Vibration with shaking table, table vibrator
4) Flask vibration etc.

Selection of one of the placement methods depends on workability of the material to be placed, aggregate size within it as well as size of mould to be used and other features.

Soil (ground) is composed of water + grains + gaps. Friction among grains forms strength of the ground. Friction among grains is temporarily removed by vibration or compaction and gaps are filled.

If vibration is selected as placement system, the point to be considered is the relation between vibration frequency and aggregate size. In brief, mixtures having coarse aggregates move with low frequency and mixtures having small aggregates move with high frequency [30].

Oven soil is used with its natural granulometry in the research (Figure.2.3). Here are gravels and stones with 2-7cm diameter. While the mixture is being prepared, by adding 10% gypsum according to soil to some and 10% gypsum + 2% lime to others mortars are prepared.

All placement methods are applied to the mixture with both fine and coarse grains. Consistency for tamping and for vibration should be dry plastic and fluid plastic, respectively.

Mortar (soil + 10% gypsum) is placed into sample mould in vibration method through shaking table. Vibration with 5000 frequencies is applied to the mixture upon shaking table for 30sec. It is possible to place the mixture into the mould through this placement method so that no gaps remain. Surfaces are very smooth. Since mixing and placement periods within laboratory system are short, the process cannot be completed within setting time. In this method, which is applied at fluid consistency by purifying process water, shrinkage that may be found to be big, does not constitute an obstacle for adobe brick production and masonry constructions. Increase in strength is beneficial.

In placing through spud vibrator applied at fluid consistency, process cannot be completed within setting time. Spud vibrator is applied to hardened mixture and since crystals of mortar are broken down in some sample moulds, chemical bond is disrupted and material becomes watery.

In solid plastic consistency, sufficient placement can be materialized in mould edges, surfaces and the whole cross-section.

In conclusion, it is seen in tamping, which is tested with soil + gypsum mortar, vibration with flask table, flask vibration methods that setting time is not sufficient for placement period. During construction site phase, it is decided that lime is added to the mixture so that placement transactions can be performed within setting time. Mechanical and physical experiments are conducted upon samples placed into the mould through tamping and table vibrator by using both mortars.

2.3.2.1.4. Determination of the Mixture

The most suitable gypsum rate is accepted as 10% depending on sample characteristics (workability, physical and mechanic characteristics) prepared through testing different gypsum rates (6.5%, 8%, 10%) for wall material to be produced with gypsum stabilized adobe. (Gypsum rate in TUBITAK MAG 505 research has been determined as 10% according to soil weight in relation to application).

As a result of consistency studies conducted to determine water rate to be added to the mixture, a mixture at plastic consistency with 20% water content is decided to be determined.

In addition, since placement of the mixture into the mould is difficult as it hardens rapidly due to gypsum admixture, lime addition is necessitated (see Sec. 2.3.2.1.3). To examine effect of lime admixture on characteristics of mixture, effect of lime admixture in different rates (0.5%, 1%, 1.5%, 2% and 2.5%) is observed.

2.3.2.2. Determination of Characteristics of the Selected Mixture

2.3.2.2.1. Preparation of Experiment Samples

Based on preliminary studies and TUBITAK MAG 505 research conducted on workability of the mixture, six different mixtures are prepared with 10% gypsum and six samples from each mixture, i.e. totally 36 samples are produced. By maintaining 10%gypsum and 20% water rates added to the mixture constant in these samples prepared in 10x10x50 steel moulds, optimum lime amount is researched through adding lime at the rates of 0.5%, 1%, 2%, 2.5%.

The same method is followed in preparation of all of the samples and 20 min after the mixture is poured into moulds, moulds are removed and shrinkage values are measured in every 24h. Shrinkage period is determined as 15min for all samples. Experiments are conducted on samples, which have completed their shrinkage.

2.3.2.2.2. Physical Experiments

During preparation of samples, gypsum with and without admixture (raw or base) (see Sec. 2.2.2.2) are added to soil and thereby, which gypsum type will be used is determined based on the obtained experiment results.

To this end, the following experiments are conducted on samples predicating on two different mixtures, which are “with 10% gypsum and lime” and “without 10% gypsum and lime”:

1) Shrinkage
2) Unit Weight
3) Capillarity (water increase within time) and the findings are evaluated.

2.3.2.2.2.1. Shrinkage

Sample sizes are measured in every 24h with composing stick (Figure.2.1) and shrinkage rates are calculated based on the difference between first and last measurement. In Figure 2.10, the shrinkage change curve of samples on which effect of lime admixture is examined by maintaining 10% gypsum rate constant is between shrinkage limits defined by SIA Standards [19] for clay types. Gypsum used in these samples is with admixture. As can be understood from the curve, an effect similar to that of gypsum admixture can be observed in shrinkage due to lime admixture (Figure 2.6).

Picture 2.1.

Figure 2.10. Shrinkage Measurement

Figure 2.10.

Figure 2.11. Shrinkage Change According to Lime Addition to Samples Prepared with 10% Gypsum

In samples prepared with 10% gypsum without admixture, in case of 0.5% lime admixture, 1.88% shrinkage and in case of 2% lime admixture, 1.07% shrinkage are calculated.

2.3.2.2.2.2. Unit Weight

Experiment samples, whose dimensions are measured and volumes are calculated, are weighed by OMEGA balance with maximum 30kg capacity and their unit weights are calculated basing on these two measurements. In Figure 2.11, change in unit weight depending on lime admixture rate in samples prepared with 10% gypsum with admixture can be seen.

When the curve is examined, it can be said that lime admixture leads to decrease in unit weight. In fact, unit weight decreases down to 9% with 2% lime effect. This graphic displays resemblance to the graphic in Figure 2.7, where change in unit weight depending on lime admixture rate is demonstrated.

Figure 2.12. Unit Weight Change According to Lime Addition to Samples Prepared with 10% Gypsum

In samples prepared with 10% gypsum without admixture (raw), in case of 0.5% lime, unit weight value is found to be 1,768kg/lit and in case of 2% lime, unit weight value is found to be 1,744kg/lit.

2.3.2.2.2.3. Capillarity (Water Increase Within Time) Experiment

Samples having completed their shrinkage are placed into a container with water above glass sticks and by having their lateral surfaces covered with paraffin in such a way that bottom surface touches water (Figure.2.2). Water increase is followed in every 1hour in this mechanism. It is observed that after 24h, water increases approximately 4cm in the sample with 10% gypsum (Figure 2.3) and approximately 17cm in the sample with 10% gypsum + lime, however, scattering is not observed (Figure 2.4). Increase in water due to lime admixture results from the fact that hydration of lime occurs in a longer time than gypsum. It is known that lime admixture increases resistance against moisture and water after hydration occurs in long-term [31].

Picture 2.2, 2.3, 2.4

Figure 2.13. Capillarity Experiment

Figure 2.14. Water Increase Amount in Samples Prepared with 10% Gypsum Addition after 24 hours

Figure 2.15. Water Increase Amount in Samples Prepared with 10% Gypsum + 2% Lime

2.3.2.2.3. Mechanical Experiments

2.3.2.2.3.1. Bending Tensile Strength

Generally, bending tensile strength increases depending on the increase in gypsum addition rate (Figure 2.9). In addition, lime admixture decreases strength. In bending experiment performed according to TS 3286 [32] in order to determine how this decrease will occur in prepared samples, Amsler bending machine with maximum 2000kg-f capacity is used (Figure 2.5).

Picture **2.5.**

Figure 2.16. Bending Tensile Strength Experiment

According to the bending strength results obtained from samples prepared with 10% gypsum with admixture (Figure 2.12), strength, which is 0.96 N/mm² prior to lime admixture, decreases to 0.63 N/mm² with 2% lime admixture. In samples prepared with 10% gypsum without admixture, 0.91 N/mm² bending strength is obtained with 0.5% lime admixture, while 0.84 N/mm² bending strength is obtained with 2% lime admixture. These obtained values are higher than 0.3 N/mm² bending strength defined by SIA Standards for earthen blocks whose unit weight is 1.60-2.20 kg/l [19].

Figure 2.17. Bending Tensile Strength Change in Samples Prepared with 10% Gypsum According to Lime Addition

2.3.2.2.3.2. Compressive Strength

Amsler compressive press with maximum 10,000 kg-f capacities is used in compressive experiments (Figure.2.6). Each part of samples, which are divided into two as a result of bending experiment, is subject to compressive experiment where 10x10cm steel plates are used.

