Journal of Ferdowsi Civil Engineering, Vol.34, No.2, 2021.

Economic and Durability Optimization of Asphalt Pavement with Cement Stabilized Base Mixtures Ardakan-Naeen case study

Mostafa Adresi[1]

1. Introduction

One of the most important issues for road engineers is finding the proper properties for the stabilized layer containing reclaimed asphalt pavement (RAP) in the process of pavement structural design. Finding the optimum answer for the pavement layers thickness design treated by different binders (cement, bitumen, or emulsion) with or without RAP materials is the important step in pavement economical design. To have the most economical performance in process of pavement design, choosing the right percentage of RAP and different binders in the mixture for soil treatment are two critical points that should be considered. First, will decrease the cost of implementing while the second will increase the structural strength that will help to decrease the thickness of the pavement layers.

One of the most important applications of RAP is its use in the base layer, which can significantly reduce the use of natural materials amounts, the price of materials used, their transport fee. In addition, due to the thin layer of bitumen around RAP, the internal bonding with natural aggregates occurs and increases the structural performance of stabilized layer that helps to decrease the layer thickness.

Strength characteristics of cement-stabilized base layer are the effective factors in pavement thickness design layers. The compressive and tensile strength of the mixtures are the most common when strength characteristics are considered. In addition the structural performance, the mixture should be satisfied the durability threshold.

The allowable range of unconfined compressive strength between 300 and 500 psi has been proposed among different authorities. A maximum of 500 psi has been set to control the rigidity of the stabilized layer, prevent cracking in the stabilized layer and reduce the risk of reflective cracking in the surface layer.

According to the Institute for Asphalt Recycling and Reclaiming Association (ARRA), the minimum TSR for cold recycled asphalt mixtures (CRAM) should be 0.70, however, it may be reduced to 0.60. ARRA also stated that the minimum of the indirect tensile strength (ITS) for CRAM at 25 °C should be 310 KPa.

According to previous studies, the allowable threshold for unconfined compressive strength is considered as an acceptance criterion in pavement structural design. The point to be noted here is the limited studies that examine the issue of durability and its impact on the mixing design and determine the optimal amount of RAP and cement binder when the stabilized layer is considered. The innovation of this research is determining the percentage of RAP and optimal cement binder in the cement-stabilized base mixtures under a wide range of traffic loading, taking into account the two perspectives of durability and whole pavement construction cost simultaneously.

2. Experimental program

In this research, compressive and tensile strength was obtained in different percentages of RAP, including 0%, 40%, 60%, and 80%, and indifferent percentages of cement, including 3%, 5%, and 7%. The structural design of the pavement was further determined under 10, 20, 35, and 50 million ESALs. By establishing the relationship between the percentages of RAP, percentage of cement, and moisture sensitivity index (TSR) as an effective parameter in durability, and the cost of paving at different loads, a simultaneous cost-durability equation of pavement was formed. Finally, based on the optimization technique, the optimal percentage of RAP and cement for achieving the expected durability (TSR = 70) was determined.

3. Results and discussion

Based on the results of the laboratory phase, a suitable relationship between the unconfined compressive strength of cement stabilized base containing the RAP can be obtained related to these two variations as presented in equation (1).

$$\mathrm{UCS} = 4.350 - 0.062 * \mathrm{Rap} + 0.583 * \mathrm{Cement} \tag{1}$$

Using equation (1) and the relationship presented by Van Teel equation, the resilience modulus and the layers structural coefficients related to the cement-stabilized base containing different amounts of RAP, can be calculated, and finally, the thickness design under different loading levels achieved.

Considering the results of indirect tensile strength tests in dry and wet conditions and determining the TSR parameter, the durability equation can be obtained as described in equation (2).

$$\mathrm{TSR} = 47.49 - 1.116 * \mathrm{Cement}^2 + 0.0033 * \mathrm{Rap}^2 + 13.029 * \mathrm{Cement} - 0.769 * \mathrm{RAP} + 0.061 * \mathrm{RAP} * \mathrm{Cement} \tag{2}$$

In the above equation, TSR is defined as a durability criterion (i.e., 70), "Cement" is the percentage of cement in the stabilized mixture and, "Rap" is the percentage of RAP.

