Construction and Building Materials 158 (2018) 873–882

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Artificial neural networks approach to predicting rut depth of asphalt concrete by using of visco-elastic parameters

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HIGHLIGHTS

- Proposed ANN model for rut depth has shown good agreement with experimental data.
- Proposed model is able to predict rut depth with an acceptable degree of accuracy.
- Proposed ANN model is valid for the ranges of the experimental database.
- Based on the results, the proposed model shows less sensitivity to loading time.
- Proposed model can estimate rut depth of asphalt based on effective parameters.

ARTICLE INFO

Article history:
Received 10 May 2017
Received in revised form 7 October 2017
Accepted 19 October 2017
Available online 5 November 2017

Keywords:
Asphalt concrete
Visco-elastic parameters
Artificial neural network
Rutting depth
Dynamic creep

ABSTRACT

Performing comprehensive research on the functional behavior of asphalt pavements under the influence of various environmental and structural parameters can better assist the engineers in the design and maintenance of asphalt pavements. Using a solution that can reduce the cost and time of assessment is very important. Using artificial neural networks in many facilitates operations on data engineering sciences. It is necessary to ensure that a comprehensive study is performed through considering all or most of the parameters affecting the behavior. The aim of this study is to provide an experimental model to estimate the rut depth of asphalt concrete by using viscoelastic parameters and artificial neural networks. Accordingly the asphalt concrete specimens containing 3, 5 and 7 percent void with two types of limestone and siliceous aggregates and PG64-22 and PG58-28 bitumens were made and exposed to dynamic creep tests under 50–60 °C and the stress range of 100–300 kPa. Then the viscoelastic parameters of asphalt specimens were extracted from the creep diagrams and eventually the asphalt concrete's rut depth prediction model was trained and provided by artificial neural network. Comparing the output results with the experimental test results show that by using this model it is possible to estimate the creep behavior and rut depth of asphalt concrete pavements based on the effective parameters without the need for costly and time-consuming tests.

1. Introduction

1.1. Rutting in asphalt pavement

Permanent deformation depends on the axial load, the number of repeated loadings, environmental temperature, bitumen type, amount of bitumen, aggregate material, aggregate form and grade, stone material angularity and surface texture and the internal space of the mixture [1,2]. Aging is another effective factor on rutting [2]. Among all the effective parameters, mixture temperature, tire pressure and aging are considered as the main parameters affecting permanent deformation [3]. Increased rutting causes problems such as hydroplaning, freezing accumulated waters in the cold and make the vehicles out of control. Since the ruts formed on the pavement surface make the surface impermeable, with accumulation of water or snow in the ruts, the travel safety is reduced and road hazards are increased [4]. So rutting not only raises the cost of repair and maintenance of roads but also puts human lives at risk due to accidents caused by water accumulation in the ruts [5,6]. Xiao et al. (2015) studied rut resistance in a mixture of aggregates with low Los Angeles wear and compared it with three mixtures with high wear stone materials on the basis of three grain size (coarse, fine and South Carolina Department of Transportation (SCDOT) specifications). The rut resistance of the mixtures was examined by the wear mix recorded by the Asphalt

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https://doi.org/10.1016/j.conbuildmat.2017.10.088
0950-0618/

Pavement Analyzer (APA). The results showed that the aggregates' grading has a significant effect on rut resistance of Open-Graded Friction Course (OGFC) mixtures [7]. Golalipour et al. (2012) examined the effect of aggregate gradation on hot asphalt mixtures' rutting. To investigate the effect of aggregate gradation on rutting, dynamic creep test was done in accordance with British Standard (BS DD226) and using UTM14P with axial stress 100 ± 2 kPa at 1800 loading cycles and unloading on the compacted specimens. The results showed that mixtures with high level grading include minimum permanent deformation and mixtures with low level grading include maximum permanent deformation [8]. Dong Wang et al. (2013) analyzed the performance of three SMA mixtures prepared by wood, basalt and polyester fibers using the wheel track and Marshall Tests. Four marshal specimens were prepared for each fiber and they were placed in a water bath at 60, 65, 70 and 75 °C for 30–45 min. The results showed that by increasing temperature, the Marshall strength and dynamic strength of all three types of SMA mixtures are reduced but the mixture prepared by basalt fibers showed the best performance at high temperatures [9]. Lu et al. (2015) examined Open Gradation Porous Asphalt (OGPA) mixture in which epoxy bitumen was used. The results showed that the use of tar epoxy bitumen in open gradation porous asphalt mixtures improved pavement performance including sound absorption, resistance to damage, moisture, surface friction at high speeds, resistance to premature failure due to combined moisture and load traffic and resistance to rutting and crack reflection [10].