Picture 2.6

Figure 2.18. Compressive Strength Experiment

The results obtained for samples prepared with 10% gypsum with admixture are demonstrated in the graph in Figure 2.13. For example, compressive strength, which is 3.14 N/mm^2 before lime is added, decreases to 2.21 N/mm^2 with 2% lime admixture.

Figure 2.19. Compressive Strength Change in Samples Prepared with 10% Gypsum According to Lime Addition

In samples prepared with 10% gypsum without admixture, compressive strength of 4.02 N/mm^2 is obtained with 0.5% lime admixture and compressive strength of 3.63% N/mm^2 is obtained with 2% lime admixture. These values are higher than the minimum compressive strength value suggested by SIA [19], CRATerre [33] for adobe blocks, which is 2.0 N/mm^2, and by New Mexico Adobe Regulation [16], which is 250 $pounds/inch^2$ (1.75 N/mm^2).

When fracture sections of these samples (as in concrete) prepared with gypsum with and without admixture due to compressive experiment are examined, it is seen that they are triangular prism (Figure.2.7 and Figure.2.8). It can be said that material has almost concrete's characteristics.

Picture 2.7 & 2.8.

Figure 2.20. The Sample in Compressive Press

Figure 2.21. Cross-Section of Fracture After Compressive Experiment

2.4. CONCLUSION

In this section, findings obtained as a result of experimental studies are summarized and material decisions suitable for mechanization are made.

To improve mechanical and physical properties of stony and pebbly soil to be used as taken out of oven, 10% gypsum is added. To extend setting time of gypsum so that time is sufficient for working in site, 2% lime is added to the mixture. Lime admixture, which is related to setting time, can also be sufficient at low rates.

The following conclusions are made for application in line with the findings obtained as a result of experiments:

* The rate of lime to be added to the mixture is accepted as 10% by weight in terms of both mechanical strength and cost.
* As a result of preliminary studies conducted to determine water rate to be added to the mixture, it is decided that the mixture obtained at plastic consistency due to water addition at 18-20% is the most suitable mixture in terms of workability.
* Firstly, lime used to retard setting time of gypsum should be added to mortar water. Limed gypsum obtained by adding gypsum to lime + water mixture is added to soil + water mixture and thus, homogenous mixture is obtained.
* Casting into industrial moulds method is accepted for wall formation and the mixture is placed through tamping method.
* After the wall is formed and before it dries, gypsum inside completes its setting. The framework formed by gypsum due to setting prevents shrinkage behaviour of clay during drying. Thus, shrinkage decreases and a porous structure is obtained. Decrease in unit weight results in decrease in thermal conductance value. All of these will contribute to the decrease in heating energy in buildings constructed with this material.
* Gypsum added to the mixture increases material's resistance against water. Thus, material does not scatter although it absorbs water due to its porous structure.
* The framework formed by gypsum within the material increases bending and compressive strength. It is observed that samples broken during compressive test display the same characteristic with concrete and when they are broken, their shape is triangular prism.

SECTION 3. MECHANIZED CONSTRUCTION TECHNOLOGY SUITABLE FOR GYPSUM STABILIZED ADOBE

3.1. Introduction

The physical and mechanical characteristics of gypsum stabilized adobe material have been improved in the laboratory level and its experimental treatment has been increased.

A building construction has taken place on the soil for the building site mechanization and applicability of the material whose characteristics have been brought to a standard degree. A single storied, detached house with 100m² gross area, which meets all the comfort requirements, has been built. When the organization and mechanization of the building site in question are compared with examples applied either in Europe or in our country, positive results are obtained in construction technology, mould selection and mechanization in terms of workmanship, period, land use and environmental conditions.

3.2. Construction Technology

In this section, which studies the applicability of adobe building to mass housing, concrete technology has been used in order to develop the construction technology. In other words, appropriateness of mortar preparation; use of cast form in the wall dimensions; placing the mortar into the mould and production with the machine in concrete technology have been studied. In this respect, universal horizontal-axis concrete mixer, “PERI Hand-Set” industrial mould, vibrator, shaking panel, “WACKER” compactor and sledge-hammer (tamper) are used. Such use of universal construction machines has never been applied in international literature and researches (German, France, U.S.A., Indonesia). Thus, the “special” adobe block production machines and techniques recommended by the United Nations even for housing studies, for which “licensee agreements” are required, are not needed anymore.

In the previous studies (i.e. MAG 505), the gypsum +lime stabilization of the material has been obtained. The second step is the development of a construction technology suitable to the adobe construction material with the help of the mechanic characteristics of the concrete technology.

3.2.1. Determination of The Situation

The construction technologies developed for the adobe buildings vary from country to country and from community to community. To determine the situation, it will be worthwhile to scan some technologies.

A) <u>Traditional (Anatolia</u>) [34]

-Time choice	:	Beginning of spring-summer
-Soil choice	:	When the soil paste which is shaped compressing in hand, is left from a height of 1 m, it must not scatter but only change shape.
-The admixture	:	Plant remains... fibrous, tree originated The admixture in stone species ... sand, pebble
-The Digging Process	:	In a place where there is suitable soil, after lifting the plant soil, an excavation is opened.
-Elimination	:	The aggregates with diameters bigger than 2 cm. and foreign materials are eliminated.
-Preparation of mortar	:	Mortar pits are opened. By wetting and treading under soil becomes as dense as plastic. Admixture is added.
-Leaving the mortar to rest	:	The mortar with the admixture is left 1-2 days to rest for yeasting.
-Shuttering (casting)	:	The mortar is poured in timber mould. The placement is made with manual instruments.
-Drying	:	Protected from rain and sun. For moistening, the wet moulds are left to dry in wind and shade
Protection	:	If not used immediately, it is taken under a cover to be protected from sun and air.
-Transportation	:	According to the distance between the production site and the construction site, a hand - cart, a timber stretcher and a caterpillar are used.
-Mesh	:	Meshing with lime-soil mortar.

B) France [20] (Figure 3.1 & 3.2)

-Time choice	:	A factory is constructed for block production.
-Soil choice	:	Soil, which has lab values of 40% sand+35% blue limestone + 20y. clay is suitable.
-The Admixture	:	Cement
-The Digging Process	:	With the help of pickaxe and shovel.
-Conveyance	:	According to the distance of the excavation area to the factory it depends which vehicle will be used.
-Grinding +elimination +depot	:	It is eliminated in the desired dimension or is grinded in the mechanical grinding machine.
-Conveyance +dosage +mixing	:	Conveyance is done with simple construction site vehicles. The dosage of cement + water is regulated. The mixture is made with a machine.
-Press +Conveyance	:	Motor presses are used.
-Primary drying	:	Under a plastic cover (3 days) it is left to dry by wetting to prevent from chaps.
-Conveyance +Stocking for 21 days	:	Transport in the construction site with a hand-cart or horse-carriages.
-Meshing	:	Meshing with clayey-earth mortar.

FIGURE 3.1. STABILIZED ADOBE BLOCK PRODUCTION SCHEME/ **FRANCE** (REPUBLIC OF MALI – SANON KOROBA)

FIGURE 3.2. PRODUCTION PLACEMENT SCHEME/ **FRANCE** (REPUBLIC OF MALI – SANON KOROBA)

C) Switzerland (Traditional) [35] (Figure 3.3)

-Time Choice : Summer and spring months.

-Soil Choice	:	Soil, which has lab values of 40% sand + 40 % blue limestone 5% clay.
-The Admixture	:	No admixture.
-The Digging Process	:	It is made with simple construction tools.
-Conveyance	:	According to distance, done with horse or hand-cart.
-Soil +Material Stocking	:	According to the distance of the excavation area to the construction site soil stocking is made.
-Elimination	:	Soil is eliminated with manual methods.
-Mixing	:	Soil is mixed to become at mortar density.
-Leaving to rest		The mixture is left to rest at pits.
-Giving a shape	:	It is given shape at moulds.
-Drying	:	The material is dried in sunlight or wind.
-Stocking	:	If the production and construction periods are different, the blocks are stocked.
-Conveyance	:	Carrying an essential amount to the construction site.
-Meshing	:	Meshing with mortar.