Considering the durability threshold equal to TSR=70 and plotting the durability number of different mixtures in Figure 1, only the codes R3, R5, R7, R407, R405, R607, R607, and R807 meet the durability criteria.

[1]. Assistant Professor, Civil Engineering Department of Shahid Rajaee Teacher Training University. Email: m.adresi@sru.ac.ir

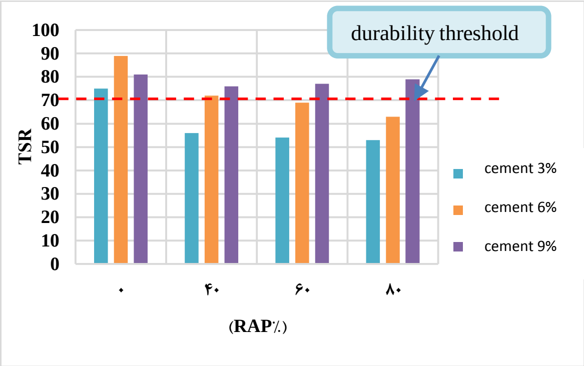

Figure 1. Qualified mixtures in terms of durability

The cost of pavement construction is model based on pavement thicknesses (calculated based on different materials properties and level of traffic loads), and some field assumptions (i.e. transport distance, etc.) according to Iran price list code for the road, railway, and airport runway and presented in equation 3.

$$Costs = 34267.74 + 1.098 * RAP^2 - 201.00 * Rap + 33.793 * RAP * Cement - 1078.61 * Cement + 191.454 * ESALs \quad (3)$$

As shown in Equation 4, the minimum answer for the cost model is solved subject to the present conditions.

$$Costs = 34267.74 + 1.098 * RAP^2 - 201.00 * Rap + 33.793 * RAP * Cement - 1078.61 * Cement + 191.454 * ESALs$$

$$TSR = 47.49 - 1.116 * Cement^2 + 0.0033 * Rap^2 + 13.029 * Cement - 0.769 * RAP + 0.061 * RAP * Cement$$

$$100 \geq TSR \geq 50 \quad (4)$$

3≤Cement≤7
0≤RAP≤80
10E6≤ESALs≤50E6

In this regard, the minimum acceptable TSR is 70 and the maximum is 100. In addition, other added conditions are the limits of changes in RAP materials, cement, and loading. In this study, Excel Solver was used to optimize the cost Equation. In order to extract all possible answers, the range of TSR was considered larger than the recommended limits (100≥TSR≥70). The minimum cost of the pavement construction based on TSR range 50 <= TSR <= 100, is shown in Table 1.

Table 1. Minimum cost model response

TSR	RAP	Cement	cost
55	51.93	3	30,734.21
60	38.93	3.14	30,767.75
65	34.33	3.60	30,869.88
70	29.60	4.15	30,869.07
75	24.89	4.93	30,687.91
80	15.88	6.27	29,868.37
85	0	6.51	29,151.53

In this case, there is no optimal point cost for TSR smaller than 55 and larger than 85 functions. According to Table 1, by reducing the TSR limit, more RAP and less cement can be used for the construction of pavement layers with cement stabilized base layer containing RAP. It should be noted that the trend of changes in the minimum response of the cost model is not linear and has a maximum with a quadratic power at TSR = 65.

4. Conclusion

The results of this study can be used in the design of durable and economical pavement structures Contains a stabilized base with cement and various amounts of RAP. In this regard the main result is presented below:

The optimum cost, which is a function of the loading level, was obtained in the amount of 29.6% of RAP, 4.16% of cement, and in the minimum loading level.