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Analysis of landfill design variables based on scientific computing

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ABSTRACT

The optimal design of waste landfills is a complex, still unsolved issue. Each design variable influences the rest and it is difficult to quantify their interactions. Recent advances in scientific computing, however, allow this problem to be approached from a new perspective.

Thus, in this paper a new method is proposed for the analysis and optimization of design variables in waste landfills. This method is based on the computer simulation of multiple models and the systematic analysis of the resulting data to extract knowledge. It can be extended to the optimization of other complex systems with a direct impact on the environment.

Its efficacy is tested by studying the effect of five common design variables on landfill hydrology. The main results show the benefits of temporary surface lining and intermediate covers on the volume of leachate generated. Intermediate covers, however, may jeopardize landfill stability and significantly affect the variability of the leachate flow.

The case studied demonstrates the usefulness of the proposed method to improve the design and operation of waste landfills. It also shows the need to analyse multiple scenarios in order to generalize the conclusions obtained.

1. Introduction

Landfill disposal is the last but inevitable step in solid waste management (Dajić et al., 2016). A significant amount of waste is still disposed of in landfills. For instance, in the European Union, most of the member states dispose of more than 50% of their waste in landfills (EEA, 2013). In the United States, 50% of the total waste generated is also disposed of in landfills (USEPA, 2015). Solid waste landfills are engineering construction works under continuous development. They are facilities which, by nature, produce several impacts on the environment, such as land use or generation of liquid and gaseous contaminants (Slack et al., 2005). They can also have positive effects, such as power generation from the methane gas produced in them.

The negative environmental impact of landfills can be reduced by applying protection technologies in landfill design, such as the use of an appropriate impermeable material for bottom and top capping. The most important technical elements in the design of a landfill are details concerning the requirements and recommendations for water and soil protection (Dajić et al., 2016).

The optimal design of waste landfills is a complex, still unsolved issue. In the design process and operation of a landfill, several variables must be defined, including the height of the landfill layer, the thickness of the intermediate cover between layers (if one is present) and the material used, the waste compaction level or the leachate extraction systems. This paper refers to such variables as "design variables".

The main processes occurring in landfills (hydrology, degradation, settlement) are closely linked to each other. Each design variable influences all the rest of them and, therefore, it is difficult to take all these interactions into account in order to optimize the overall landfill design. For example, if the intention is to exploit the landfill volume as much as possible, the height of the waste layer can be increased in order to reduce the space taken up by the intermediate covers. However, the consequences of this change on power generation or on the amount of pollution emitted should be investigated. Furthermore, boundary conditions such as the weather or the type of waste generated in a specific community affect these interactions, thus preventing the design criteria from being generally applicable in any geographical location.

Various works have analysed some of these design variables from an empirical point of view through laboratory tests (Ko et al., 2016; Ng et al., 2016; Reddy et al., 2011) and also from scale models (Albright et al., 2012; Andreas et al., 2014; Apiwantragoon

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et al., 2015). Although some interesting results have been obtained, various authors have highlighted the difficulty involved in attempting to extrapolate the laboratory results directly to reality (Dajić et al., 2016). Additionally, full-scale pilot cells have been built and monitored to obtain data which allow the analysis of the influence of the design variables (Mijares and Khire, 2012; Saravanathiiban and Khire, 2014). In this case the results have been satisfactory, but they have entailed enormous economic costs and require great amount of time. Besides, the full-scale tests are carried out for a particular case (with a given value for the design variables), in a certain geographical context and over a specific period of time (usually several years). Although nowadays, in the information society, it is possible to share, compare and integrate these experiences, it continues to be an expensive and cumbersome work method.

Scientific computing allows a large number of scenarios to be evaluated and analysed in a faster, cheaper and more secure way than with the traditional methods of prototyping and experimentation (Denning, 2000). Over the last few years various authors have proposed mathematical models which make it possible to achieve approximate descriptions of the processes involved in landfills. Such proposals include hydrological models such as HELP (Berger, 2015), degradation models (Gawande et al., 2010; Robqeck et al., 2011; Sanchez et al., 2010), biogas generation models, (Kamalan et al., 2011) and settlement models (Babu, 2010). Moreover, a number of different applications use these models to calculate certain processes, although very few of them make an integrated calculation of every process in full-scale landfills and over the course of time. With this aim, some authors have worked on the development of general-use software which adds hydrological, degradation and settlement models, for example: Hydro-Bio-Mechanical model (HBM) (McDougall, 2007), Landfill Degradation and Transport processes model (LDAT) (White et al., 2014) and MODUELO (Lobo and Tejero, 2007a, 2007b).