FIGURE 3.3. ADOBE BRICK PRODUCTION STAGES/ **SWITZERLAND**

D) <u>United Nations (UN)</u> [6]

-Time Choice	:	A factory is constructed for block production.
-Soil Choice	:	Simple construction site methods (smell, colour, compression, etc.)
-The Admixture	:	Cement, lime bitumen emulsions, chemical stabilitors, tamping, agricultural wastes, natural organic fibers...
-The Digging Process	:	Dry and dried soil, simple hand-tools and simple machines.
-Elimination +Grinding	:	For foreign materials and stone, pebble, etc.
-Mortar Preparation	:	The proportions are measured with simple tools.
-Leaving to rest	:	If the stabilitor is lime, it is left to take the moisture of the soil totally, If it is cement, as it starts immediately to hydration, production starts right away.

-Mixing	:	As the cement-mixer is not found useful, mixing is made with simple tools.
-Shuttering (casting)	:	Shaping with hands in the moulds.
-Drying	:	Blocks taken out of the moulds are left in plastic bags.
-Secondary Drying	:	If the stabilitor is cement, a drying period of 3 weeks; if lime, a period of 4 weeks.
-The Wall	:	Meshing with mortar.

3.2.2. Contribution of The Research

Regular and comprehensive studies aiming at the improvement of adobe construction technology have not been conducted in our country up to day. In 1984, a high bachelor thesis with the title "The Research on the Opportunities of Gypsum Stabilized Adobe Production" concerning the gypsum stabilized adobe research and experimental house built in 1983 by I.T.U was completed. In the thesis, the improvement of the characteristics of the material was put in the foreground.

A) Thesis'84/ ITU [12]

-Time Choice	:	Spring - Autumn
-Soil Choice	:	With simple manual methods. Except plant soil, clayey earth is suitable.
-The Digging Process	:	Relevant to the conveyance, the excavation area is preferred to be close to the construction site.
-Elimination	:	Stones with diameters bigger than 2 cm. are eliminated, as they reduce the resistance.
-Mixing	:	Mud (soil + water) is prepared. Gypsum + lime + mixture is put into the hole opened in the middle of the mud mixture.
-Mould	:	1. Adobe brick mould 2. Single in-situ moulds 3. Continuous in-situ moulds

-Shuttering (Casting) : It is put in moulds with shovels. Tamping is made. It is smoothed with screed board.

-Walling : 80th the two types of moulds are set up on the wall.

B) <u>TUBITAK INTAG-TOKI 622/ 1995</u>

-Time Choice : 4 seasons (universal construction site calendar).

-Soil Choice : Natural clayey and graveled soil extracted from the excavation area close to the construction site is used. There are no beginning preparations.

-The admixture material : 10% gypsum + 2% lime + 19% water of soil weight.

-The Digging Process : Digging is done from the excavation area with a ship. In the construction site, soil stock is prepared according to X%+ wall volume.

-Mixing : Soil is put into the cement mixer with a hard cart. It is left to moisten. The mixture is added with values of 10% gypsum + 2% lime + 19% water.

-Mould : An industrial steel construction mould in the wall dimensions is set up in the place of the wall.

-Conveyance to the : Suitable to carry with shovels, conveyor, mould belts, scoops and crane buckets.

-Compression : With tamper and compactor. In plastic fluid phase, a vibrator can be used.

3.3. Adobe Construction Site

3.3.1. Determination of the Situation

As can be seen from the scanned researches, each country has developed different construction technologies for adobe production according to their needs and construction cultures. In Table 3.1, comparison of four separate construction processes according to transaction criteria can be seen.

TABLE 3.1. PROCESS COMPARISON OF ADOBE PRODUCTION TECHNOLOGIES (ACCORDING TO TRANSACTION CRITERIA)

3.3.2. Contribution of the Research

In this section, the developments at the phases of suitable soil choice, mortar preparation, casting, and wall formation in adobe construction, which has been built within the scope of the research studies, can be examined.

The construction area in I.T.U Maslak Campus was assigned by the rectorate for the research. This site consists of a research building area, mixture preparation area, experiment platform, building site administration office, a dormitory and a dining hall for the workers, and a tent that contains the material stock units (Figure 3.4).

Figure 3.4. INTAG TOKI 622 Adobe Construction Project Location Plan

In addition to its production period, which is shorter than the other examples, this construction technology having been applied regardless of the climate conditions has given rationalism especially to the mass production.

3.3.2.1. Selection of Suitable Soil

In large scaled adobe construction sites, the suitable soil can be chosen by lab experiments. Lab experiments are both time-consuming and increase the costs due to the technician and equipment requirements. In single constructions, positive results can be achieved with simple experiments.

The most suitable soil is known to be the one including light colored chine-clay. This soil which is thought to be suitable due to its color proves to be useable in gypsum stabilized constructions since it does not scatter when pressed in hand and later released or is not broken into pieces but divides into large particles when it is released from 1 meter height after it has dried.

Another method used to decide the suitability of the soil is making sample block and drying it in open air in such a way that it is also protected from water. The ideal soil mixture is the one that does not result in severe and dangerous cracks in the blocks. The salts that dissolve in water and are going to be used in the suitable adobe mixture of clay and sand should not exceed 2%.

The soil used in the research has been examined in tab, and besides, casting and observing the block in the building site have determined the suitability (Figure3.1).

Picture 3.1.

Figure 3.4. Sample Block Casted in Construction Site

3.3.2.2. Mortar

3.3.2.2.1. Preparation of the Soil

It has been stated in the previous researches and experiments that the stones with diameters bigger than 2 cm play a resistance reducing role in the soil [12]. But in the adobe production, which has been stabilized with 10% gypsum, elimination of the soil is not necessary. It has been found in the lab experiment (see Sec.2) that the compressive strength is 2,2 N/mm² in average in the samples produced with coarse aggregate.

After it has seen that stones with diameters of 6 cm. can be used, the stage involving the elimination of the soil in the building site is removed from the production period. The costs for the time and workmanship spent in the elimination and grinding stages to keep all the material in a diameter of 2 cm are also saved. Thus, special samples of tools and instruments used in various countries did not take place in this building site organization.

3.3.2.2.2. Preparation of the Mixture

Due to the results of the experiments, the preparation of gypsum adobe mixture has rather been simplified. The production period, labor and cost units have been reduced. As regards the working comfort during ALKER wall production in the building site and the rational usage of the material, the soil amount is determined to be 50 kg (approximately 1 full handcart). 50 kg of soil was taken out of the stock and emptied into the cement-mixer in utmost 3 minutes. A cement-mixer of 250 lit is accepted to be sufficient for the production (Figure3.2).

Picture 3.2.

Figure 3.5. Shoveling Soil into Concrete Mixer

According to the dryness of the soil and the weather conditions, the soil in the cement-mixer may need to be moistened. When the soil is in the most dry form, a maximum amount of 2 kg has been added from the total water reserve. This process is not required when the soil moisture is sufficient for the plastic consistency achieved with 19% water. The cement-mixer is worked for approximately 1-2 minutes, that is the time required for the dissolving of water homogenously in the soil. During this time, the second worker can prepare 5 kg base gypsum (that is 10% of the weight of the dry soil), 1 kg lime (that is 2% of the weight) and 9 kg water mixture (that is 19% of the weight) in 3 minutes for the mixing process (Figure3.3).

Picture 3.3

Figure 3.6. Preparation of Gypsum + Lime + Water Mixture in Scale Buckets

The lime used to retard the setting time of gypsum in the mixture is added to the water before gypsum and it retards the initial set of gypsum. Due to the delayed setting time, the treatment period is extended.

The dissolution of the mixture added to the soil in the cement-mixer throughout the whole soil can be seen with naked eyes. After the adequate time - 1 minute in average- the cement mixer is stopped and the mixture is emptied into handcarts (Figure3.4).

Picture 3.4.

Figure 3.7. Discharge from Concrete Mixer

The proportions and the scales in the mixture are turned into norms that a worker can understand easily:

50 kg soil	= 1 full hand-cart (0,06m3)
5 kg gypsum	= 4 full shovels
1 kg lime	= 2 shovels full to the brim.
Max. 2 kg water	= If the soil is to be moistened.
17 kg water	= To ease the work, 2 different scaled containers are used (containers of 8 kg and 9 kg). Thus, gypsum

and lime are mixed according to these scales (Figure3.5).

Picture 3.5.

