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LIFE CYCLE COST ANALYSIS FOR USE OF PRECAST PRESTRESSED CONCRETE SLABS IN REPAIR OF CONCRETE PAVEMENT

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ABSTRACT

Precast pre-stressed concrete has historically been used for a variety of infrastructure facilities and projects in developed countries. Its popularity in the transportation industry has especially increased during the last few decades, as it offers several important advantageous aspects over traditional cast-in-place concrete. Such advantages are a lower impact on environment, lower maintenance and rehabilitation activities, savings on total construction and repairs time, and ultimately savings on final project cost. On the other hand, precast pre-stressed concrete has some downsides such as high cost of construction and unknown service life span. Further research is needed to evaluate this aspect of precast pre-stressed concrete slabs used in the transportation industry, particularly in road construction. Therefore, the ultimate goal of this research is to make a model and calculate the life cycle cost assessment of precast pre-stressed concrete slabs (PPCS) used in road construction. In this research, two types of concrete pavements were compared, namely, PPCS and Jointed Plain Concrete (JPC) cast-in-place to construct 1 mile road in California, USA by utilizing techniques of the Life Cycle Cost Analysis (LCCA). All future costs were converted to current dollar values by applying the Net Present Value (NPV) method.

Keywords: Life Cycle Cost Analysis, precast pre-stressed concrete slabs

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1. INTRODUCTION

Roads represent one of the most important components for transportation infrastructure, and they directly affect the lives of people and merchandise transportation. With the growth of population, road infrastructure continues to expand to accommodate the increasing growth. Besides the expanding of road networks in every decade, these systems require ongoing maintenance and repairs (Chen & Chang, 2015). Concrete pavement represents one of the main types of pavements. The Portland Cement Concrete (PCC) cast-in-place method was used in the past decades for repair works of the concrete pavements. Naturally, PCC needs more time to gain the design strength, which leads to rising congestion traffic time and, consequently, increased user cost (Merritt et al., 2002). Components of user costs are the delayed time cost (i.e., loss of work time), the operation cost (e.g., cost of oil and gas), and the crash cost of vehicles. Traffic congestion results in and consequently contributes to increasing rates of emissions in the environment. These reasons encourage transportation agencies to find more rapid pavement construction methods, especially in urban areas, to help to minimize the required time of road closure and reduce user costs. Precast Concrete Pavement is not a new concept to repair concrete pavement (Merritt et al., 2002). A broad range of stages has been implemented to develop the idea of precast concrete, and one of them includes the pre-stressing precast concrete. In 1998, the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA) conducted an operation research and feasibility study to use precast pre-stressed slabs in roads construction (Merritt et al., 2002). The objective of the study was to evaluate the cost-efficiency of precast pre-stress concrete slabs (PPCS) and traditional cast-in-place concrete. Durability was also evaluated in this study by using precast and pre-stressing methods. Fabrication of slabs in a controlled environment yielded a reduction in the problems associated with concrete cast-in-place such as method of mixing, ratio of quantities, curing, and protection of concrete from weather change. Pre-stressing is very important to reduce cracking, which leads to minimizing the maintenance and increase the surface life of the pavement. In this study, two different projects will be compared by using the method of LCCA. The projects were constructed in different geographical locations. The analysisperiod was 40 years. The first project is the El Monte I-10 which was constructed in California in 2004 using PPCS. Another project is in Michigan which was constructed in 1993 using JCP.

2. CONCEPT OF PRECAST PRE-STRESSED CONCRETE SLABS IN THE PAVEMENT

PPCS notion includes pre-stressing the steel reinforcement bars in both transverse and longitudinal directions in the form of pre-tension and post-tension (Merritt et al., 2008). The pre-tension process is performed in the transverse direction, which would be perpendicular to the direction of the traffic flow, before casting the concrete in the panel form. The post- tension process is performed in the longitudinal direction after installed the slabs. Full depth panels are used by precast pre-stressed concrete pavement concepts (Merritt et al., 2004). For a highway that has heavy traffic most of the time, PPCS can be the best solution to replace full depth panels because these slabs already received the designed strength before installation. Figure 1, shows an example of placing a full depth PPCS after removing the old pavement. Additionally, the slab surface does not need any kind of overlays such as hot asphalt or thin bonded concrete. Therefore, the traffic flow could be opened directly after installing the slabs. Using full depth panels requires more attention when the base is prepared. The base surface beneath the slabs should be smooth to avoid vertical misalignment.

Figure 1. Full depth pavement replaced with PPCS.

3. PANEL ASSEMBLY

The base panel, joint panel, and anchor panel represent the three parts of panel assembly, as can be seen in Figure 2. All these components are placed perpendicular to the direction of traffic flow. While pre-tension is applied through the long side of panels (transverse direction), post-tension is applied through the short side (longitudinal direction) via ducts cast into the panels. The base panel is the basic part between the three types of panel assembly in each post-tensioned slab. As shown in Figure 3, the typical details of the base panels consist of posttensioning ducts, continuous shear keys on the longitudinal panel sides, lifting anchors located on the top surface with a distance of approximately 0.2 L (L is the length of smaller side of panel) from the edge of the panel on each side, and pretensioning strands uniformly distributed to achieve a uniform transverse prestressing (Merritt et al., 2007).

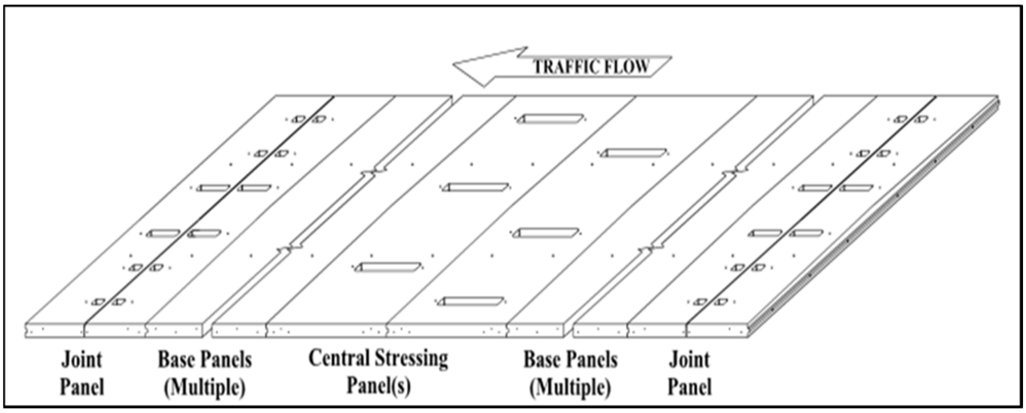

Figure 2. Precast prestressed assembly panels.

