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Original article

# Optimization of equivalent modulus of RAP-geopolymer-soil mixtures using response surface methodology

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ABSTRACT

This study focuses on assessing the resilient characteristics of a clayey soil modified with a fly ash (FA)-based geopolymer and reclaimed asphalt pavement (RAP) as an unpaved road material. RAP-geopolymer-soil mixtures were designed using the response surface methodology-central composite design with 0–40% RAP and 0–25% FA. The repeated-load California bearing ratio (CBR) testing method was used to determine the recoverable and permanent deformations and then obtain the equivalent (resilient) modulus ($M_{equ}$). The $M_{equ}$ values were used to develop predictive models and determine the optimum soil–RAP–geopolymer mixture. The effects of the load level and soaking period on the stiffness of the optimum mixture were also investigated. The results revealed that the geopolymer binder played a significant role in enhancing the stiffness of the mixtures, with the maximum $M_{equ}$ obtained at 25% FA and 0% RAP. However, it was determined that RAP has an adverse effect on the stiffness for almost all the studied cases and more significantly for the 40% RAP and 0% FA mixture. The optimal mixture was found to be 25% FA and 30% RAP. The developed model exhibited excellent predictive capability based on ANOVA results. The optimum mixture exhibited stress-softening behavior at an increased load level. No clear trend was observed in the effect of the soaking period on the resilient modulus within the examined soaking period range. Overall, this study agrees with several pavement design guidelines to limit the RAP content used in road applications owing to uncertain adequacy. Additionally, it suggests that the geopolymer binder is an effective stabilizer with excellent environmental and economic potential.


## 1. Introduction

The world is currently competing to apply sustainable development concepts, including sustainable transportation, to address climate change and natural resource depletion challenges. A key aspect of sustainable transportation is the optimization of natural resource usage and the reduction of environmentally harmful emissions. Therefore, construction and demolition waste and industrial byproducts are gaining increased attention in the field of pavement research and technology. Reclaimed asphalt pavement (RAP) is a road rehabilitation/reconstruction waste material that can yield economic and environmental benefits. It is generated by crushing old pavements to a given depth, which are further milled (if necessary), screened, and reused in pavement layer construction (FHWA, 2011; Mamlouk and Zaniewski, 1998). RAP has been assessed as a pavement material for base, subbase, and subgrade layers (Avirneni and Peddinti, 2017; Hasan et al., 2018; Taha et al., 1998). The effects of RAP inclusion on the resilient modulus are conflicting. The stiffness of RAP may be higher, equivalent, or lower than that of virgin aggregate depending on several factors, such as RAP age and quality, moisture content, dry density during testing, and the content of asphalt binder that coats RAP grains (Bozyurt et al., 2012; Mokwa et al., 2006; Song and Ooi, 2010).

Studies have found that a higher percentage of RAP replacement results in poorer mechanical properties (e.g., California bearing ratio (CBR) and unconfined compressive strength (UCS)) (Puppala et al., 2011; Saride et al., 2016; Taha et al., 1998). Therefore, the

*Abbreviations:* OMC, Optimum moisture content; MDU, Maximum dry unit weight; $M_{equ}$, Equivalent modulus; CPD, Cumulative permanent deformation; RL-CBR, Repeated load CBR; RSM, Response surface methodology; CCD, Central composite design.

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