Figure 3.8. Turning Gypsum + Lime + Water Rates into Hand Chart and Shovel Units

3.3.2.3. Mould

There are different construction techniques and mould types for adobe construction in the world. In our country, the construction technique of adobe masonry and adobe block: production is the most available. The tamping method is generally used in garden wall construction. But the users have had some problems with the durability of this kind of production. If the tamping process is not applied successfully in the adobe wall, which has only binders of clay and soil, deformations are seen [14].

In this study, since the stabilization is performed with gypsum and lime, the drawback in question disappears.

3.3.2.3.1. Mould Types to be used for Adobe Production in Our Country

A. Traditional Adobe Brick Casting Mould

Rigidity is obtained through fitting wood pieces of mould to each other. It is the oldest mould type. For this mould type, where maximum 4 blocks can be produced at a time, ease of use can be provided through a model change so that more blocks can be produced [12] (Figure 3.5). However, due to the phases of block production (drying, stocking in site, transportation, masonry workmanship, masonry material etc.), time is lost between adobe brick production and construction phases. Besides, it is not possible to improve production conditions in terms of costs and workmanship.

Figure 3.9. Traditional Adobe Brick Casting Moulds

B. In-Situ Casting Moulds

B.1. Individual In-Situ Casting Moulds

Wall is obtained by pouring mortar into moulds mounted in the place of wall (Figure 3.6). By leaving a certain distance in order to reduce the effect of shrinkage on wall, which may be encountered in daily castings, the mould is placed forward. In this system, level differences emerge in places where the mould is transferred. Plaster with equal thickness on equal surfaces will be more durable [36].

Figure 3.10. Individual In-Situ Casting Mould

It is observed that the mould is weak and it loses rigidity and compressive strength during tamping. The mould model is modified by adding stretcher bars in order to prevent wood pieces of the mould from separating from each other during tamping [12]. However, since time and the number workers spent for mounting, demounting and cleaning increase, it affects production negatively.

B.2. Permanent In-Situ Casting Moulds

It is the mould type that continues throughout all walls (Figure 3.7). Although mounting, demounting problems can be partially overcome and since wood pieces of mould are at least 2cm, they become deformed after several castings [12]. The desired wall surface cannot be obtained.

Besides, if mixture rates are not sufficient to reduce shrinkage and castings are continuous, severe and dangerous shrinkage cracks may occur (Figure 3.6).

Figure 3.11. Permanent In-Situ Casting Moulds

Picture 3.6

Figure 3.12. Shrinkage Fracture of the Mixture in Liquid Consistency

C. Developed In-Situ Casting Moulds

Moulds used in wall construction in research site are HAND- SET system moulds of PERI company. These moulds are rather used in concrete technologies. These moulds have conformity with all building types, minimize workmanship costs, provide labor and worker safety as well as rapid mounting and demounting opportunities, can be renewed and provide solutions to all technical problems and are durable and all of these prove that they are economic.

Such moulds are independent from cranes and are modular moulds whose board length is 30cm and its multiples. The weight of the largest board, whose dimensions are 150x90cm, is 39.4kg. Lightness of boards makes working period of worker more efficient. Another advantage is that transportation costs are reduced.

These moulds designed for concrete technology are durable against 50 KN/m^2 compression and hydrostatic mortar pressure on boards are balanced by tie rods, which connect moulds to each other and are resistant to 9 tones shrinkage. There are standard holes above boards for these bar transitions. Connection of boards to each other can be easily realized with clips put manually without requiring any tools or instruments.

Contact surface of fin-ply in 12mm thickness, which is used in the mould, is covered by $240g/m^2$ phenol plate. 30x30cm plywood cells are fixed to steel framework with fasteners. The width of steel framework is 8cm. This width facilitates mould connections. Scale and plumb line works are rationalized. Since mould levels are equal in all parts, material to be used for plaster is reduced. If one face of plywood material gets old, it can be removed and the other face can be placed instead or it can be completely replaced with a new one. Thus, moulds can be used countless times (Figure3.7).

Picture 3.7.

Figure 3.13. PERI Handset System Moulds Used for Adobe Wall Casting

3.3.2.3.2. Casting- Shaping

While the mixture is prepared in the cement-mixer, 2 workers make mould montage in the place of the wall. The cleaning and thoroughly lubrication of the moulds after each use have ensured to get a clean, smooth plaster surface (Picture.3.8).

Picture 3.8.

Figure 3.14. Cleaning and Lubrication of Moulds

The mixture brought from the cement-mixer by the hand-carts is emptied into the moulds with shovels (Picture.3.9).

Picture 3.9.

Figure 3.15. Discharge of the Mixture from Handcarts into Moulds

The tamping process is performed for each uncompressed height of 20 cm. For adjustment and compression processes, first, simple wooden tamps have been used. Since the material sticks to the wood and makes tamp heavier, the wooden tamp has been abandoned. Later on, for the simplest compression process, a 6 kg wooden handled iron hammer is used (Picture.3.10).

Picture 3.10

Figure 3.16. Compression of Mortar Poured into the Mould through Sledge Hammer

For the adjustment and compression processes in the production of gypsum stabilized adobe wall, the best results are achieved with the use of compactor.

BS 45 Y type gasoline powered WACKER vibration compactor weighing 53 kg is used in the construction (Picture.3.11).

Picture 3.11

Figure 3.17. BS 45 Y Type Gasoline-Powered WACKER Vibration Compactor

This compactor, which can be used even by single person, has especially succeeded in attaining smooth surface. Due to it is shoe-form, the edges could not be compressed as neat as the lateral wall surfaces. It is decided to use a smaller compactor within the mould.

In edges, compression process is reinforced by tamping with a hammer. The cavernous surface formed by the tamping helps the mortar to hold on to.

In order to save time and workmanship through mechanization in the production stages, HILTI impact splitter is used as a compactor. A special, pin-jointed end is designed and produced for the tool. But as a result of misuse, it is broken without being used much (Figure.3.18).

Picture 3.12

Figure 3.18. HILTI and Its Special Top Produced for Compression

When the material has fluid plastic consistency, a spud vibrator is used for the adjustment in material tests (Picture.3.13).

Picture 3.13

Figure 3.19. Use of Spud Vibrator in Mixtures at Fluid Plastic Consistency

In the mixtures applied without lime admixture that acts as a retarder for the gypsum, when the gypsum is emptied into the mould, it starts to set. When the vibrator is used firstly in this stage, good results are achieved. But as the rovibration, which is applied for increasing the resistance in the concrete technology, cannot be performed in the setting time and since it is not performed according to the methods, this procedure could not utilized. It is observed that the set of the gypsum breaks down and giving shape becomes impossible (Picture.3.14).

Picture 3.14

Figure 3.20. The Result of Rovibration Method Applied out of Gypsum's Setting Time

3.3.2.4. Curing-Leaving to Rest-Stocking-Conveyance

Both in European countries that make studies on adobe production and in the traditional applications in our country, it is observed that most of the time between the casting of the mixture and construction is spent for curing, leaving to rest, stocking, and conveyance stages (Table.3.1).

Especially for the curing and leaving to rest stages among all, a very broad area is required in the production plants (Table.3.2). Especially when mass production is in question, very large area is needed for the curing of the moulds and for leaving them to rest. In the 'France' example, the area assigned for the preparations of the construction before production stage was approximately 2400m² (Figure.3.2). Both the large preliminary preparation area and the initial costs for investment and plant increase the total production cost.

3.3.2.5. Masonry Wall System

In the technologies having been used for adobe wall production until today, the wall masonry with soil and lime mortar in block construction process requires a long time. This stage increases the labor amount and the total period during both preparation and application stages.

When the wall surface formed by masonry is not homogenous, different wearing surfaces emerge. Accordingly, plaster damages can be seen.

Especially the walls constructed by using industrial and rational moulds with in-situ tamping system provide smooth plaster surfaces. This enables the mortar to be applied in equal thickness and thus a longer duration. Hence, in the research site, the wall masonry process is removed from the production stages and multi-dimensional savings are made.

3.3.2.6. Cast Wall System

In this section, the applied alternatives and results of mixing and adjusting processes in the building site for cast walling are compared.

A. Preparation of Mixture

Four different experiments are conducted to find the most suitable mixture preparation method.

1. In the applications without lime, the dry soil, and the powdered gypsum was put into the cement mixer. The material was mixed for some time, taken out and mixed with water. This procedure was tested to make more use of the materials treatment period, for gypsum sets in short time, but it was observed that the mixture of powdered gypsum with dry soil is not rational (Figure3.15).