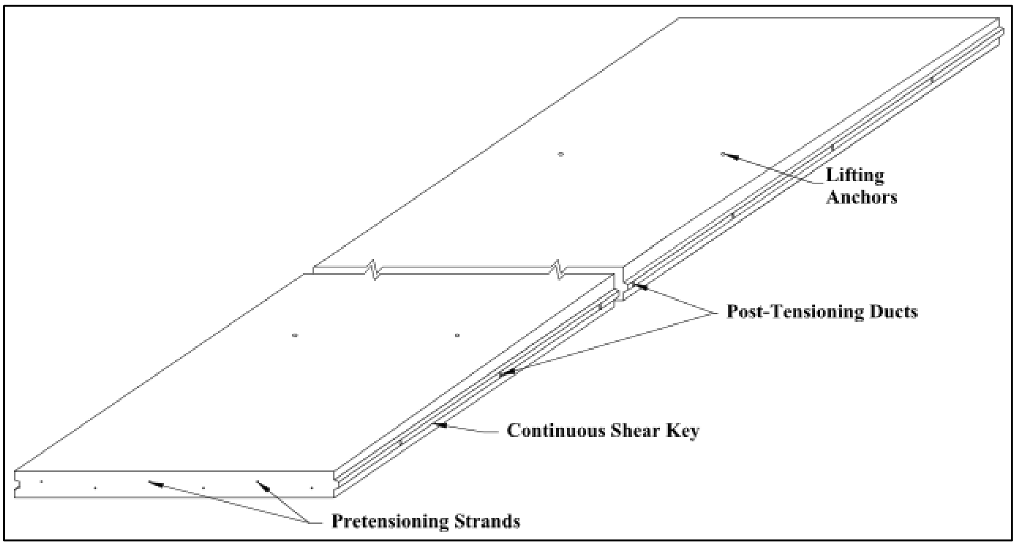

Figure 3. Typical base panel

The second part of the slab assembly is the joint panel. As can be seen from Figure 4, the post-tensioning anchorages and the expansion joint are located on this panel. The variation in temperature during the day and throughout the seasons will cause a large horizontal movement in the slabs. Therefore, the primary goal of the expansion joint is to control these movements, in addition to providing a load transfer mechanism through the joint (Merritt et al., 2004). Detailing for PPCS joint will be explained in Figure 5. The purpose of pockets is to provide access to the post-tensioning anchors to permit stressing the tendons with a monostrand stressing ram.Another purpose of the stressing pockets is to allow for temporary post-tensioning during installation of the panels. Grouting of the longitudinal tendons is done through the grout ports, which are located in front of the post-tensioning anchors.

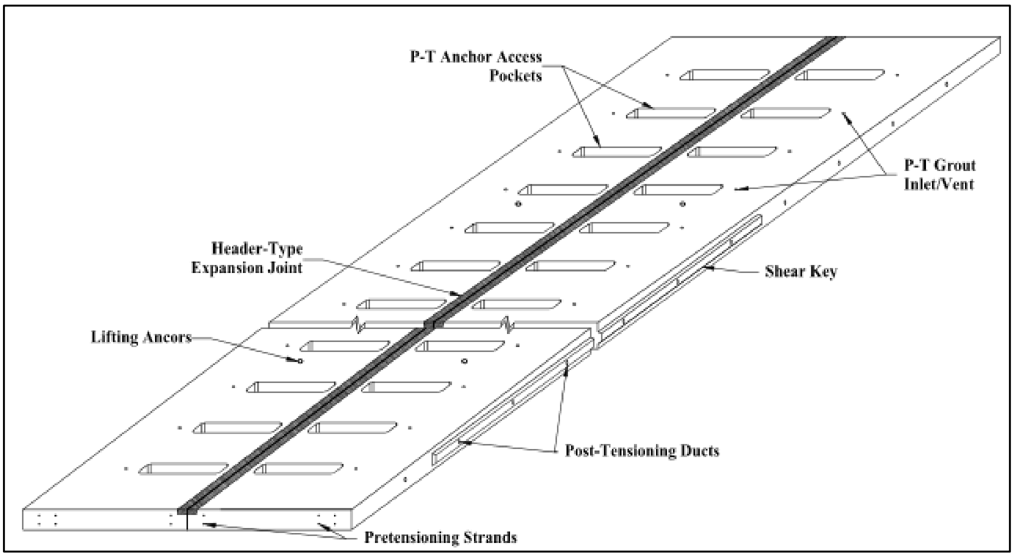

Figure 4. Typical joint panel.

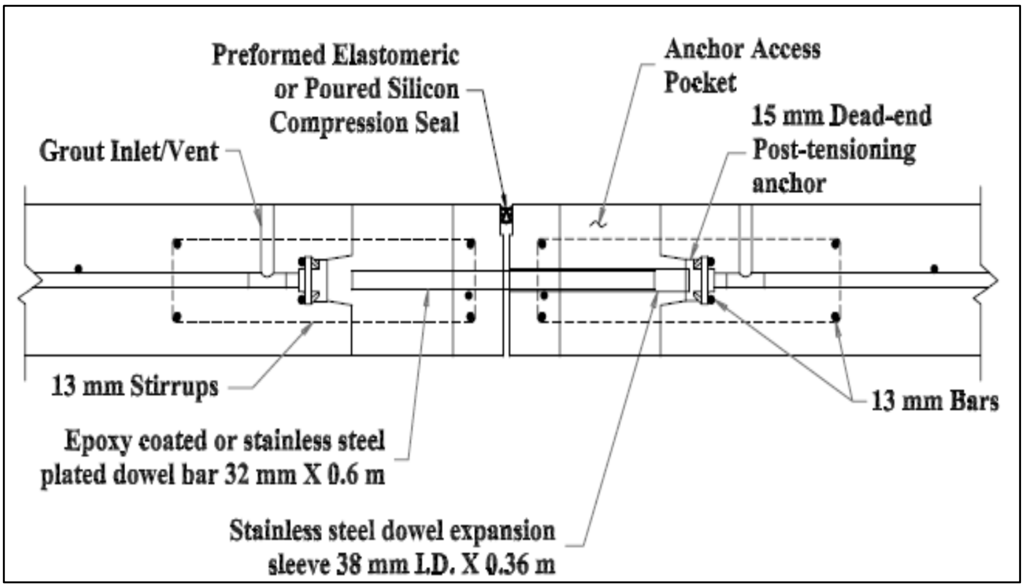

Figure 5. Detailing of joint for PPCS

The third part of the panel assembly is the anchor panels, which are located at the middle of each post-tensioned section. Drilling and grouting anchor pins into the underlying base/subgrade are performed through sleeves cast into the anchor panels. Anchoring the post-tensioned slab underlying base/subgrade is crucial to allow for expansion and contraction of the pavement from the center. This will somewhat ensure uniform expansion joint widths and prevent occurrence of creep in or slow movement of the pavement in the direction of traffic over time.

4. BASE PREPARATION

Base preparation for PPCS requires more attention than other types of pavements. The final surface of the base should be flat and smooth. The ratio of voids that could be created in the base layer must be at the lowest amount to provide more stability for the slabs. There are two popular kinds of bases that are used under PPCS: the hot mix asphalt and the lean concrete base, as can be seen in figures 6, 7.

Figure 6. Lean concete base.

Figure 7. Asphalt base.

5. BENEFITS OF PRECAST PRE-STRESSED CONCRETE SLABS

PPCS has many advantages that might encourage transportation agencies to implement it in their future projects. The following are some of benefits of using PPCS:

1. Time efficiency
2. Reducing user costs
3. Improving the durability
4. Reducing slabs thickness

1. Time-efficiency is very important in pavement projects. Pre-stressed slabs are fabricated and cured off-site in a controlled environment until they gain the desired strength. These processes provide an option for the contractor to use off-peak hours during nighttime or weekends to install the panels, because in these times the traffic will be lower than during normal daily hours. Therefore, the traffic could open immediately after placement of the slabs without disturbing commuters during daily work hours.
2. The major advantage for PPCS is minimizing user costs. By applying PPCP techniques in the pavement, the required duration to complete the construction will be less than the duration to construct a project using cast-in-place concrete. Components of user cost such as delay cost, vehicles operation costs, and accident rates will be dramatically reduced by minimizing the project duration.
3. Improvement in the durability of the concrete slabs can be achieved in PPCS. Cracks can be controlled by using pre-stressing and applying a high degree of control in mixing and during curing the concrete. These control options also work to raise the service life for the slabs. Furthermore, the short distance between the batch plant and the forms helps control segregation and flash set.
4. Pre-stressing helps to reduce slab thickness by applying post-tension.

