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Adaptive quality control and acceptance of pavement material density for intelligent road construction

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ABSTRACT

During conventional road construction, quality control and acceptance (QC/QA) are based on limited spot tests of material density at random locations which may not be representative of the compacted area and may consist of potential bias. This research presented an innovative material-machine-information and human-decision integrated system for adaptive QC/QA using the intelligent compaction (IC) technology to overcome the above limitation of conventional testing. In this integrated system, compaction properties such as material stiffness are monitored in real time with 100% coverage of compacted areas by instrumented IC rollers. By monitoring compaction process and roller–ground interactions, this system can be used to determine compaction target values, which are in-turn fed back to the IC system to optimize compaction efforts and improve construction quality. This approach can also be used to determine compaction uniformity for the as-built in order to assess pavement performance. Recommended further development of the intelligent road construction technology is presented to fully leverage the IC technologies in the future.

1. Introduction

During road construction, compaction is the last and also the most important step in achieving proper material stiffness, strength, and density to sustain designed traffic loading and environmental effects. The type of power used to compact material has evolved from animal force, to steam, and then to gasoline and diesel as shown in Fig. 1. With the development of steam engine technology in the 1800s, the steamroller that used smokestack [2] (see Fig. 1b) was invented. France's L. Lemoine, and Britain's W. Clark and W.F. Batho demonstrated the uses of early steamrollers in 1860 and 1873, respectively [2]. In the 20th century, the gasoline and diesel-powered rollers gradually replaced steam-powered rollers. Today, modern rollers with advanced mechanical controls are used (see Fig. 1c). Modern rollers may also use an electronically-controlled system. Integrated rollers—with mechatronic instruments including the accelerometers mounted on the roller axle (see Fig. 1d) measuring material properties via roller–ground interaction—are termed as "intelligent" rollers. The first intelligent compaction (IC) systems were implemented in Europe and Japan more than two decades ago [3]. However, IC was not introduced to the US until the 2000s [3]. From 2007 to 2014, the Federal Highway Administration (FHWA) carried out extensive research efforts to advance the IC technology by working with consultants, roller manufacturers, States department transportation of and paving contractors [3,4]. As part of the investigation results, FHWA has defined IC "modern vibratory rollers equipped with an integrated measurement system, an onboard computer reporting system, Global Positioning System (GPS) based mapping, and optional feedback control" [3]. IC also includes infrared thermal sensor to measure temperatures for asphalt compaction (see Fig. 1d).

Fig. 2 illustrates an IC operation on an airport, where the satellite navigation system with GPS base station is instrumented to provide the real-time dynamic (RTK) GPS information with a precision of 2 cm. The on-board computer system records and plots the real-time material stiffness in a color-coded map with 100% coverage of the compaction zone. Here it shall be noted that the concept of intelligence can be broad in the construction industry as it has been defined to improve the efficiency, quality and safety. This includes the intelligent navigation strategies [6], autonomous systems using the artificial intelligence [7], the instrumented roller compaction system [8], the automatic object recognition and rapid surface modeling method for heavy equipment operation [9], and so on.

As compared to the steam and other older rollers, modern rollers (including both the conventional and intelligent ones) are vibratory ones that use the eccentrics (additional mass mounted on the roller) to induce additional dynamic force. Fig. 2b presents three vibratory models: a) the rotating exciter model where a single eccentric is used for the conventional roller; b) the oscillation exciter in which two eccentrics rotate in the same direction with a constant angle between, resulting in higher shear forces than case a) and c) the director exciter which uses two eccentrics to rotate in opposite directions when the