Picture 3.15

Figure 3.21. Problems Encountered While Mixing Dry Gypsum with Dry Soil

Also, in the samples formed by this method, the desired plastic density could not be achieved and the compressing process was not done successfully (Picture.3.16 & 3.17).

Picture 3.16 & 3.17

Figure 3.22. Difficulty in Compressing The Mixture at Dry Consistency

Figure 3.23. Adobe Sample Obtained with The Mixture at Dry Consistency

2. In this alternative mixture, a liquid density with 25% of water had been achieved. The mortar was directly emptied from the cement-mixer to the mould with it is own fluidity (Picture.3.18).

Picture 3.18

Figure 3.24. Discharge of Mortar at Liquid Consistency into the Mould

But segregation was observed as a result of the big particles being unable to suspend in the mortar and collapsing with gravitational force (Picture.3.19).

Picture 3.19.

Figure 3.25. Segregation Observed In Mixtures At Liquid Consistency

This alternative has been done in the experimental base. As it will be another problem to use the cement-mixer in this way in the construction, this mixture has never been used in the construction technology.

3. In the mixture prepared with 22% water, as stated before, in the lab, a jolt panel and in the construction site, a spud vibrator are used. Vibration must be made within the setting period. When the vibration is not applied within the setting period, it breaks the binding of the gypsum; the materials get wet and cannot maintain their form. As can be seen in Figure3.20, vibration has been applied within the setting period in the sub-half of the sample and positive result has been achieved. But as a result of the vibration, which has not been applied within the setting period in the upper half, it has been observed that the material, which has not hardened after dismantling, has changed its shape.

Picture 3.20

Figure 3.26. The Result of Vibration Applied on A Sample in Different Times

4. It is observed that before lime is added to the mixture prepared by 22% water in order to delay the setting time, the mortar has shown cohesive characteristics. Since it sticks to the tools and instruments, the continuity of the procedure is disrupted (Figure3.21). This behavior changes after lime is added and the mortar does not stick to the shovel, handcart, cement-mixer, etc.

Picture 3.21

Figure 3.27. Workability Difficulty of Cohesive Mixture

B. Placing The Mixture in the Moulds

In the walling stage in the research site, both to reduce the risks of dangerous cracks appearing due to contraction, as well as to improve the mechanization at the production, 6 different methods have also been tested.

The mixture carried from the cement-mixer to the casting area with the hand-carts is thrown into the moulds with the shovels. When the uncompressed height is 20-25 cm, tamping starts. The rational usage of the moulds and the continuity of the procedure are considered to be the most important factors.

1. In every 1 meter, 30-35cm holes are opened and wall casting is performed interruptedly (Figure3.22). It is waited for 1 day for the casted adobe to set and the next day the holes are filled. This method is abandoned because the mould amount is so much; it disturbs the continuity of the production and vertical construction joints are formed.

Picture 3.22

Figure 3.28. Example of Interruptedly Casted Wall

2. In a daily work, 3.00-4.00 m of wall pieces are casted at storey height for the rational usage of mould modules. The next day, casting continued from the point it is left. Before new casting, the contact surface of the previously casted part is irrigated and made wet to ease the combination. But the vertical construction joint formed through the whole height causes an undesired gap due to shrinkage after the next wall casting height (Picture.3.23).

Picture 3.23.

Figure 3.29. Problem regarding Construction Joint in Walls Casted at Different Times

Because of this defect, this method has been abandoned, the construction gap is demolished and another casting is made by degreed combining method (Picture.3.24).

Picture 3.24

Figure 3.30. Repair of Defected Construction Joint

3. The most rational method is considered to be the compression of the walls ascended in equal proportions in the continuously set moulds. The galvanized welded-wire tie beams, which are adjusted in every 60 cm height, balances and prevents the gaps due to contraction throughout the building.

4. In certain parts of the walls that increase horizontally in length, where construction joints will be formed, the walls are finished in stair forms (Figure3.25). At different casting times, cracks due to shrinkage are not observed in such construction joints.

Picture 3.25

Figure 3.31. Working Difficulty when Stairs are 50cm

It is seen in this application that the wideness of steps must not be lower than 50 cm in order to allow compactor usage.

5. The effort of forming ramped construction joint tested as an alternative to the degreed combining method got to be meaningless. Because, the compactor or the tamper that stroke the ramped surface had broken off the mortar rather than compressing.

3.4. Construction Performance and Adobe Construction Behavior

Reference values are required to determine efficiency of construction performance at the stage of transforming existing resources into housing. After reference values are determined, they should be compared with the values obtained from previous studies on gypsum stabilized adobe construction.

In traditional adobe construction sites and construction applications, sensitivity of the material against water and moisture imposes restrictions to the project. Physical performance of traditional adobe is improved with gypsum stabilized adobe studies and project and application restrictions are not required any more.

The two main functions of the construction have been defined as load-bearing and protection. When load-bearing in construction is referred, not only the system that conveys loads to the ground but also “load-bearing and being born” relation is implied (such as bearing wings, wall's bearing of structure, column and tie beams' bearing of wall etc). In such case, "load-bearing" covers all requirements in relation to bearing function of the construction at system and element level. This meaning is defined with "construction" term. In other words, "construction" covers all types of bearing.

On the other hand, "Protection" term covers not only protection function within construction system and element but also protection required for human life.

Construction performance can be summarized as construction's fulfillment of its functions. Thus, requirements for evaluating performance are as follows:

a. Construction systems
b. Protective systems.

a. Requirements for construction systems

- Determination of load-bearing system types,
- Determination of project characteristics,
- Determination of production technologies,
- Determination of production process and organization
- Determination of natural environmental conditions
- Production capacity.

In this research, requirements for construction and production, which are subcategories of construction systems, are researched and determinations are made. What distinguishes adobe construction from others is the performance it displays in protective systems due to its physical properties.

b. Requirements for protective systems

In the research conducted for mass housing, the literature is utilized to evaluate performance of gypsum stabilized adobe construction. Performance degree expected from protective systems as well as the performance displayed by adobe construction are explained within

- Fire,
- Sound,
- Heat – moisture system by benefiting from previous studies in this field.

*** Fire performance**

Construction's behavior during fire is directly related to its material properties and size. Measures to be taken are divided into two groups as construction and operation.

Measures to be taken in the construction against fire involve

- Behavior of construction material,
- Behavior of construction element,
- Behavior of construction system.

Measures against fire for walls can be examined under

- Behavior of load-bearing wall
- Behavior of non-load-bearing wall
- Other elements carried by load-bearing wall (cladding facades)
- Insulations.

Construction materials are divided into two groups as A and B according to their behavior during fire. In Table 3.2, class codes of construction materials according to combustion behavior can be seen [38].

Material Class	Behavior	Material Type
A	Inflammable	
A1		Concrete
A2		Rock wool
B	Flammable	
B1	Hardly Flammable	Timber
B2	Normal Flammable	Hard foam insulation mat.
B3	Easily Flammable	With cotton

Table 3.2 Behavior Class of the Material During Fire [38]

Fire performance of wall changes according to material and determined shape of load-bearing and protective layers [39]. As can be seen in Figure 3.8, various layers are used in reinforced exterior wall to provide thermal and moisture balance.

Figure 3.32. Reinforced Exterior Wall Whose Temperature- Moisture Balance is improved (Insulation outside)

Thermal insulation either interior or exterior poses a big threat if it is made of a flammable material or its fire resistance is low.

Fire resistance period is expressed with 30,…,120min that take place near F letter and material class with A, B. "Istanbul Metropolitan Municipality Regulation for Protection Against Fire" [40] imposes restrictions on load-bearing walls where buildings have 2 or more stories: "… load-bearing walls in buildings are constructed as at least F90- A class." According to these restrictions, wall material should be within inflammable class (A) and protect people during fire for 90 minutes.

Behavior of adobe construction material during fire based on Swiss Cantonal Fire Insurance Association (1993) can be seen in Table 3.3 [41].

Material	**ρ (kg/m³)**	**Thickness d (cm)**	**Flammability/ smoke**	**Fire resistance duration in element**
Massive adobe	2000	25 15	-	F180 F120
Light adobe	900	25	-	F180
Concrete	2300	20	-	F180A

Table 3.3. Behavior of Adobe Building and Material During Fire [41]

In this case, 25 cm adobe wall resists against fire longer than the F90-A class accepted in fire regulation. According to DIN 4102 and DIN 18951 (Annex 3), if adobe construction material does not include any flammable admixture, it does not burn, deflagrate and result in smoke or odor.