6. LIFE CYCLE COST ANALYSIS FOR PAVEMENT

Life Cycle Cost Analysis (LCCA) is an economical and analytical method to evaluate the economic effectiveness for investigating several alternatives. It incorporates all kinds of overall costs, such as the initial cost, maintenance, rehabilitation, and operation cost over the service life of the project from the construction through the demolition or salvage stage (Walls & Smith, 1998). While LCCA is being used as a decision support tool when selecting pavement type, it is also used to assess different rehabilitation strategies within the same pavement type (Reigle & Zaniewski, 2002). Figure 8, illustrates the categories of costs that could be included in the calculation of

LCCA for the pavement.

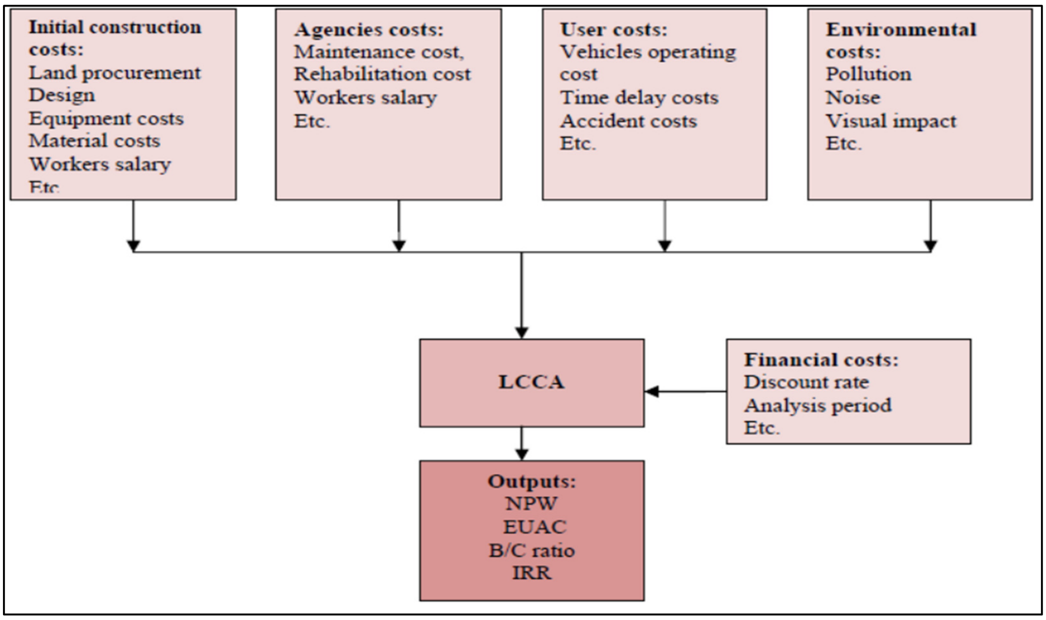

Figure 8, Flow chart showing LCCA steps.

Cost parameters include the initial construction, maintenance, rehabilitation, user, environmental, and salvage costs. The initial cost will cover the construction for each supported layer beneath the pavement. For maintenance cost, different types of activities are suggested for both alternatives. Rehabilitation cost will be applied just for JPC. These costs will be converted to the current dollar's values. Estimation of user costs contains delay cost and operation cost. For future maintenance and rehabilitation activities, their user costs will be calculated and then converted to the current value. Total user cost gathers all the user costs for each stage for the project. Environmental cost is another factor that will be included in the model of LCCA. This cost concerns the cost of emission for GHG. GHGs are produced during production of materials, mixing, transporting concrete to the site, and pouring the concrete. For materials, the rate of emissions varies from one type to others. The last parameter in the LCCA is the salvage value, and it represents the value of pavement at the end of service life.

7. LIFE CYCLE COST ANALYSIS PARAMETERS

Parameters represent the general form for the LCCA requirements, and they included evaluation methods, discount rate, and period of analysis:

1. Net Present Value, sometimes called Net Present worth (NPW): It is the most widely recognized method for cost analysis of pavements. It is the total initial cost and any future costs related to the maintenance and rehabilitation discounted in today's monetary value.
2. Analysis Period: The analysis period is the length of time to assess the differences between costs of future maintenance and rehabilitation for suggested alternatives of pavement (Caltrans, 2013). According to the FHWA Technical Bulletin, the analysis period should be adequately long to reflect the long-term cost differences associated with reasonable repair strategies. In general, the analysis period should be more than the pavement design period and at least long enough to include one complete cycle of rehabilitation (VDOT, 2002).
3. Discount Rate: The discount rate is used to convert the future costs (in dollars) and benefits to current value (Caltrans, 2013). In other words, it is a percentage used to

minimize expected future costs such as maintenance and rehabilitation costs, user cost, and salvage cost to present value.

8. COST FACTORS

Cost factors contain initial cost, maintenance cost, rehabilitation cost, user cost, and salvage cost. All these costs require an adjusted cost to the current value for dollars except the initial cost

1. Initial Cost: Initial construction cost has a major impact on the value of NPV and plays a key role in the process of comparing. This cost is determined when the analysis period equals zero. In this study, parameters of initial cost represent labor, material, and equipment without including taxes or profits.
2. Maintenance and Rehabilitation Costs: Maintenance and rehabilitation for pavements need preventative or corrective actions during the service life of the road to keep it in a safe condition for users. Maintenance and rehabilitation costs are different from one project to another, and they are mainly dependent on the type of pavement, weather, percent of deterioration, and the type of materials that use for treatment. Common types to maintain the concrete pavements are crack sealing, diamond grinding, and joint sealing.
3. User Cost: User costs are important components in approach of LCCA. During the construction, maintenance, and rehabilitation stages, traffic flow delays as a result to the closure of one lane or more. At the same time, delay will lead to increase fuel consumption and raise the rate of vehicles accidents. Therefore, user costs are an aggregate for three different cost elements: travel time costs; vehicle operating costs; and
4. Crash costs (Ehlen, 1999).
5. Salvage Value: Salvage value represents the worth of alternatives at the end period of LCCA. Some pavement alternatives have rehabilitation processes close to the end of the analysis period. While the service lives of these alternatives are going to increase, the salvage value will increase. Residual value and serviceable life are the components of salvage value (Walls & Smith, 1998). Residual value is implemented using the net value for recycling the pavement after the end of analysis period. Serviceable life is the major part for the salvage value, and it represents the net value for the remaining life for the pavement at the end of analysis period. When the alternatives have different service life at the end of analysis period, serviceable life should be calculated.
6. Environmental Cost: Environmental cost is a reference to the cost of greenhouse gas (GHG) emissions, which is produced during construction of concrete pavements and which has effects on the environment. Emissions of GHG come from three stages such as production of raw materials, manufacturing concrete, and placing concrete in the location (Ma et al., 2016). There are three main types of GHG that will be evaluated during this study, and they are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2).