1.2. Viscoelastic behavior of asphalt concrete

Unlike pure elastic materials, a viscoelastic material has an elastic component and a viscous component. Pure elastic materials do not dissipate energy but the energy is dissipated in viscoelastic materials. In general, materials the change of which are reversible in a short time and are dependent on time are called the viscoelastic materials.

$$\varepsilon^{ve} = \varepsilon^{e} + \varepsilon^{c}. \tag{1}$$

The loading and unloading stages in the stress-strain curves are based on Fig. 1, in which the immediate strain $\varepsilon^{e} = \varepsilon_0$ is created in the specimen after loading that the amount of strain is increased over time and if unloading is performed in this short period of time (AB), the immediate strain is removed and then all deformation in the specimens reaches the zero level. In fact, in this part of the curve a time-based elastic behavior i.e. viscoelastic behavior is caused that no permanent material deformation remains in this part of the curve after unloading. So this part of the curve (AB) is called damping creep region. It should be noted that a gradual increase in strain on a constant stress represents creep. Over the time and increasing strain such that the increasing strain rate over time becomes linear (BC) a steady-state creep is created that immediately after unloading the immediate strain disappears and the amount of strain is reduced over time. But the total existing strain will not be zero. Generally the material behavior in the first two creep regions consists of three reversible parts of linear elastic, retarded elastic and viscoelastic. As a viscous material in the loading cycle dissipates the energy, according to this energy dissipation the plastic deformation occurs.

The most practical mechanical models for viscoelastic materials include:

- Maxwell Model: series connection (consecutive) of the spring and oil (damper) containing piston
- Kelvin Model: Parallel connection of the spring and damper
- Burgers Model: A combination of Maxwell and Kelvin models

Burgers model is a combination of Maxwell and Kelvin models connected in series mode and are exposed to the constant stress, so:

$$\varepsilon(t) = \sigma_0 \left[\frac{1}{E_1} + \frac{t}{\eta_1} + \frac{1}{E_2}\left(1 - \exp\left(-\frac{E_2}{\eta_2}t\right)\right)\right] \tag{2}$$

where E_1 and E_2 are Young's moduli and η_1 and η_2 are the viscosities [11]. This model shows the behavior of viscoelastic materials.

When analyzing asphalt mix permanent deformation, all non-recoverable components must be included, particularly viscous deformation. The plastic strain can normally be divided into three phases [12,13]:

1. In the primary stage the strain rate decreases. The additional permanent deformation caused by applied load is decreasing with the number of load applications. It is mainly associated with volumetric change;
2. In the second stage the strain rate is constant. It is also associated with volumetric change; and
3. In the third stage the strain rate is increasing until failure occurs. It is associated with plastic deformation under no volume change.

Creep function's parameters in Burgers mechanical model are shown in Fig. 2. Based on previous studies by other researchers [14–16], the Burger model shows a very good performance in the prediction of permanent deformation of materials within the range of the first two (out of three) characteristic stages of creeping (Fig. 2). So, it will be utilized and subjected to the analysis in a further part of this work. This model is termed as mechanical model for creep. Such model is particularly attractive, similarly as other mechanical models in the analysis of creep phenomena, because its parameters can be identified with the characteristic periods of creep [14].

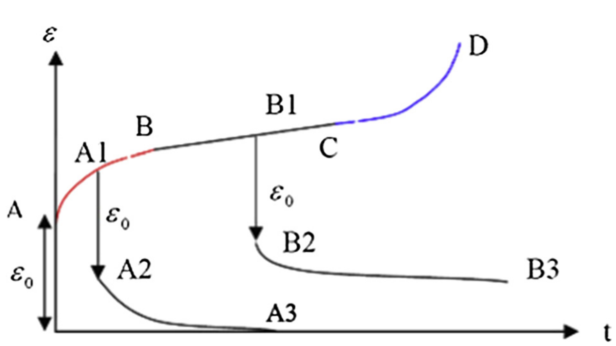

Fig. 1. The loading and unloading stages in the stress-strain curves.

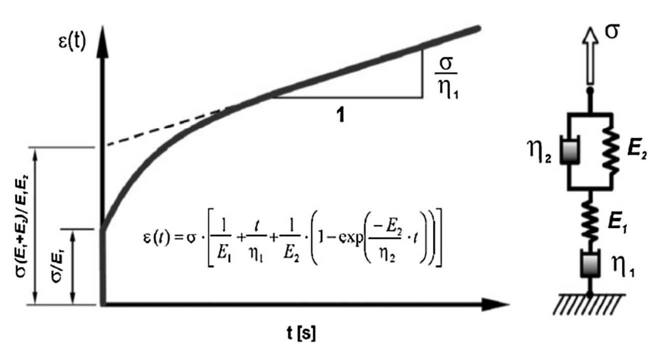

Fig. 2. Creep function's parameters in Burgers mechanical model [14,16].