*** Sound performance**

Undesired sounds are called noise. Sound level is demonstrated with dB. Sound level up to 65 dB causes psychological disturbances in people and sound level above 70 dB results in neurovegetative system disorder. In this case anorexia and anxiety may emerge. Sound levels above 90 dB may lead to hearing disturbances. Appropriate environmental sound level for places used can be seen in Table 3.4.

ENVIRONMENT	**DB**	
	Day	**/ Night**
Commercial	70	70
Workplace-settlement	55	40
Settlement	50	35
Resting-hospital	45	35

Table 3.4. Sound Level Appropriate for Different Environments [42]

Adobe is sound absorber due to its material properties. As a result of calculations obtained from SIA- Norm 181 [43] values, it is proved in Table 3.5 that adobe is sound absorber according to its thickness used.

Air Sound	**ρ (kg/m³)**	**30dB**	**40dB**	**50dB**	**55dB**
Massive adobe	2000	0,03	0,07	0,20	0,40
Light adobe	1200	0,04	0,12	0,33	0,73

Table 3.5. Sound Absorption Values of Adobe Construction Material According to Thickness Used (thickness as meter) [43]

Since the material in gypsum stabilized adobe case-study building, whose unit weight is 1800kg/m³, is used as a wall with 45cm thickness, sounds above 55dB spreading in the air will be absorbed by the wall.

*** Thermal-Moisture Performance**

The fact that human health is directly related to the environment, in which he lives, has been mentioned in Section 1.2.A, where healthy buildings are introduced. The relation between environmental conditions and energy, which is required for heating and cooling the environment in conformity with human health has been explained in Section 1.2.B. The negative effect of environmental conditions on building health is determined as condensation to occur in wall cross-section and wall surfaces. As a result of this condensation, deformations occur due to dissolution of salts as well as fungi and microorganisms due to moisture in the cross-section and on the surface of wall. Thus, environmental and wall conditions should be defined.

Performance expected from the environment should be at the values suitable for climatic conditions affecting the region so that people can live in comfort in any built environment [44]. These values are determined to be

* Relative humidity 50%
* Environmental temperature 21-25,4°C

* The difference between element surface temperature and environment +3°C [45].

Apart from single values, tables demonstrating lower and upper limits will also be presented here.

Table 3.6. Comfort Zones When Environmental Temperature is between 18-22 °C

After limit boundaries of the performance expected from the environment is seen in Table 3.6, the performance of building component will be presented in Table 3.7 [39]. The Table indicates thermal conductance coefficient k (W/m²K) values, exterior temperature ga, interior temperature gl and relative moisture φ. Gs in Table is dew temperature.

ga	gl	+ 10 C			+ 15 C			+ 20 C		
	Φ	50%	60%	80%	50%	60%	80%	50%	60%	80%
	gs	0,1	2,6	6,7	4,7	7,3	11,6	9,3	12,0	16,4
-10		2,97	2,19	0,99	2,71	1,85	0,82	2,14	1,60	0,72
-5		3,96	2,92	1,32	3,39	2,31	1,02	2,57	1,92	0,86
0		5,94	4,38	1,98	4,52	3,08	1,36	3,21	2,40	1,08
+5		11,9	8,76	3,96	6,78	4,62	2,04	4,28	3,20	1,44
+10		-	-	-	13,56	9,24	4,08	6,42	4,80	2,16

Table 3.7. Thermal Conductance Coefficients, k Values, According to Environmental Conditions in Exterior Walls [39]

When the temperature difference between two faces of a component (wall, floor etc.) in any d (m) thickness is 1°C, thermal conductance coefficient is thermal amount conducted through unit area of component (1m²) in unit time (1h) [25]. If k value is small, this means that total heat loss of the building is low. In case thermal loss of housings is low, thermal energy consumption of individuals and countries will also be reduced. Considering this, countries gradually decrease these values in regulations. K value in Germany, a member of European Community, was determined to be for

Masonry wall	kw <	0,5 W/ m²K
Concrete wall	<	0,4 W/ m²K
Windows	kF <	1,8 W/ m²K
Roof	kD <	0,32 W/ m²K
Basement floor	kG <	0,5 W/ m²K.

According to TS 825 in Turkey [25], k value is determined to be k average (D + P) for average thermal conductance coefficient of windows, exterior doors and exterior walls.

1st Climatic Zone	<	1,9 kcal/ m² h°C
2nd Climatic Zone	<	1,6 kcal/ m² h°C
3rd Climatic Zone	<	1,3 kcal/ m² h°C

Thermal conductance coefficient of gypsum stabilized adobe wall obtained in 1st Case-Study Building is k= 0,4 W/ m²K. This value has been calculated in accordance with the values obtained from measurements having been performed throughout a year. The findings of the research [46] are presented in United Nations Meeting held in Amman in 1987.

Atmospheric conditions of the building are determined by physical properties of the material. Symbol and unit of the properties to be examined are as follows:

Unit Weight	ρ (kg/ m³)
Thermal Conductance	λ (W/ mK)
Specific Heat	c (kJ/ kg K)
Vapor Diffusion Resistance	μ (dimensionless)

In Table 3.8, physical properties of some construction materials, which affect their thermal behavior, are presented so as to allow comparison with physical properties of adobe building.

	Material	ρ	λ	c	μ (20°C/%60)
[SIA] 381/1	Brick	1100	0,37	0,9	4,0- 6,0
	Lime, Sandstone	1600	0,80	0,9	10- 25
	Gas Concrete	400	0,18	1,1	3,0 – 5,0
	Timber (glass)	450-500	0,14	2,0-2,4	20-40
	Timber fiber board	350-500	0,09	1,6	2,0-5,0
CRA Terre	Massive adobe	2000	0,46-0,81	1,0	10,0-11,0
	Cement stabilized adobe (8%)			0,65-0,85	
	Light adobe	1200	0,47	1,0	8,0-10,0
[Al-ker]	Gypsum stabilized adobe	1600	0,40	-	-

Table 3.8. Physical Properties of Some Construction Materials

Vapor absorption property of the building surrounding the environment, d (10 kg/ m²h), gains importance in places where vapor is considerably generated. Bathroom, kitchen, fitness center, class are among the places where vapor is generated very much. In such places, vapor absorption of interior surfaces of construction element makes the place more comfortable.

200gr water vapor is supplied to a 4x4x2,5m room, where 50% relative moisture exists, for half an hour. In Table 3.9 [39], relative moisture change within time in the room can be seen if the room is painted with lime paint A or oil paint B.

Figure 3.33. Change in Relative Moisture According to Wall Surface Characteristic [39]

Thermal performance values obtained as a result of measurements of interior-exterior moisture as well as interior-exterior temperature differences in the 1st case-study building performed during a year can be examined in resource number 46.

3.5. INTAG TOKI 622 Adobe Construction Stages

The project prepared for the research is designed to be used as the research building in the future. The project is planned to be a mass-housing unit consisting of 2 bedrooms, a living room, bathroom and kitchen (Figure 3.34).

Figure 3.34. INTAG TOKI 622 Gypsum Stabilized Adobe Building Project

Picture 3.26 & 3.27

Figure 3.35. INTAG TOKI 622View of Case-Study Building

Figure 3.36. INTAG TOKI 622 Case-Study Building

All the stages in the construction period of this project, except the wall construction stage, are equivalent to current construction period.

3.5.1. Footing Tie Beams

In accordance with the footing application plan of the project, a rope scaffold is set up. Later on, with a skip, an excavation of 70 cm of depth and 45 cm of width is performed. After a mould for the tie beam is prepared, the reinforcement is set and footing tie beams are completed by casting 12 m^3 of ready-mixed concrete (Figure3.28).

Picture 3.28.

Figure 3.37. Rope Scaffold Set Up for Footing Tie Beam and The Excavation

3.5.2. Floor Embankment and Its Compression

After the casting of the footing tie beams, the ground below the floor is compressed with a vibration cylinder and crushed stones are spread until 5cm height is achieved (Figure.3.29).

Picture 3.29

Figure 3.38. Compression of the Ground

3.5.3. Floor Concrete

After crushed stones are spread on the compressed soil ground, 7,5 m^3 plain concrete is poured until 10cm height is achieved (Figure 3.30).