9. CASE STUDY

Two old projects, PPCS in I-10 El Monte, CA and JPC cast-in-place in Detroit, Michigan, will use as case studies to compare LCCA costs. Both of these projects are chosen because they designed with the same axial load factor. The design axial load factor for roads is 80 KN, and it is equivalent to 18 kips. The project of I-10 El Monte, CA will be the case for the PPCS. This project was constructed at eastbound Interstate-10 approximately 2 miles west of the San Gabriel River Freeway (Interstate 605) in El Monte, California in 2004 (Merritt et al., 2004). The goal of this project was to expand the old jointed plain concrete pavement with precast pre-stressed concrete slabs. The project length was approximately 250 ft. (76m). Slabs dimensions were 27 ft. in length for the two traffic lanes and 10 ft. as an outer shoulder, 8 ft. for panel width, and the thickness is 10 in. (25 cm). Supporting structure beneath the slabs includes sub-base, aggregate class 3 with 8.5 in. (21.6 cm) thickness, LCB 6 in.(15.24cm), and a single sheet of polyethylene between the lean concrete and slabs. The layers of pavement will explain in figure 9.

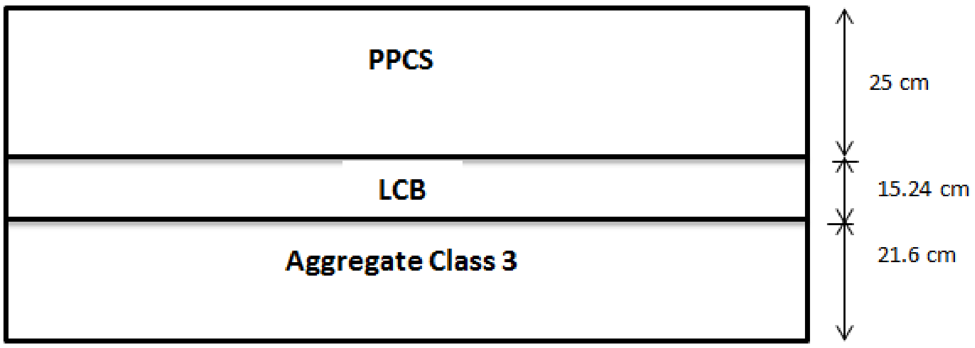

Figure 9 Shows layers of PPCS' project

For JPC cast-in-place, the project, which was constructed in Detroit, Michigan on NB I-75 (Chrysler Freeway) in 1993, was taken as reference to compare with the PPCS project. The layers below the jointed concrete included 16 in. of aggregate, LCB with 6 in., and 10 in. concrete pavements, as illustrate in figure 10.

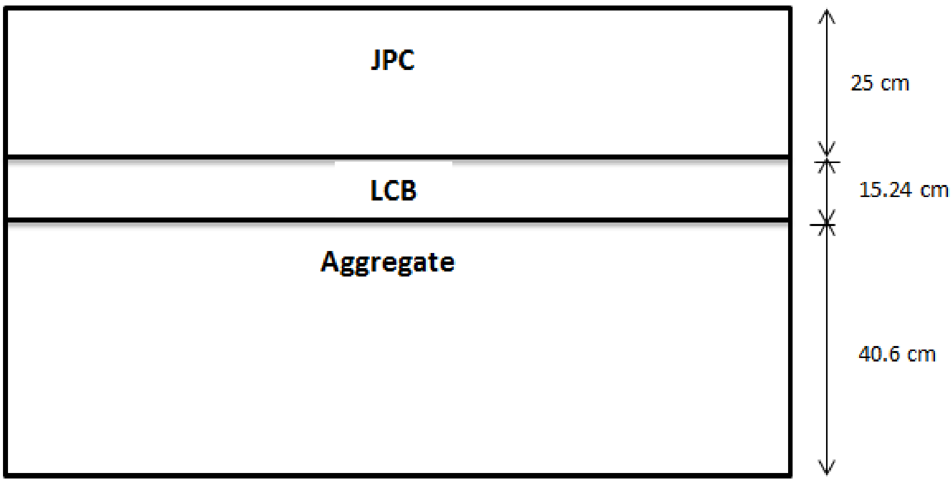

Figure 10 Shows layers of JPC' project

Following costs will include all kinds of costs for PPCS and JPC cast in place.

1. **Initial Cost and Duration**:

- Initial cost for PPCS: It represents the cost materials, works, and equipment of slabs and all the layers beneath. Following result represent the price for the total initial cost of PPCS' project:
- Total Initial cost = $2,648,611, Total duration = 35 days
- Initial cost for JPC cast in place : Supported structures beneath the concrete
- pavement will be similar to the supported structures for PPCS, but with different
- Thicknesses. Following result represent the price for the total initial cost of JPC'project:
  - Total Initial cost = $1,869,282 (70 days)

2. **Maintenance and Rehabilitation Cost:**

- Maintenance and Rehabilitation for PPCS: PPCS is a new technology, and the oldest

PPCS project is only about 15 years old. There is no available data on maintenance and repair carried out on these few projects, because none of the PPCP projects have required any traffic loading related repair work to date. Many discussions with representatives of Caltrans District 8 and other researchers have been conducted to define the kinds of maintenance required for PPCS. But from their experiences in this field they expect that PPCS will need two sets of maintenance; one after 25 years (2041) and the second after 35 years (2051) without major rehabilitation. The maintenance is considered to include joint sealing and diamond grinding. Minor crack sealing will not appear because the pre-stressing will help to prevent these cracks. The ratio of maintenance will be equal to 3% from the total area of pavement.

- Following cost represent the total cost for all the maintenance types with different ages for the project:
- Total cost for maintenance and rehabilitation = $373,892 (for 40 years)
- Maintenance and Rehabilitation for JPC cast in place: JPC pavement is very popular for division of maintenance in Caltrans. It is expected that three rounds of maintenance will occur for
- Sealing joints and diamond grinding. These kinds of maintenance will begin after 10 year
- From installation. The ratio of maintenance for JPC will be equal to 5%, and it is higher
- Than the ratio of maintenance of PPCS. For cracks sealing, the data was taken from study
- That done by Abdelaty et al. (2015).
- Following cost represent the total cost for all the maintenance types with different ages for the project:
- Total cost for maintenance and rehabilitation = $859,266 (for 40 years)

3. **User Costs:**

User cost calculations will focus on two components: travel time cost and vehicle Operating cost. All the future maintenance and rehabilitation activities for both pavement alternatives will be covered in addition to the initial stage.

- Total user cost for PPCS (construction and maintenance stages) = $1,022,069
- Total user cost for JPC (construction, maintenance, and rehabilitation stages) = $2,613,381

4. **Salvage Value:**

- Salvage Value for PPCS equals to zero, because there is no rehabilitation.
- Salvage Value for JPC = 50% × rehabilitation cost = $46,537

5. **Environmental Cost:**

Here the cost of greenhouse gas (GHG) emissions will be estimated during three stages: production of raw materials, manufacture of concrete, and onsite construction of pavement. For both concrete alternatives (PPCS and JPC), these three stages will be applied on the construction, maintenance and rehabilitation activities.