This study presents a new generalizable structured methodology for the optimization of the design variables of any environmental management system. The novelty of the proposal is the idea of analysing multiple design variables together, along with their interactions, in order to evaluate their relative importance in the impacts under consideration. It is based on the computer simulation of many scenarios and uses a calculation engine that integrates the main processes occurring in a full-scale landfill. In addition, the tools and techniques used to apply the proposed method are described, along with some of the results obtained in a case study focused on the design variables of a waste landfill, which allows its usefulness to be demonstrated.

By applying this methodology, two objectives can be achieved. Firstly, quantitative and qualitative information can be obtained about the effect of each design variable on the behaviour of the system under study, in this case, the waste landfill. Secondly, a decision support system can be developed. This allows the user to calculate the optimal values of the design variables for the system under study, once the relative importance of each impact to be evaluated has been quantified.

2. Methodology

2.1. Proposed method

The object of the proposed method is to model and simulate all possible combinations of the usual values of the design variables to be studied. Once the impacts produced by each combination have been obtained, data analysis tools are used to extract knowledge about the influence of those variables and what their optimal values are for a particular purpose.

The proposed methodology is structured in seven steps (as described in Fig. 1): selection of the design variables, definition of scenarios, creation of the base model, generation of all the variations of the base model, definition of the control parameters, simulation of the models and generation of results and analysis of results and knowledge extraction

In the first step it is necessary to select the set of design variables to be studied. Design variables are those decisions taken when designing or operating a facility. They are, for example, in the case of waste landfills, the intensity with which waste will be compacted once it has been dumped, the height of the waste layer or the systems used to cover each layer until the next one is dumped. Two or more representative values, within the range to be analysed, are assigned to each variable.

In the second step different scenarios representing several geographic locations can be defined. This may include aspects such as changing the weather conditions or, in the case of landfills, entering various patterns of waste generation, which depend very much on the population. This is an optional step, since if the methodology is applied to an actual landfill, the geographic location may already be defined, and both meteorological conditions and waste generation may be fixed input data. However, from a scientific point of view it can be useful to evaluate the influence that different weather conditions or various waste streams have on landfill behaviour and, as a result, on design and operation decisions.

Next, a base model representing the system under study is created. It may be either a theoretical model or represent an actual facility. The base model will define general aspects of the system which are not altered by the design variables. These aspects are transversal and can include, in the case of landfills, the morphology of the terrain where it is located, the filling order or the drainage systems, if these factors are not under study. If they were to be analysed, these factors would become design variables and would no longer be part of the base model.

Numerous variations which combine each value of the design variables and each scenario are generated upon that base model. A variation of the model will include one possible value for each design variable and a specific scenario (in our example, the meteorological conditions and a pattern of waste generation).

The next step is to define some output variables, which will be called control parameters, that quantify the impacts produced by the system. They can be both negative (land use or leachate

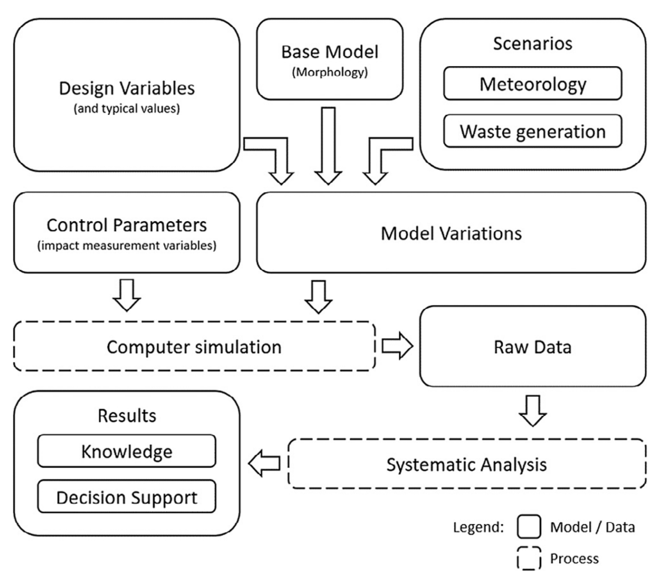

Fig. 1. Elements of the proposed methodology.

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