Picture 3.30.

Figure 3.39. Cast of Floor Concrete

3.5.4. Water Insulation

After footing tie beam and the floor concrete dry, two layers of BTM Elastosol water insulation with 50 cm wideness are applied to all the surfaces on which walls will be constructed (Figure.3.31).

Picture 3.31.

Figure 3.40. Water Insulation Applied to Lower Surfaces of Wall

3.5.5. Moulds for the Walls and Casting

It has been explained in 3.3.2.

3.5.6. Tie Beams for Earthquake

In the adobe wall structure that is casted in the research site, galvanized welded-wire is used (at intervals of: 2,5x8 cm), which functions as tie beam that increases the resistance against an earthquake. Against the diagonal loads that may occur during earthquake, these tie beams are placed in every 60 cm height as 3 levels in the wall with 2.40m height. They are placed regularly in 40cm wideness in 45cm exterior walls and in 20cm wideness in 30cm interior walls (Figure.3.32).

Picture 3.32.

Figure 3.41. Tie Beam for Earthquake Placed into the Wall

3.5.7. Over-Wall Tie Beams

The walls of the building are elevated up to 2.4m including the door and window openings. At this height, a reinforced concrete tie beam is passed over all of the walls. The tie beam is casted together with the floor elements of Moyap firm (Figure.3.11).

Figure 3.42. Cross-Section of the System

For the exterior wall tie beam, a ready-mixed reinforced concrete tie beam with dimensions of 30x16 is used beginning from the inner wall surfaces towards outside.

After the tie beam elements had been set in the exterior walls, the gap of 15 cm that is left on the adobe wall is filled again have formed in the reinforced concrete elements will be prevented, and also the entirely and aesthetics of the adobe construction, concerning the outside view of the building, will be protected.

3.5.8. Upper Floor

After setting the tie beam elements, masts are set at the needed interval to form the upper floor. Over the set masts, ready-made girders of 12 cm are mounted. Between the girders, floor units are furnished. Later on beginning from the lower floor level, at a height of 16 cm. (12+4), 11 m3 of concrete is casted and the upper floor is completed.

3.6. The Evaluation of the Workmanship for the Productions at Construction Site Level

3.6.1. Preparation of the Soil

For the adobe production, a total of 60 m3 (108 tons) of soil had been brought from various construction areas in the campus to the research site and they had been stocked. As there are no elimination and grinding processes in the procedure, there has been no question of the loss of volume whereas the 90 m3 of soil having been brought to the first Experimental House for adobe production is eliminated and after a loss of 30 % it is left with a volume of 60 m3. The 30 % of the material had to be removed from the building site.

3.6.2. Preparation of the Mixture

During the preparation of the soil required for adobe production, 1 worker is employed. 1 worker can reload 1 handcart of (50 kg=0,06 m3) dry soil from the soil stock into the cement-mixer in 3 minutes.

When the soil amount is 100 kg during the preparation of gypsum+ lime+ water mixture, only 2 workers are employed. But as the replacement of 100 kg soil takes time, the soil amount is reduced to 50 kg and only 1 worker is employed for the soil preparation process.

The mixture composed of 9,5 kg water, 5 kg gypsum and 1 kg lime, which is required for 50 kg soil, can be made ready by 1 worker in 3 minutes to be emptied into the cement-mixer. For the conveyance of this mixture more easily and quickly, 2 different scales are prepared. Maximum 2 kg water, which will be used if soil is required to be moistened, is used from the defined 19% water proportion.

The prepared mixture is mixed with the soil in the cement-mixer and is made ready for casting in 2 minutes by only 1 worker.

In every 2 casts, the mortar, which will stick to the cement-mixer and affect the performance, is thought to be advantageous to be cleaned. This process will be carried out by one worker in 3 minutes.

The adobe material having been taken from the cement-mixer by the hand-cart, is carried to the casting place by 1 worker. While the same worker will empty the mixture with the shovels to the moulds, 2 workers will do the compression and adjustment processes if tamp will be used. But if a compactor will be used, then 1 worker could carry the work out.

55m3 of dry soil had been used in the research site, for adobe production. In the dry soil amount, a loss of 8% is made because of sticking to the tools after the production, spilling, being cleaned from the cement-mixer. As a result, 50.6m3 of adobe is produced. As a result of tamping process with a volume loss of 11%, 45 m3 of wall volume had been achieved.

During the construction of first Experimental House, 40% of volume loss is seen in the ALKER (a term used for gypsum +adobe) production; 22% of volume loss is seen in the single in-situ casting application, and 40% of volume loss is observed in the continuous in-situ casting application.

3.6.3. Cleaning and Setting up of the Moulds

During the preparation of the materials for casting, 1 worker could clean and grease the biggest panel (150+90) in 1 minute. In this period, 2 workers could do the mould montage needed to construct 1 m3 of wall, in 9 minutes. Also, in this period, the vertical and horizontal adjustments of the moulds are made.

When this value is compared with the cleaning and setting periods of the moulds used in the construction of the first Experimental House, in terms of unit volume, the following results are gotten;

1-1/2 ALKER mould	67,5 unit time
Single in-situ casting mould	10,9 unit time
Continuous in-situ casting mould	2,3 unit time
Industrial mould (622)	1,0 unit time

3.6.4. Comparison of the Daily Production Amounts

In the research site, in 1 day, 4 workers can carry out the casting of 2,8 m3 of adobe walling.

When this value is compared with the daily production amounts of the first Experimental House, in unit time, using the same number of workers, it can be observed that most of the production is done by using these modern moulds.

1-1/2 ALKER casting	1 unit volume+ Wall Construction Process
Block casting	1,8 unit volume+ Wall Construction Process
Continuous casting	2,5 unit volume+ Wall Construction Process
Industrial Mould (622)	2,8 unit volume

3.7. Conclusion

In this section, the development in the mechanized construction technology suitable to the gypsum stabilized adobe and the methods applied for the rationalization in the building site have been declared. The casting, mixing techniques and the transfer to the mould and compression stages in the concrete procedure, have been used being adapted to experimentally improved materials.

The factors to be taken care of in the gypsum stabilized adobe production in the research site can be briefly summarized as follows:

*For the gypsum stabilized adobe production, there seemed no need for elimination and grinding stages of soil. Thus, many savings have been made concerning use of land, labor and casts.

*In the preparation of the mixture stage, the measures are reduced to simple scales.

*The excess adobe mortar which has taken from the universal horizontal-axis cement-mixer, at certain intervals, with a cleaning purpose must not be used, and must be removed from the production area.

*By the use of industrial moulds rationalizm has been acquired in the casting stages. By the application of casting by testing on the design, both in mould amount, and also in production continuity, so much has been benefited.

*By the use of mechanic compressors in the shaping stage, homogenous wall surfaces for mortar can be achieved.

*Degreed construction joints are formed due to shrinkage observed in wall castings performed at different time intervals.

*4 or 5 workers will be enough for the production of single adobe construction. Since a few processes can be done at the same time, excess number of workers will affect the site mechanization negatively.

SECTION 4. CONTRIBUTION OF THE RESEARCH TO STANDARDIZATION

Technological Researches are composed of the phases explained in Section 1.5. Among a wide range of researches carried out since 1978 in order to develop adobe construction technology, “Basic Research”, “Development through Experiments”, and “Pilot Study” have been completed. The next step is to provide “Standardization” so that a resource will be provided for those who are interested in this material such as

1. Project producer
2. Occupant
3. The institution granting approval
4. Investor, private and official authorities.

TS 2514/ February 1977 “Adobe Blocks and Construction Rules” and TS 2515/ February 1977 “Adobe Blocks and Construction Rules” are the references for those who would like to construct with adobe and to control adobe buildings.

In Germany, standards for soil mortars for walls; adobe buildings construction rules; definitions for construction soil, methods for experiment; soil construction materials; protection of adobe buildings against moisture; plaster upon adobe building exist (Annex 3).

Standards for adobe construction rules have been established by Union of Chambers of Swiss Engineers and Architects (Schweizerische Ingenieur Und Architekten-Verein) [19].

Adobe buildings are still used in southern states of the United States. Adobe regulation’82 of New Mexico State provides in “Unburned Clay Masonry, Section 2405” [16] definitions that facilitate construction with adobe starting from soil selection and extending to construction rules.