- Cost of PPCS emission = $ 156,138
- Total cost for emission of JPC = $183,363

10. MODEL OF LIFE CYCLE COST ANALYSIS

After recognizing all parameters of costs and discounting them to current value by implementing the NPV method, the last step is collecting them in the model that represents the general form for the life cycle cost analysis. The LCCA model is:

LCCA = I + M&R + U – S + E + O

Where;

LCCA = Total life cycle cost analysis in present value.

I = Initial cost and it is not required to be discounted.

M&R = Present value for maintenance and rehabilitation cost.

U = Present value for user cost.

E = Present value for environmental cost.

S = present value for salvage cost.

O = other costs

For PPCS, LCCA is equal to:

LCCA = $4,200,707

For JPC,

LCCA = $5,478,755

11. CONCLUSION

The objective of this study was to evaluate and compare two types of concrete pavements (PPCS and JPC cast-in-place) by applying the LCCA approach. Cost components included in this comparison are initial, maintenance, rehabilitation, user, environmental, and salvage costs. In addition, four projects constructed by using PPCS are reviewed and discussed. In light of the outcomes of this study, the following can be

Concluded

- Results of the initial construction cost have shown that PPCS (i.e. $2,648,611) is less cost-effective than JPC (i.e., $1,869,282). This is primarily attributed to the high cost associated with casting, curing, and lifting (to the trailers) the slabs.
- The required time to construct JPC (78 days) is more than that of PPCS (35 days) because JPC needs some additional time in the field to gain the required strength.

- PPCS requires less maintenance than JPC cast-in-place. Therefore, the maintenance costs (i.e., $766,191) of JPC are approximately twice that of PPCS (i.e., $373,892).
- During the 40-year service life cycle, is contrast to PPCS, JPC requires one major rehabilitation after 35 years.
- The results also exhibit that the largest saving obtained by utilizing PPCS is the user cost.
- PPCS imposes less negative environmental impacts than JPC. This contributes to the cost-effectiveness of PPCS in comparison to JPC.
- Salvage value of PPCS is zero because PPCS does not need major rehabilitation.
- The base layer beneath the PPCS should be smooth and flat to prevent creating any voids below the panels that would subsequently lead to cracking in the slabs if grouting is not provided.
- Finally, using night and weekend hours to install PPCS can help reduce the
- Congestion and disruption on the freeways.

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Effect of Method of Soil Drying On Atterberg Limits and Soil Classification

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Abstract

One of the most significant factors that effects the soil classification is Atterberg limits, liquid limit and plastic limit. Atterberg limits were developed by a Swedish scientist at the early 1900's called Atterberg. These limits could express the consistency of fine-grained soils due to variety of water content. These limits divide the soil into four major states, solid, semi-solid, plastic, and liquid state. According to American Standard for Testing and Materials (ASTM), to check liquid limit and plastic limit tests for a soil, the soil should be dried before the test for preparation purpose. ASTM specified two ways to dry the soil specimens, oven dry and air weather dry and both should give same results. Most of engineers will go with dry oven method to speed up the specimen preparation process assuming there is no any difference between these two methods of drying. In this research, the effect of the drying method has been studied. The results showed that the drying method has a significant effect on the liquid and plastic limits and then on the classification of soils. The soil specimens of this research were brought from all over Iraq cities to ensure studying different soils that could exhibits different behaviors.

Keywords: Atterberg limits, liquid limit, Plastic limit, Plasticity index, soil classification.

1. Introduction

The classification of soil is considered major factor for designing geotechnical structures, no matter what the use of soil is, either supporting soil or as a constructional soil. Supporting soil could be existing under shallow foundations such as spread footings or mat foundations, around and below deep foundations such as piles and drill shafts, behind the retaining walls etc. on the other hand constructional soil could exist in all earth structures such as earth dams. All these geotechnical structures required deep study about the soil physical properties before getting started the structural design. The physical properties of soil and then the design of the geotechnical structure significantly depend on the plasticity of soil, which can be expressed by Atterberg limits. Atterberg limits, liquid limit and plastic limit, were firstly developed by the Swedish scientist namely Atterberg at the early 1900's. The consistency limits are greatly important to classify the soils, Serge Leroueil 1996. R. T. ODELL has made a study on Illinois soil properties showed a relevant relationship between Atterberg limits and some engineering properties of soil. For example, there are more than a relation among the consistency limits and some physical and chemical properties such as the organic content matter, percentage of clay particles smaller than 0.002 mm, percent of Illite and Montmorillonite in the clay, percent of silt particle with size range between 0.05 and 0.002 mm. Haigh, in 2014, has correlated the liquid limit with the clay strength and the plastic limit with the soil capillary suction. Therefore, the importance of Atterberg limits could be clearly visualized due to the previous studies. However, not many research studies are available to estimate the correlation between the effect of way of calculating consistency limits and soil classification. In this paper, a study has been made to show the effect of the drying method of soil on the values of liquid and plastic limits and then on the classification of soil.

1.1. Atterberg Limits

Fine-grained soils can be remolded in presence of water without crumble if clay minerals are existing. This phenomenon happened due to the cohesion exists between particles because of the water surrounding them, Das 2010. There was a method to describe the consistency of fine-grained soil concerning the change of water contents. The Swedish scientist Atterberg developed this method.

The consistency limits were proposed to distinguish among four states of soil. These four states of soil are solid, semi-solid, plastic, and liquid state, stated from low to high moisture content respectively. The consistency limits among them are shrinkage limit to separate between solid and semi-solid state, plastic limit to separate between semi-solid and plastic state, liquid limit to separate between plastic and liquid state as shown in figure 1. In this study, it is focused on the effect of liquid and plastic limits due to their important on the classification of fine-grained soils.

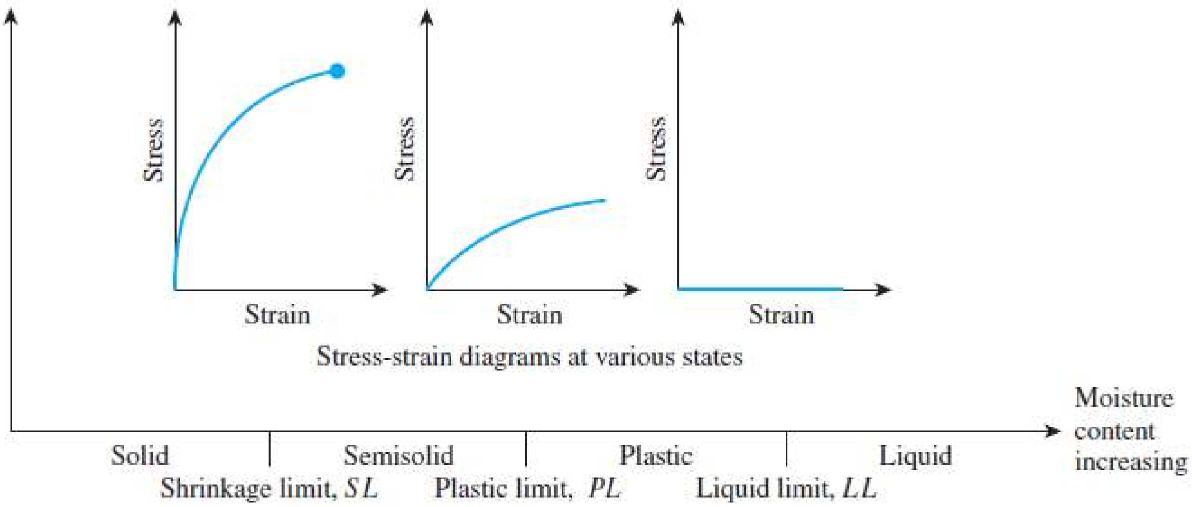

Figure 1 The consistency limits and soil states (Das, 2010)