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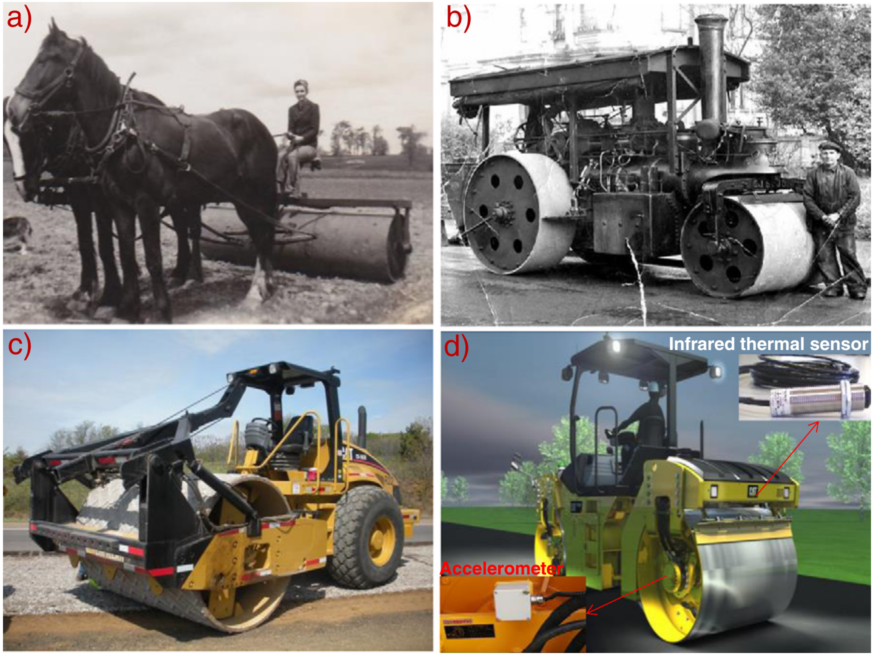

Fig. 1. a) A horse-drawn roller in early 19th century [1], b) steamroller with smokestack [5], c) modern conventional roller and d) IC roller with accelerometer and infrared thermal sensors.

angle between the two eccentrics varies with time. IC rollers usually use either the oscillation or director exciters. The director exciter produces the maximum compression force when the two eccentrics are at opposite positions, which optimize the construction efforts and efficiency. The eccentrics produce vibration forces in the following equilibriums:

$$F = m\omega^2 r \tag{1}$$

$$F_x = m\omega^2 rCos(\phi) \tag{2}$$

$$F_y = m\omega^2 rSin(\phi) \tag{3}$$

where F, F_x, and F_y are the total vibration force, and that in the x (shear) and y (compression) directions, respectively; m is the eccentric mass; r is the radius of eccentrics; ω is frequency and ϕ is the angle.

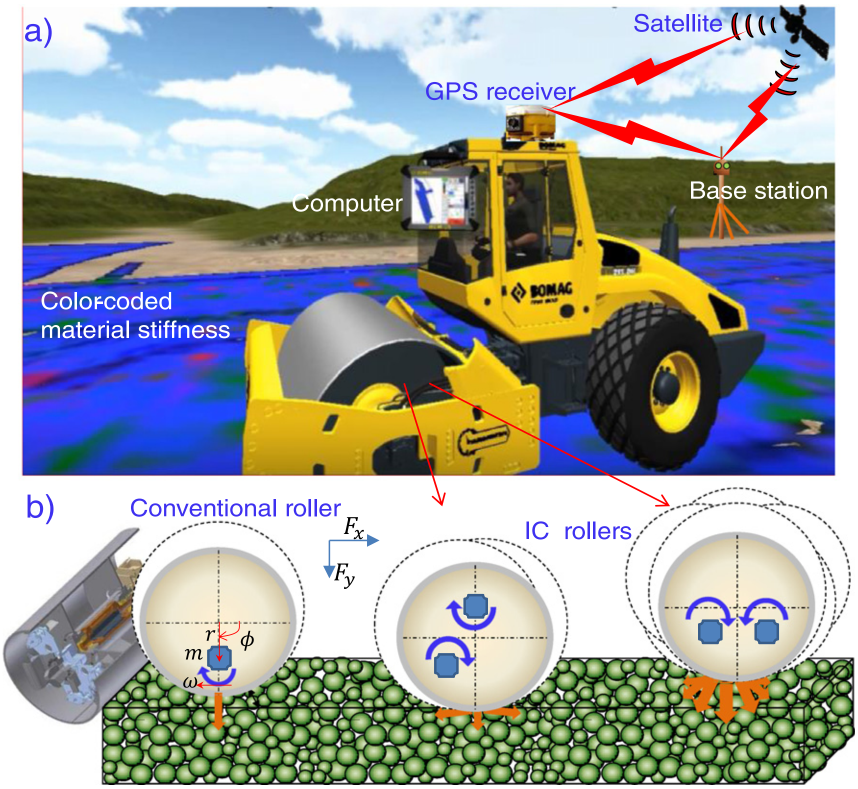

Fig. 2. Intelligent compaction: a) IC roller (modified from Bomag); b) roller vibration modes.