SECTION 5. COMBINATION OF RESULTS & SUGGESTIONS

As it has known, although the traditional adobe is a low resistant building material that has damaged by water, it creates suitable environmental conditions for human health. Because of these advantages, there has been researches going in, to use it not only in low budgeted but also in wealthy countries.

The research consists of; defining the aim, experiments and construction stages. The sections of the report has been accordingly arranged and the results out of the sections are presented as follows:

SECTION 1. AIM

The aim on the research of gypsum stabilized adobe technology and standards, is the improvement and transformation of local building materials and labor, into mechanized technology that is to be used in mass housing sector, and the saving up of the countries budget and energy sources. The managers who build their own dwellings, who can design adobe buildings in mass housing sector, who approve adobe buildings and who aim to protect country's budget, cultural heritage and ecology will be able to use this technology.

SECTION 2. MATERIALS

In this section, the findings achieved as a result of experimental studies are compared with the previous studies, and materials suitable to mechanization are decided.

Soil

The soil is used without elimination as soon as it has taken from the excavation area (including 6-7 cm stones). The procedure is not bound to conditions such as high clay value, or suitable granulometry, but to the factors such as plant soil or pollution.

The Findings: There is no condition for searching for special soil type. Since furnace of the material is close to the site, the conveyance costs are low. Many savings are achieved from the elimination and grinding periods, labor, energy and machine engagement.

Stabilization

Stabilization is obtained by 10% gypsum+2% lime (AL-KER). The proportion of the fine-grained binding material in the soil has initially been 8% (clay), afterwards, 12% is added, and 20% fine grained binding material has been achieved.

The Findings: Thus, the high clay proportion provided for in the previous building material studies on soil is not required any more.

After the setting of the gypsum, as the clay continues to dry, the contraction, which will form as a result of drying, is partially prevented by the gypsum. The contraction is lesser (%1,07). As a setting material is achieved, the need for place, labor, and time due to drying in the broad site during the traditional adobe production disappears.

The industrial material produced and conveyed for walling is 12% of wall volume; the industrial production energy is very low. The material amount coming from the fabric is small. These materials can also be burned in the local hearths-thus the conveyance cost is less. The initial investment cost of the production is low.

The physical and mechanical properties of the wall material are good: The lime in the mixture when compared to a mixture without lime, recede the physical and chemical properties a little. Even these new values are higher than the limit values declared in the standard. The compressive strength is 2,21 N/mm^2 and it is higher than the standard value 2 N/mm^2; the bending strength is 0,63 N/mm^2 and it is higher than the standard value 0,3 N/mm^2. Also, as a result of the hydration of lime in time, the physical and mechanical properties of the building increase in the usage time (as a result of the 1^{st} Experimental Building).

Lime is added to the mixture due to two primary reasons. The first is; soil+10% gypsum set in a very short time (3-5 minutes) that makes it impossible for treatment in the construction site. This period lengthens after the addition of the lime so that it is possible to work in the site. The second is; soil+10% gypsum mixture sticks on the construction machines and tools. At the condition of adding lime, treatment has been improved, that is, the mortar does not stick to the tools as much as to hinder the work.

As the lime arranges the setting time in the mortar, the sequence of the mixture should be as; 18-20% of mortar liquid is clarified. Then 1/3 of this is spread on the soil in the universal horizontal-axis mixer to dampen the soil, and is mixed for a short time. Then first 2% of lime and then 10% of gypsum, which are both scaled, are added to the left over water, and mixed. This process lasts for 1/2 minute. The mixture of water+ lime +gypsum is poured on the soil in the mixer and mixed for 2 minutes. With the handcarts (or conveyor belt; loader) it has emptied into the mould.

Workability

The usability of the gypsum stabilized adobe (AL-KER) together with universal building site machines, tools and vehicles, to be used in mass housing, is scanned.

The Findings: The mortars in which there's 18-20% of water, are in plastic density and are suitable to mechanical or manual compaction. The mortars with 20-22% of water are in fluid plastic density, and are suitable to placement by vibration. The mortars with more than 25% of water have segregation.

Water having been added to the mixture for treatment is affected from the water in the soil. The soil must be considered to be in hearth moisture. For the soils obtained from drier (summer heat) or damper (after rain) surroundings, density experiments must be made and water proportion must accordingly be determined.

SECTION 3. MECHANIZED CONSTRUCTION TECHNOLOGY

The phases of gypsum stabilized adobe construction; the transport of the raw material from the excavation area to the site, obtaining of gypsum and lime arranging of the dosage mixing of them with a machine, conveyance of them to the moulds made ready in wall places, and the compression. In this section, the development of the mechanized construction technology suitable to the gypsum stabilized adobe and the methods to be carried out for the building site rationalization are scanned. As a result of this examination; many decisions are made concerning the preparation of the raw material, the mould mixing of mortar, transport of the mortar to the mould, placing the mortar into the mould, the stabilization of the construction system and related stages and labor.

The Preparation of the Raw Material

For the gypsum stabilized adobe production, there has accepted to be no need for elimination and grinding processes. Thus, the material amount, land use, labor, time and costs have been economized.

Mould

PERI industrial mould is used in the adobe construction site.

The Findings: These moulds are produced with steel frames and fin plywood. This has a weight and dimension that can be carried by only 1 worker. The casting and releasing from the standard dimensioned moulds, takes less time. The vertical and horizontal adjustments are done easily and in less time smooth surfaces are obtained. The wall surface is obtained smooth and without warping. Smooth surfaces and walls without warping reduce the coat wastage in great amounts. In big dwellings, the amount of moulds increases. In individual buildings, there is an opportunity to hire according to the need. It shows high resistance in the compressions with machines.

The Mixing of the Mortar; Treatment

After the addition of the lime that improves the preparation and the treatment of the mortar and after the preparation of the suitable water mixture, a universal horizontal-axis cement-mixer has been used.

The Findings: The mixer must not be full-filled to get a satisfying result. All the mixing process lasts for 2-3 minutes for one circle. The emptying process is simple. The leftovers that partly stick must be cleaned at regular times. These must not be added to the mixture again.

Transport of the mortar to the mould

For the transportation of the mortar from the mixer to the mould, handcarts are used.

The Findings: In the individual building capacity, 2 handcarts are sufficient to carry the mortar. The material can easily be removed from shovels, handcarts and cement-mixer. In the productions with big capacity, for the lifting of the mortar especially in storey height, a mobile+ conveyor belt or small loaders can be used.

Adjustment

For the mortar that has been emptied into the mould to have high resistance, a smooth geometry and surface, and a good durability when it forms the wall, a few experiments on homogenous placements have been performed. Tamping compactions with hand compactions with mechanical compactors and compressions with special tips adjusted to electrical hand-breakers are a few which have been applied.

The Findings: All of the three applications have resulted the same. Compaction with hand lasts long. A special mechanical compactor increases the speed. In compressions with hand, 20 cm layers, and in mechanical compressions 30 cm layers are compressed. As the vertical construction joints form cracks due to contraction, the wall is preferred to be casted lengthwise. In the wall casted lengthwise, the galvanized welded-wire prevents the cracks due to contraction.

The Stabilization of the Building System

For the stabilization of the building system, in every 60 cm, a row of galvanized welded-wire is placed in different layers in the wall. The reason of this tie beam reinforcement is to confront with the forces due to earthquake, that form diagonal cracks, especially in block buildings.

The Findings: The 4-5% of contraction problem that especially arises in soil dwellings, has been reduced to 1,07% both by the use of natural-large grained granulometry and also with the contribution of the gypsum. Even this value causes 1 cm cracks due to shrinkage in every 1 m. The galvanized welded-wire reinforcement, which can be used provided that all the building will be casted continuously, has balanced the shrinkage forces and no cracks due to shrinkage occurred in the building at the level of stability and exquisiteness.

Workmanship and Construction Site

The gypsum stabilized adobe construction site has been reduced to a less number of processes when compared with the traditional adobe construction and the developed adobe construction sites in foreign countries.

The Findings: In individual building production, a team of 4 persons cast 2,5m^3 wall in one day. 45m^3 wall volume of a house, which is totally 100 m^2, can be completed in approximately 18 days.

SUGGESTIONS

This research is in the “prototype” level among the technologic studies. It is observed that the material can be mechanized and applied to mass housing. The next phase should be “mass production”. Mass production requires different environmental conditions than the prototype production. Thus, scientific support must be provided to the first building site, which will skip to mass production, at the research study level.