1.1.1. Liquid Limit

The liquid limit is can be described by the water content that transmits the soil from plastic to liquid state. In other words, the soil is transmitted to a state like a liquid if the water content increased passing the liquid limit. Two methods are specified by ASTM D4318 to make liquid limit test. These two methods are the one-point liquid limit and multipoint liquid limit. The first method is not quite precise as long it takes one test in consideration and the number of blows should be ranged between 20 and 30. Otherwise, a second method depends on setting up the moisture content to exhibit the required number of blows. Therefore, the second method is more precise than the one-point liquid as long as it depends more than one point for evaluating the liquid limit. Three liquid limit test must be made at least to ensure the required precise. The first test is made with a water content corresponding to a number of bows of 25 to 35 blows. The second test is made with a water content corresponding to a number of 20 to 30 blows and the last one with is done with a water content required to achieve 15 to 25 blows. Multipoint liquid limit method is the method that has been used in this study due to its accurate.

1.1.2. Plastic limit

The ASTM D4318 procedure is strictly followed. Two method can be followed to calculate the plastic limit. First method is made by rolling the soil with hand at sufficient pressure by the palm of hand or the fingers. Second method is the rolling machine method. The first method, hand roll method, has been used in this study.

1.2. Soil preparation

According to ASTM D4318, there are two ways for preparing the specimens, dry preparation method and Wet preparation method. In this paper, dry preparation method will be dependent. Two different drying methods are mentioned in the ASTM D4318, weather temperature drying method and oven drying method. The weather temperature drying method includes that the soil remains in the weather for days until its weight becomes constant with time. On the other hand, the oven drying method consists of placing the soil in the oven at temperature of about 60°C until the soil pulverized easily. After drying, the soil should be pulverized with a rubber hummer to avoid crushing the soil particles. After that, the soil is sieved on sieve No. 40 taking in considerations that pushing the soil particles to make them pass the sieve is forbidden. Two ways are allowed to remove the particle stuck in the sieve opening, brushing the sieve with a brush or washing the sieve, and the first one is dependent in this study. The sample could be divided into two parts, one of them dried in oven and the other exposure to the weather temperature to be dried naturally. The portion of the sample used for the liquid limit test is mixed with different amount of water to achieve the corresponding number of blows. After the liquid limit test is done, small amount of soil, about 20 g could be used for the plastic limit test. The 20 g is used for the plastic limit test after reducing the amount of water in the soil to make it easy to be rolled without sticking in hands. Reducing the amount of water could be done by spreading the soil and remixing it on any surface.

1.3. Classification of soil

The main two systems of soil classification considered in the civil engineering are Unified Soil Classification System (USCS) and Classification of Soils for Highway Construction Purposes. Both of these systems will be discussed in this study.

1.3.1. Unified Soil Classification System (USCS)

The unified soil classification system, ASTM D2487 – 11, was used to classify the soil as this system describes the classification of mineral and organomineral soils for engineering uses. This system is the modified one of the Airfield classification system which is developed by Casgrande at the 1940s. If the precision is in demand while classifying the soil, particle size distribution characteristics and plasticity characteristics, liquid limit and plasticity index, are required. The fine-grained soil, silt and clay, is defined in the ASTM as that portion of soil passing sieve No.200 size (0.075 mm). The difference between clay and silt is that the clay in presence of water shows a respectable strength due to its plasticity characteristics when air-drying. Whilst, the silt has no strength or negligible strength when air-drying. Another difference between the clay and silt is that when drawing the point of intersection between liquid limit and plasticity index of clay on the plasticity chart, that point would be located above the A-line and the plasticity index of clay is greater than 4. Conversely, in case of silt, the point of intersection will be located below the A-line and the plasticity index of soil would be less than 4.

1.3.2. Classification of Soils for Highway Construction Purposes

Classification of soils for highway construction purposes, ASTM D3282 – 09, was used to classify the soil as this system describes the classification of mineral and organomineral soils for engineering uses. This system classifies the soil into two main groups depending on the percent passing sieve No. 200 (0.075 mm). These two groups are granular materials group and silt-clay materials group. The first group, granular material, is divided into 3 groups, A-1, A-3, and A-2. The other group, silt-clay materials group, divides the soil into 4-subaltern groups, A-4, A-5, A-6, and A-7. If the precision is in demand while classifying the soil for highway construction uses, particle size distribution characteristics and plasticity characteristics, liquid limit and plasticity index, are required.

2. **Materials and Soil Testing Method**

All the soil samples in this study were carried out from almost all over Iraq country. The soils have wide-ranging physical properties and initial vision classification, but all soil samples were classified as fine-grained soils. The grain size distribution curves of all the soil samples used in this study are presented in Fig 1.The samples were collected from Baghdad, the capital of Iraq, and cities located at different distances from Baghdad. As the target of this study is evaluating the effect of the liquid and plastic limits on the soil classification, some samples were eliminated because they did not show any plasticity properties, non-plastic soils. As a result, nine soil samples from different cities, Baghdad, Anbar, Karbala, Diwanya, Samawa, Nassirya, Rumaitha, Basrah, and Hillah, were chosen to evaluate their properties in this study.

The weight of each soil sample was 4 Kg. these samples were brought from nine cities and each sample was divided into two parts and prepared as mentioned in the soil preparation section. Each sample divided into two specimens. One of these two specimen was tested based on air-dried method and the other specimen was tested based on the oven-dried method.

All results of the samples were analyzed manually and using a software program to make sure the accuracy of obtained results. The software that so called Soil Tester, which is specialized in analyzing soil tests results was used to analyze the results. The software program interface can be shown in Fig 2. The test procedure that were performed in this study followed the ASTM recommendations, as it has been aforementioned.

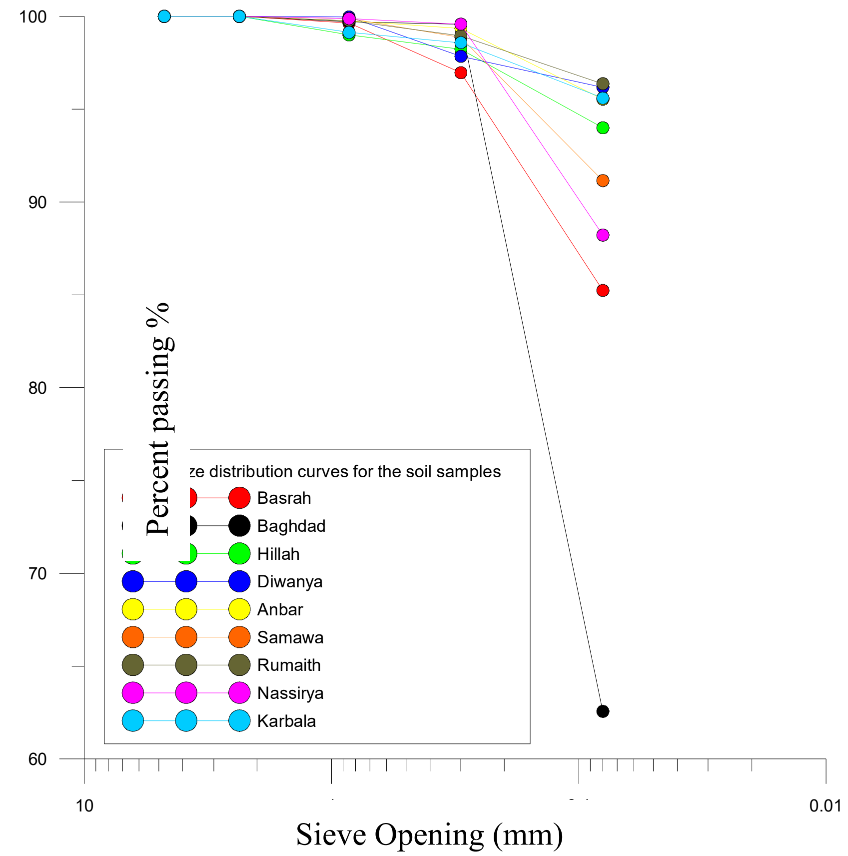

Figure 1: Grain size distribution curves for the soil samples used in this study

Figure 2: soil tester program

3. Results and Analysis

3.1. Analysis of consistency limits for oven-dried and air-dried methods

All the Atterberg's test results were represented in table 1. The results showed that liquid limit of most oven-dried samples is higher than that of air-dried samples. Since, seven oven-dried samples have greater liquid limit and just two have less value of the liquid limit than air-dried samples. On the other hand, there is no Clear preference for the air or oven drying method regarding to the plastic limit results. Four oven-dried samples have greater plastic limit values. Whilst five air-dried samples have greater plastic limit values. All the results are presented in Radar charts to show the difference in the values. Figs. 3 and 4 show the liquid and plastic limit results respectively based on the cities that have been taken from. Figure 3 clarifies how the liquid limit values of oven-dried samples are greater than those of air-dried samples. Whilst Fig 4 clarifies that, there is no clear correlation between plastic limit and the use of specific of the two methods of drying.

Table 1 Liquid and Plastic limit for air and oven dried samples

city	location	Liquid limit		plastic limit	
		oven dry	air dry	oven dry	air dry
Baghdad	Capital of Iraq	26	25	15.81	19.38
Anbar	243 Km south west of Baghdad	51.3	40	35.59	30.13
Hillah	116.8 Km south of Baghdad	34	28	21	23.8
Karbala	102.9 Km south of Baghdad	44.5	45.5	27.33	28.8
Diwanya	192.1 Km south of Baghdad	48	44	24.57	27.54
Samawa	271.3 Km south of Baghdad	38	36.5	28.5	25.51
Nassirya	347.1 Km south of Baghdad	26.8	27.2	22.51	22.7
Rumaitha	248.8 Km south of Baghdad	50	46	28.66	23.74
Basrah	535 Km south of Baghdad	35.2	34.2	30.64	27.64

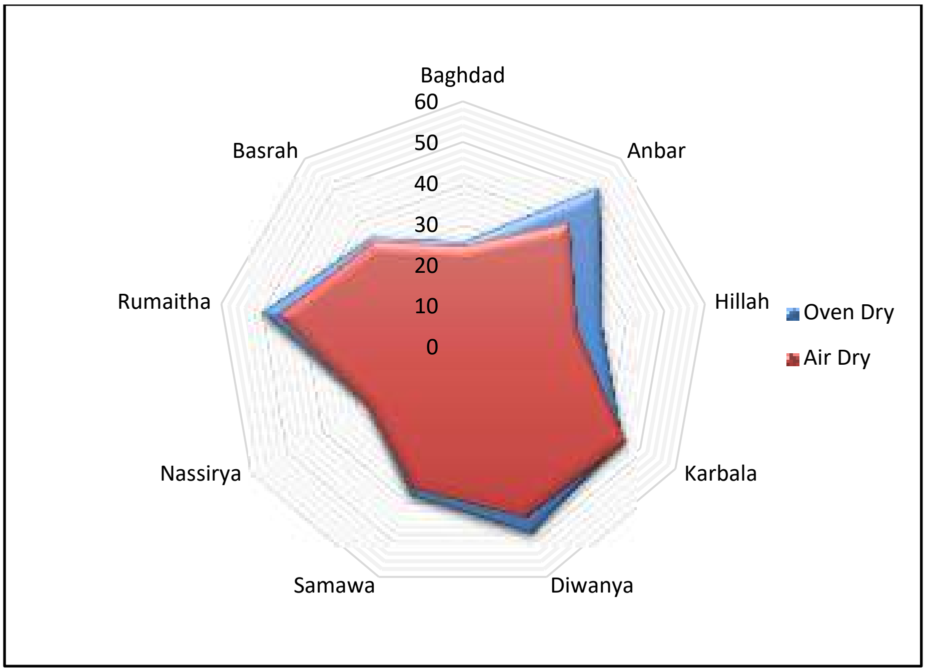

Figure 3 liquid limit comparison of air and oven dried samples

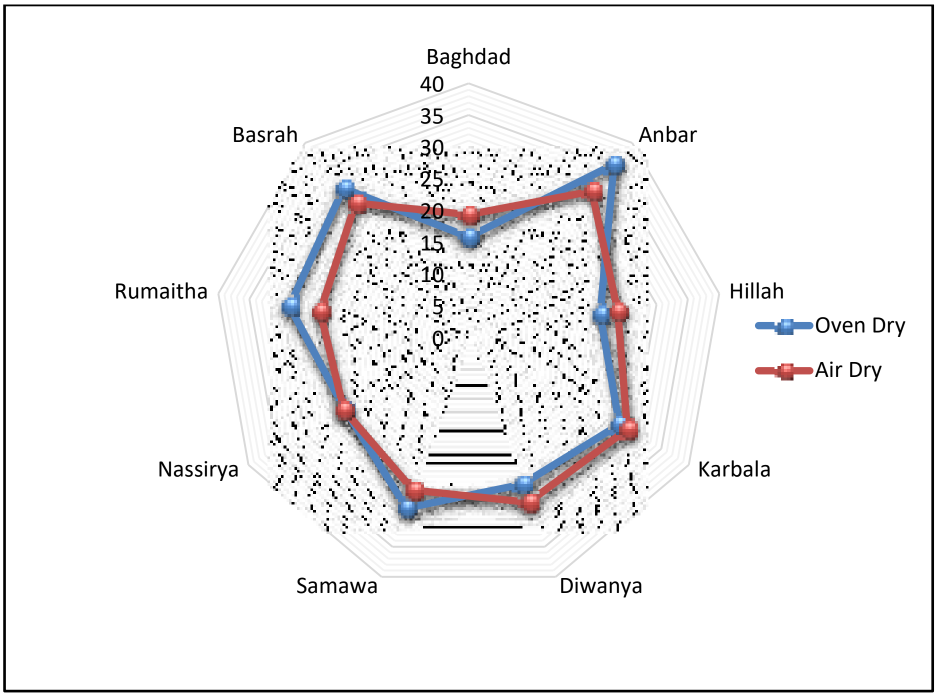

Figure 4 Plastic limit comparison of air and oven dried samples

3.2. The effect of drying method on the soil classification

Soil classification due to unified soil classification system (USCS) and American Association of State Highway and Transportation Officials (AASHTO) system respectively were Presented in table 2 and 3. Four of the samples exhibited similar classifications either oven-dried or air-dried. For example, the soil of Karbala, Diwanya, Samawa, and Nassirya were classified as CL, CL, CL, and CL-ML respectively for both methods of drying.

However, five samples showed different classifications due to the method of drying. For instance, Baghdad, Anbar, Rumaitha, Basrah, and Hillah have been classified as CL, MH, CH, ML, and CL, respectively if oven was used to dry the soils. On the other hand, these samples have been classified as CL-ML, CL, CL, CL-ML, and ML, respectively if the samples were exposed to weather temperature and dried naturally. Now it could be said that replacing the air-drying method with oven-drying method to speed up the drying process would give different classification results.

The classification results of the nine samples according to AASHTO classification system for both methods of drying were represented in Table 3. The results showed that five of nine of samples have got different groups when dried by different methods. For example, Baghdad, Anbar, Karbala, Samawa, and Hillah have been classified under the groups A-6, A-7-5, A-7-6, A-4, and A-6 respectively when samples were dried using oven. Whilst these samples have been classified as A-4, A-4, A-7-5, A-6, and A-4 respectively when the soils samples were dried naturally. These results confirm that there is no possibility to replace the natural drying method by weather temperature with the oven drying method without changing in the classification accuracy. Both the two ways of classification, USCS and AASHTO, exhibited a match in the classification groups regarding the two drying methods.

On the contrary, there is no any effect of the method of drying on the value of group index GI, but this is not a significant point to be focused on, as the group index is just a number to modify the classification obtained from the procedure specified by ASTM D3282 – 09**.** The group index in a number gives a prediction whether the soil is suitable to be used as a highway subgrade or not, Das 2013. Table 4 represents the values of the group index for all soil samples for both methods of drying. While table 5 clarifies how these numbers, classify the soil as a highway subgrade material.

Table 2 Classifying the sample due to USCS

city	percent finer sieve # 4	percent finer sieve # 200	Oven Dry				Air Dry			
			L.L	P.L	P.I	USCS	L.L	P.L	P.I	USCS
Baghdad	100	62.56	26	15.81	10.19	Sandy Lean Clay CL	25	19.38	5.62	Sandy Silty Clay CL-ML
Anbar	100	95.54	51.3	35.59	15.71	Elastic Silt MH	40	30.13	9.87	Lean Clay CL
Karbala	100	95.6	44.5	27.33	17.17	Lean Clay CL	45.5	28.8	16.7	Lean Clay CL
Diwanya	100	96.2	48	24.57	23.43	Lean Clay CL	44	27.54	16.46	Lean Clay CL
Samawa	100	91.15	38	28.5	9.5	Lean Clay CL	36.5	25.51	10.99	Lean Clay CL
Nassirya	100	88.22	26.8	22.51	4.29	Silty Clay CL-ML	27.2	22.7	4.5	Silty Clay CL-ML
Rumaitha	100	96.37	50	28.66	21.34	Fat Clay CH	46	23.74	22.26	Lean Clay CL
Basrah	100	85	35.2	31.64	3.56	Silt with Sand ML	34.2	27.64	6.56	Silty Clay with Sand CL-ML
Hillah	100	94	34	21	13	Lean Clay CL	28	24.1	3.9	Silt ML

Table 3 Classifying the sample due to AASHTO

city	percent finer sieve # 10	percent finer sieve # 40	percent finer sieve # 200	Oven Dry				Air Dry			
				L.L	P.L	P.I	AASHTO	L.L	P.L	P.I	AASHTO
Baghdad	100	99.57	62.56	26	15.81	10.19	A-6	25	19.38	5.62	A-4
Anbar	100	99.35	95.54	51.3	35.59	15.71	A-7-5	40	30.13	9.87	A-4
Karbala	100	98.59	95.6	44.5	27.33	17.17	A-7-6	45.5	28.8	16.7	A-7-5
Diwanya	100	97.8	96.2	48	24.57	23.43	A-7-5	44	27.54	16.46	A-7-5
Samawa	100	98.86	91.15	38	28.5	9.5	A-4	36.5	25.51	10.99	A-6
Nassirya	100	99.59	88.22	26.8	22.51	4.29	A-4	27.2	22.7	4.5	A-4
Rumaitha	100	98.96	96.37	50	28.66	21.34	A-7-5	46	23.74	22.26	A-7-5
Basrah	100	96.97	85.23	35.2	30.64	4.56	A-4	34.2	27.64	6.56	A-4
Hillah	100	98.24	94	34	21	13	A-6	28	23.8	4.2	A-4

Table 4 Group Index (GI) values for all soil samples

city	Oven Dry		Air Dry	
	G.I	Subgrade Value	G.I	Subgrade Value
Baghdad	5.588	Poor	5.512	Poor
Anbar	12.544	V. Poor	8	V. Poor
Karbala	11.768	V. Poor	11.78	V. Poor
Diwanya	14.972	V. Poor	11.384	V. Poor
Samawa	8	Poor	8.396	Poor
Nassirya	8	Poor	8	Poor
Rumaitha	14.536	V. Poor	14.104	V. Poor
Basrah	8	Poor	8	Poor
Hillah	9.2	Poor	8	Poor

Table 5 Group Index and subgrade values

Group Index (GI)	0	0-1	2-4	5-9	10-20
Subgrade value	Excellent	good	fair	poor	v.poor

4. Conclusion

Liquid and plastic limit tests were conducted on nine fine-grained soils collected from nine Iraqi cities. The aim of the study is to evaluate how the method of drying, oven and air-drying methods, could affect the liquid and plastic limit and then the classification of soil. Depending on the results and the analysis of these tests, it can be concluded:

a) Soil classification systems, USCS and AASHTO, of fine-grained soils depends entirely on liquid limit, plastic limit, plasticity index, and grins size in addition to the group index which is consider as a modification factor for AASHTO classification system.

b) The results showed that liquid limit of most oven-dried samples is higher than that of air-dried samples. Since, seven oven-dried samples have greater liquid limit and just two have less values of the liquid limit than air-dried samples.

c) There is no Clear effect of the drying method on the plastic limit results. Since, four oven-dried, samples have greater plastic limit values. Whilst five air-dried samples have greater plastic limit values.
d) Four of the samples exhibit similar classifications due to USCS either oven-dried or air-dried. For example, the soil of Karbala, Diwanya, Samawa, and Nassirya are classified as CL, CL, CL, and CL-ML respectively for both methods of drying. Whilst five samples show different classifications respect to the method of drying.
e) The results show that five of nine of samples have different groups when classified due to AASHTO classification system regarding to the method of drying and the other four samples get same classification groups whether oven or air-dried.
f) Both USCS and AASHTO exhibit a match in the classification groups regarding the two drying method with a possibility of less than 45%. Whilst 55% possibility show mismatch between the classification when air-drying method is used and that of oven drying method.
g) There is no any effect of the method of drying on the value of group index GI, but this is not a significant point to be focused on, as the group index is just a number to modify the classification obtained from the procedure specified by ASTM D3282 – 09.
h) It is elicited that replacing the air-drying method with oven-drying method to speed up the drying process if strictly forbidden.

5. References

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2. ASTM D2216-10 *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*

3. *ASTM D2487-11 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

4. *ASTM D2488-09a Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)*

5. *ASTM D3282-09 Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*

6. *ASTM D4318-10 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

7. *ASTM D6913-04 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*

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